UK Health Security Agency

UK Recovery Handbook for Radiation Incidents 2024

Version 5

Contents

Abstract

The UK Recovery Handbook for Radiation Incidents version 5 is a tool to support decision makers in developing a remediation strategy following a nuclear accident or malicious use of radioactive material. It has been developed in conjunction with a wide range of experts, stakeholders, and end users. It is a compilation of practical information that can be used to identify the important issues at stake and, using that information, evaluate remedial protective actions for inhabited areas, food production systems, and drinking water supplies.

This is the fifth version of the handbook that has been published by UKHSA and its predecessor organisations. This version of the handbook builds on the information presented in previous versions by considering both developments in knowledge associated with recovery from a radiation emergency as well as additional practical experience gained during recovery from real incidents, including the Fukushima Daichi accident in 2011. In addition, to improve the usability of the handbook, the structure of the handbook as well as the way information is presented has also been changed compared to earlier versions.

The handbook is divided into several sections that provide background information on various topics including radiation hazards and exposures, radiation protection principles, management of waste during recovery, and preparedness and planning. Comprehensive information is also provided in the form of datasheets for 46 protective actions applicable to the UK. A decision-aiding framework is described which can be used to fine-tune the remediation strategy based on the various constraints associated with the protective actions for given land uses and radionuclides of interest. These constraints include technical limitations, effectiveness, waste generation, doses to implementors, timing issues, and cost. The decision-aiding framework is illustrated through application to 3 previous radiation emergencies affecting the UK.

The handbook is specifically targeted at members of the Recovery Co-ordination Group, national and local authorities, central government departments and agencies, radiation and health protection experts, emergency services, industry and others who may be involved in the recovery from a radiation emergency. In terms of application, the handbook can be used in preparedness to engage stakeholders, to develop local, regional, and national plans and to identify gaps in recovery capability. In the post emergency phase, the handbook can be used to aid decisions when developing a remediation strategy. The handbook can also be used during exercises and for training and familiarisation purposes.

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

The UK Recovery Handbook for Radiation Incidents version 5 (UKRHRIv5) is a tool to support decision makers in developing a remediation strategy following a radiation emergency. The handbook is a compilation of up-to-date, practical information to help users identify the important issues and evaluate remedial protective actions.

The first version of the UKRHRI was published in 2005, incorporating learning from the accident at the Chornobyl Nuclear Power Plant (NPP) in Ukraine in 1986. In subsequent years, stakeholder engagement at a national and European level led to numerous improvements in structure, design, and content of the handbook leading to the publication of 2 further versions. The accident at the Japanese Fukushima Dai-ichi NPP in 2011 caused widespread radiological contamination in Japan. A major remediation effort then followed, generating valuable new information on the practicability of remedial protective actions, which was collated and incorporated in the UKRHRIv4 (50).

The UKRHRIv5 is the end product of an extensive review of scientific and technical information. It consolidates 3 separate handbooks into one, thereby avoiding previous repetition. Redundant material has also been removed and where relevant, signposting to other authoritative documents is made. Emerging gaps have been addressed and changes to national and international legislation and guidance have been incorporated.

1.1 Objectives

The UKRHRIv5 has been developed to meet several inter-related objectives, namely to:

- provide up-to-date information on remedial protective actions for reducing the radiological consequences of contamination of food production systems, drinking water supplies and inhabited areas
- outline the many factors that influence the implementation of protective actions
- illustrate how to frame the decision-aiding process and select remedial protective actions to build a remediation strategy
- provide guidance on preparedness and planning for recovery

1.2 Audience

The UKRHRIv5 is specifically targeted at representatives from:

- national and local authorities, including central government departments and agencies, and local councils
- experts in radiation protection
- emergency response personnel

- agricultural and food production sectors
- water industry
- other stakeholders who may be affected or concerned, depending on the situation
- the Recovery Co-ordination Group

1.3 Application

The UKRHRIv5 can be considered solely as a reference document containing well focused and generic state-of-the-art information on scientific, technical, and practical aspects relevant to the remediation of contaminated food production systems, drinking water supplies and inhabited areas. However, when used in isolation (that is, not as part of a participatory process), the full potential of the handbook cannot be realised. In the same way that this handbook was developed through a process of stakeholder participation, it is intended to be applied using a similar participatory approach. Examples of the most likely applications of this handbook are:

- in the preparation phase, under non-crisis conditions:
    - to engage stakeholders and to develop local, regional and national plans, frameworks and tools
    - to identify gaps in capability
- in the post-accident phases by local and national stakeholders as part of the decision-aiding process to develop a remediation strategy
- for training purposes
- in preparation for, and during, emergency exercises

When used in the applications listed above, those involved benefit by developing their knowledge of ionising radiation and its effects, as well as their understanding of the complexity of the recovery challenge.

1.4 Scope

The sources of contamination considered in UKRHRIv5 include accidents at fixed nuclear sites, other sites handling nuclear materials, transport accidents and scenarios involving the malicious use of radioactive materials. A decision-aiding framework to develop a remediation strategy is provided for food production systems, drinking water supplies and inhabited areas. The primary focus is on management of the long-term recovery phase.

1.4.1 Topics not covered by the UKRHRIv5

Topics that are not covered in any detail by the UKRHRIv5 because they are addressed elsewhere (section 1.9), include:

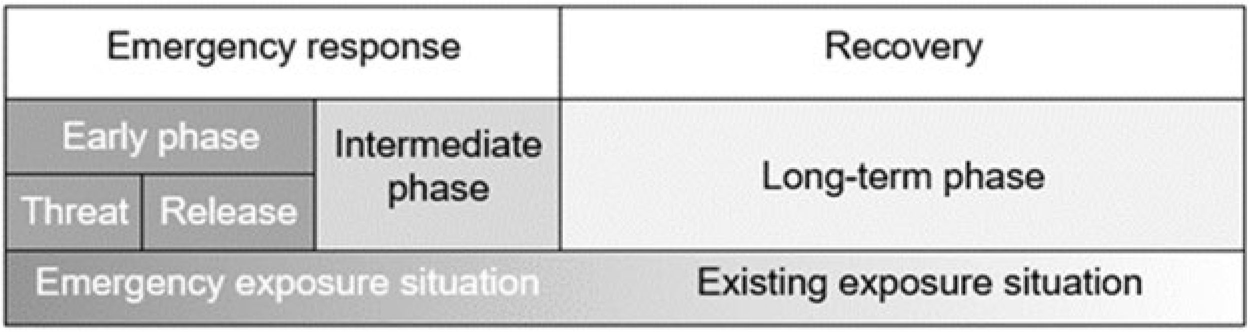
- guidance on urgent protective actions such as evacuation and sheltering
- guidance on establishing environmental and public health monitoring

- responsibilities of organisations in the event of a radiation emergency
- links between responses at different levels for example, local, regional, national
- communication strategy
- wider socio-economic aspects relating to damage, compensation, recovery of business, personal and private losses, disruption caused by protective actions

1.5 Timescales of a radiation emergency

In describing the framework for managing a radiation emergency it is helpful to distinguish between different time phases, namely: early; intermediate; and long-term phase (Figure 1). In addition, there may also be a ‘threat’ or ‘pre-deposition’ phase before any radioactive material is released, this forms part of the early phase. The International Commission on Radiological Protection (30, 31) and UKHSA’s predecessor organisation Public Health England (53) consider the early and intermediate phases of a radiation emergency to be classed as an emergency exposure situation, and the long-term or recovery phase, as an existing exposure situation. Whilst the primary focus of this handbook is recovery, it should be noted many protective actions that are taken to promote recovery, are implemented in the early and intermediate phases. It is also worth noting that the transition from an emergency exposure situation to an existing exposure situation does not necessarily take place at the same time in all affected areas.

Figure 1. Timeline of a radiation emergency



Early phase

The early phase of an emergency comprises 2 components: the threat or pre-deposition phase; and the phase when release of radioactive materials to the environment takes place, despite interventions to contain and control the situation.

The threat phase may have a timescale of hours to days, starting when a substantial risk of contamination is identified and ending when either a release occurs, or the source is brought back under control by successful interventions. During this pre-deposition phase, protective actions may be introduced on a precautionary basis to ensure that appropriate protection is in place. During this period, some initial estimates on the severity and consequences of the expected deposition would be possible and arrangements for managing the emergency response should be activated.

It is during the early phase that doses can be high and various protective actions need to be taken promptly to avoid or reduce radiation exposures. There will only be limited results from environmental monitoring to aid decisions, and the evolution of the release may be subject to substantial uncertainties. For these reasons, the response must rely on pre-established plans and procedures for implementing protective actions taking into account information about the conditions at the affected location and estimates of possible consequences. Depending on the nature of the emergency, some initial characterisation may start while releases are ongoing.

Intermediate phase

The intermediate phase of the response starts when the source has been stabilised and further significant releases are unlikely. The response in this phase will be focused on characterising the radiological situation at the affected location or locations to decide upon the best course of actions to take to protect people and the environment in the intermediate and long-term.

Long-term (recovery) phase

The transition between the intermediate and long-term phase cannot be defined exactly since the circumstances and progression of a particular emergency will influence the determination of when the response is considered to have ended. In general, the physical recovery phase begins when the source is sufficiently secured to assure no further releases and the radiological conditions of affected areas are adequately characterised to support decisions regarding future habitation and land use. Typically, doses and uncertainties are much lower in the recovery phase than in the earlier phases.

1.6 Scenarios, radiation hazards and exposures

1.6.1 Scenarios

The UKRHRIv5 has been written with a focus on certain types of radiation emergencies that could affect the UK. The sources of contamination considered in the handbook are derived from the following scenarios:

- civil nuclear emergencies
- overseas nuclear emergencies which directly affect the UK, including UK dependencies and overseas territories
- transport emergencies
- defence emergencies
- hostile use of radioactive materials

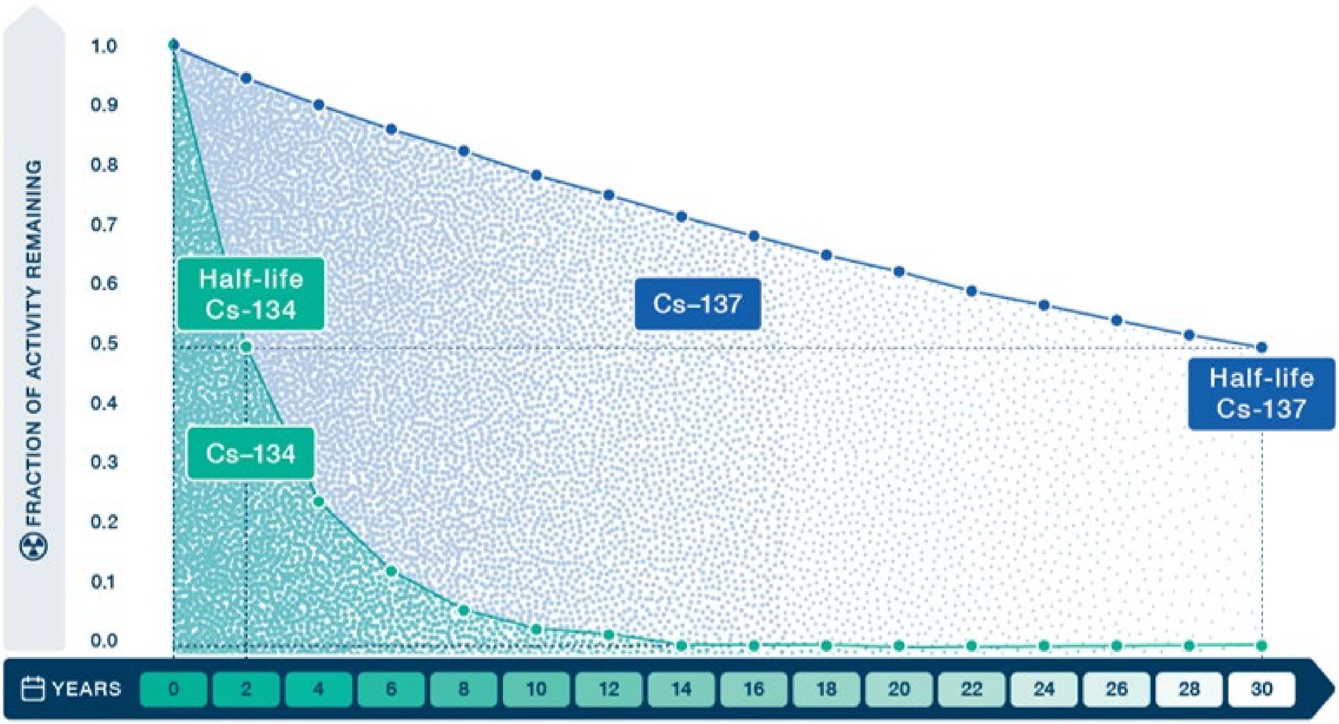
However, much of the information and guidance contained within the handbook is also applicable to a range of other possible scenarios, for example, an accident involving radiation at a hospital or other non-nuclear industries (in the very unlikely event remedial action would be required to protect the wider public).

1.6.2 Radiation hazards

In the aftermath of a radiation emergency, there may be physical and chemical hazards present, in addition to radiation hazards. When developing a remediation strategy all hazards will need to be considered.

Radiological hazards involve materials (radionuclides) that emit radiation. When a radionuclide emits radiation, its activity, measured in becquerels (Bq), decreases – a process known as radioactive decay. The time it takes for a radionuclide's activity to decrease by half is known as its half-life, and is characteristic of that radionuclide. An illustration of how the amount of radioactivity present changes with time due to radioactive decay is shown in Figure 2. In this illustration it is seen that over a period of 10 years the activity of ^{134}Cs decreases to less than 10% of its initial value as that radionuclide has undergone 5 half-lives of decay. In the same timeframe, the activity of ^{137}Cs has only dropped to around 80% of its initial value, as for that radionuclide, not even one half-life of time has passed. After 30 years, 1 half-life of time has passed for ^{137}Cs such that the activity of that radionuclide has decayed to 50% of its initial value. In that timeframe, the activity of ^{134}Cs has essentially disappeared as it has undergone 15 half-lives of decay.

Figure 2. Illustration of how the amount of radioactivity of ^{137}Cs (half-life of 30 years) and ^{134}Cs (half-life of 2 years) changes with time due to radioactive decay



The radiation hazard will depend on the characteristics of the radionuclides involved and the type of radiation emitted (section 1.6.3). A list of key radionuclides considered in the handbook, selected on their likelihood of being released in the context of the range of scenarios outlined in section 1.6.1, is shown in Table 1. Although the UKRHRIv5 focusses on those radionuclides listed in Table 1, guidance provided in the handbook can be applied to a wider set of radionuclides based on their similarity in physical and chemical properties. This allows the handbook to be used for a wide range of incidents with different radionuclides of interest.

Table 1. Half-lives and principal decay modes of key radionuclides

Radionuclide	Symbol	Half-life	Main decay mode
Cobalt-60	^{60}Co	5 years	Beta, Gamma
Selenium-75	^{75}Se	120 days	Gamma
Strontium-90 + Yttrium-90 [note 1]	$^{90}Sr + ^{90}Y$	29 years	Beta
Ruthenium-106	^{106}Ru	374 days	Beta
Iodine-131	^{131}I	8 days	Beta, Gamma
Caesium-134	^{134}Cs	2 years	Beta, Gamma
Caesium-137 + Barium-137 metastable [note 1]	$^{137}Cs + ^{137m}Ba$	30 years	Beta, Gamma
Iridium-192	^{192}Ir	74 days	Beta, Gamma
Uranium-235	^{235}U	7×10^8 years	Alpha
Plutonium-239	^{239}Pu	24,100 years	Alpha
Americium-241	^{241}Am	432 years	Alpha

Notes

[note 1] Radionuclides in secular equilibrium.

1.6.3 Radiation exposure

When radiation passes through matter, it deposits energy and electrically interacts with the material. With sufficient energy the radiation may ionise the matter, in which case it is called ionising radiation. When passing through the body, ionising radiation has enough energy to cause damage to cells. The amount of energy that is deposited by the ionising radiation per unit mass is called the dose, with a unit of the Gray (abbreviated to Gy). For most tissues and organs of the body, a radiation dose greater than 1 Gy is required to cause noticeable damage generally seen within days to weeks of the exposure occurring. Depending on which tissues and organs are exposed to radiation, such tissue damage can include blistering of the skin, hair loss, diarrhoea, or cataracts. If a high enough dose is received, then death may result. It is very unlikely that any individual exposed to radiation during the recovery phase will receive a sufficiently high radiation dose that severe tissue damage would arise; consequences arising from such health effects are therefore not discussed further.

At doses below those likely to cause severe tissue damage, the main health effect to an individual is a small increase in their probability of developing cancer later in life. There are 3 main types of ionising radiation: alpha particles, beta particles and gamma rays.

The key characteristics of the different types of ionising radiation are summarised in Table 2 and shown in Figure 3. To account for differences in the way these types of radiation interact with matter and the different sensitivities of various organs and tissues have to radiation, the potential for cancer to develop is expressed as an effective dose which has units of the sievert (abbreviated to Sv). As a single sievert represents a large dose, radiation doses are often expressed in terms of a thousandth of a sievert, called a milli-sievert (abbreviated to mSv), or a millionth of a sievert, called a micro-sievert (abbreviated to μSv). A comparison of effective dose received from various sources of radiation is given in Table 3.

Figure 3. Illustration of how different ionising radiations can penetrate different materials

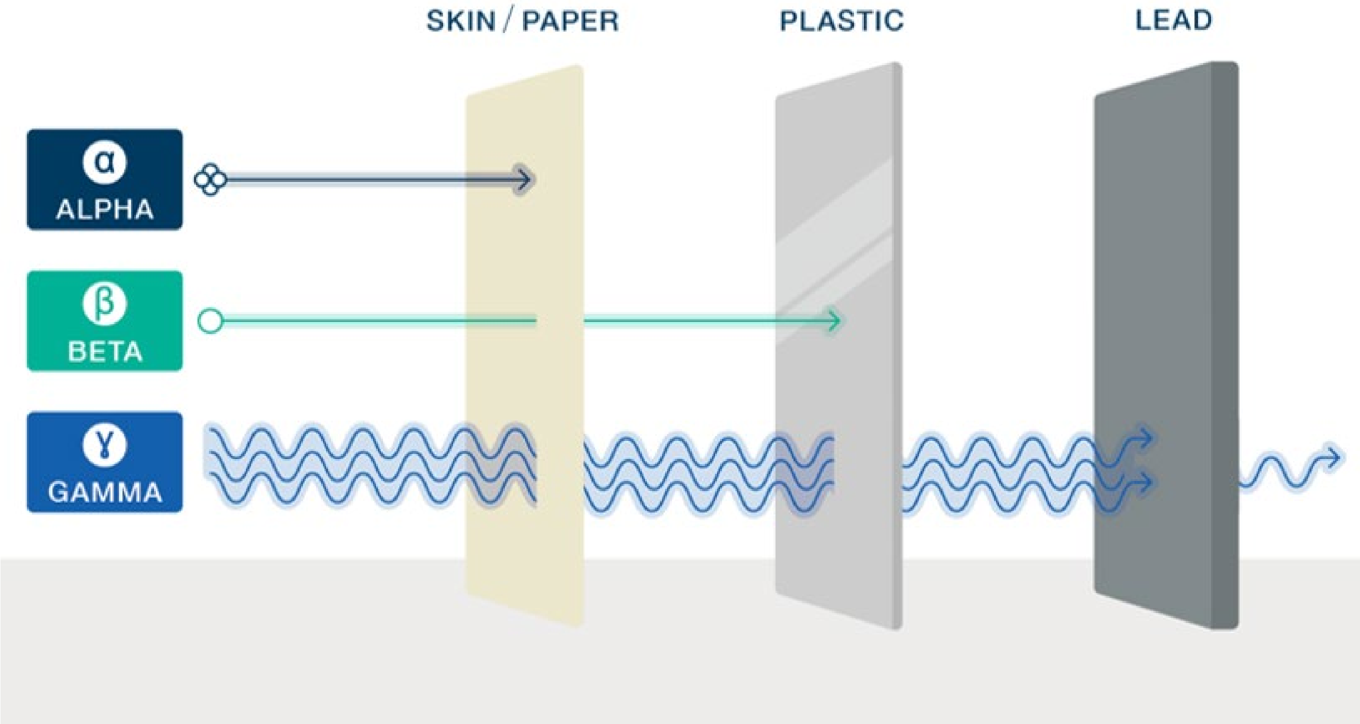


Table 2. Different types of radiation emissions that contribute to the exposure hazard

Radiation type	Description
Alpha particles	• 2 protons and 2 neutrons bound together (identical to a nucleus of helium) emitted by the nucleus of a radionuclide • alpha particles are relatively heavy and have a large electric charge, so they interact easily with matter and therefore do not travel far – for example, they are completely absorbed by a piece of paper or a few centimetres of air • only pose a direct hazard to humans if the source is taken into the body, for example, via ingestion, inhalation, or through a wound
Beta particles	• fast-moving electrons or positrons emitted by the nucleus of a radionuclide • beta particles have much less mass and electric charge compared to alpha particles, so they interact with matter much less than alpha particles – this means beta particles have a range of up to a few metres in air but can be stopped by a thin layer of metal • main risk to health is from intake of radionuclide (that is, via ingestion or inhalation), although beta particles can damage skin if significant activity is present in direct contact with the skin • capable of penetrating shallow organ depths (for example, lens of eye), when emitted outside the body
Gamma rays	• electromagnetic waves similar to light or X-rays, but with much greater energy • as gamma rays do not have mass or an electric charge, they interact with matter very poorly; gamma rays can therefore travel hundreds of metres in air or through many tens of centimetres of most materials – for example, a relatively good gamma shielding material, concrete, still needs to be around 20cm thick to reduce the dose rate from gamma radiation by a factor of 10 • capable of penetrating all organ depths even when emitted outside the body • can pose a direct hazard from sources outside as well as inside the human body

Since different types of radiation can travel different distances through body tissue, the distribution of dose and effects will depend on the type of radiation. It will also depend on whether it is received from a source outside the body (external exposure) or from a source inside the body (internal exposure). For example, alpha particles are not generally a hazard if they are emitted by radionuclides located outside of the body because the radiation cannot penetrate the layer of dead cells on the outside of the skin and irradiate internal tissues and organs. However, if radionuclides that emit alpha particles enter the body by, for example, being ingested, inhaled or through a wound, they can become incorporated into tissues and organs and any alpha particles produced can cause localised damage.

Table 3. Effective dose received from various sources by members of the UK population

Exposure	Dose (mSv)
Dental x-ray	0.005
Chest x-ray	0.014
Transatlantic flight	0.08
UK annual average radon dose	1.3
CT scan of the head	1.4
UK average annual radiation dose	2.7
CT scan of the chest	6.6
Average annual radon dose to people in Cornwall	6.9
Annual exposure limit for nuclear industry employees	20
Level at which changes in blood cells can be readily observed	100

Source: Ionising radiation − dose comparisons.

1.7 Exposure pathways

Release of radioactivity during a radiation emergency can be to the atmosphere or to waterbodies or the ground (for example as run-off of liquids). After release, radioactivity can be dispersed through the environment by wind, water flow and other processes. Any humans present will be exposed to radiation emitted by those radionuclides via a number of routes, called exposure pathways, that include inhalation of radionuclides in air, ingestion of radionuclides in dusts, water or incorporated into foods, and irradiation from radionuclides present in soils and on surfaces of buildings, roads and vegetation; these are described in sections 1.7.1 to 1.7.2 and illustrated in Figure 4.

The exposure pathways which are significant with respect to the dose received, will depend on the radionuclides present, the type of radiation emitted by those radionuclides, the relative concentration of each radionuclide in or on different surfaces or materials, and how those vary with time, and the habits of those exposed (for example the time someone spent in a particular area).

In the early phase, the following pathways tend to be important:

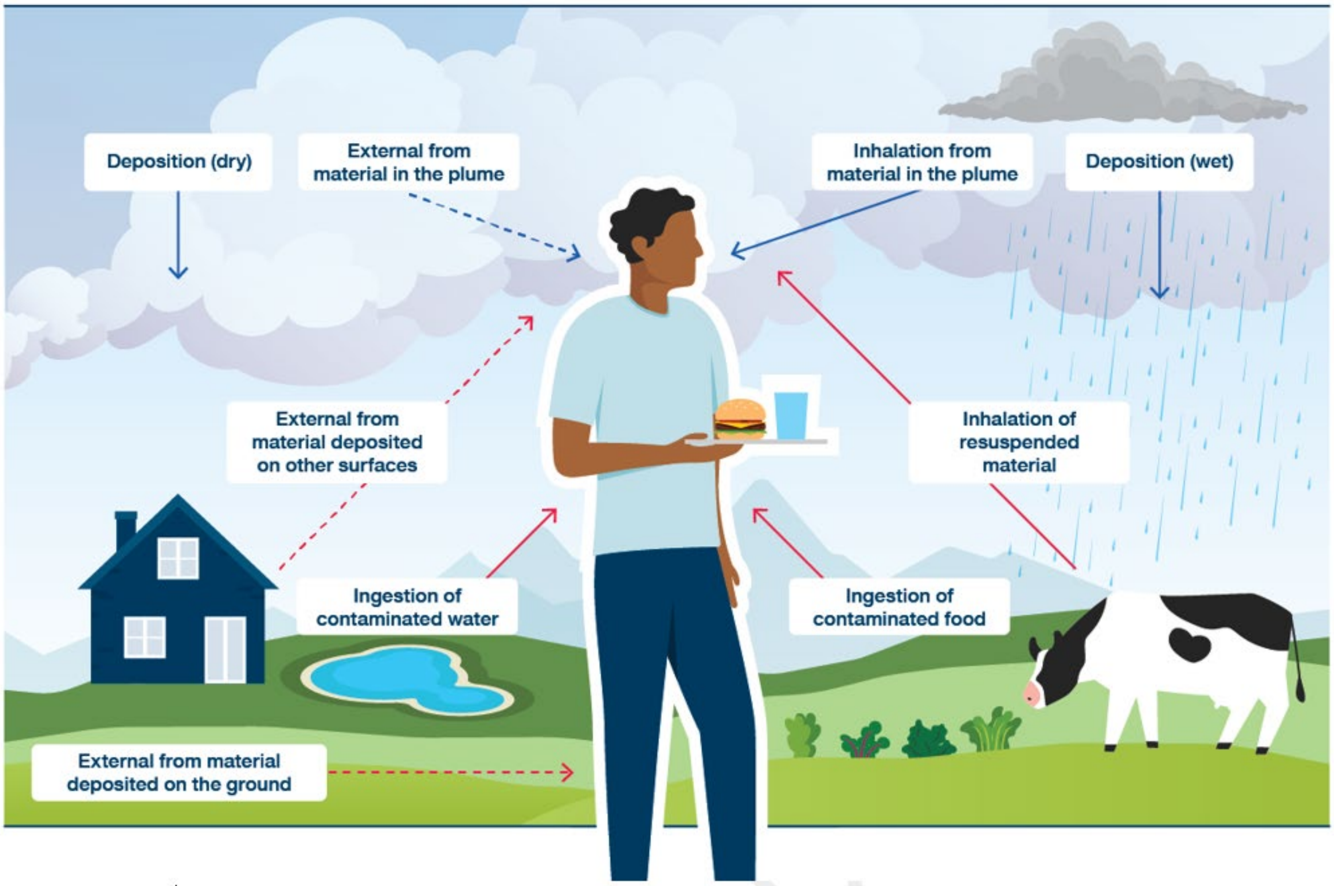
- external irradiation from radioactive material present in the environment
- inhalation of a radioactive aerosol or gas

In the intermediate phase and long-term recovery phase, other pathways tend to predominate:

- external irradiation from deposited radioactive material
- inhalation of resuspended radioactive material
- ingestion of contaminated food and drinking water

In certain cases, other exposure pathways, for example inadvertent ingestion of contaminated material, may warrant investigation. The exposure pathways most likely to be relevant in recovery are described below.

Figure 4. Illustration of exposure pathways that may be present after an accident at a nuclear facility



1.7.1 External exposure from deposited radioactive material

The amount of radioactivity deposited onto different surfaces following a release to atmosphere is likely to vary significantly depending on the scale of the release, the weather (wind direction, wind speed and precipitation) and the distance from the source. When people come into contact with, or are in close proximity to these contaminated surfaces they become exposed. The level of dose that an individual may be exposed to from a contaminated surface will depend on a number of factors including:

- the amount of radioactivity present
- the radionuclides present (and the type and energy of the radiation they emit)
- the individual's proximity to the surface
- time spent by the individual in proximity to the surface
- the effectiveness of any shielding material located between the surface and the individual

For example, the dose rate (defined in next paragraph) to an individual present inside a building from exposure to radionuclides deposited on grass outside the building will be less than that to an individual stood on the grass, as bricks making up the building will absorb some of the emitted radiation. External irradiation from radionuclides present in surface water can also occur if people spend time in that water (for example, when swimming) or close to that water (for example, when standing on a riverbank fishing).

The exposure to radiation from a surface is often expressed as a dose rate – that is the dose received by an individual at a given distance from the surface within a certain period of time; for example, 5 micro-sieverts per hour (5 μSv/h) at a distance of 1m from a surface. Due to radioactive decay and physical processes such as weathering (that is, the removal of contamination through the action of rain and wind), the amount of radioactive material on a surface (and therefore the dose rate from it) will generally decrease with time. However, in a few instances, the ingrowth of progeny radionuclides that emit more energetic gamma radiation than their parent radionuclide, or the concentration of radioactivity in certain areas due to weathering, such as in water drainage channels by roads, or run-off from gutters may mean the local dose rate can increase with time. The rate at which the amount of radioactivity present, and therefore the dose rate, may change is therefore highly variable and depends on many factors.

1.7.2 Intakes of radioactive material from inhalation and ingestion

1.7.2.1 Inhalation of resuspended material

Radioactive material that has been deposited can be resuspended by processes such as wind or the movement of people and vehicles. The amount of contamination that may be resuspended will depend on a number of factors including:

- the size of contaminated particles
- the length of time since deposition
- the intensity of the processes driving the resuspension

Once contamination is resuspended in air, it becomes available for inhalation by people. Contamination that has been inhaled has the potential to give a greater dose to the individual since the source of radiation is closer to internal organs. Furthermore, radionuclides can be retained in the body and continue to emit radiation for long periods of time. In this situation, a dose continues to be received even if the contamination is removed from the environment or the individual leaves the contaminated area.

Exposure from the inhalation pathway can be more significant for certain types of contamination (Table 2). For example, internal exposure from alpha-emitting radionuclides can be particularly significant because alpha particles deposit all their energy over short distances.

1.7.2.2 Ingestion of contaminated food and drinking water

When radioactive material is transferred through the environment into food and drinking water, it can end up being ingested by people leading to internal exposure. As with inhalation, internal exposure from ingestion can be particularly significant for some radionuclides that emit alpha radiation.

Typically, the scenario for contamination of terrestrial foods such as vegetables, fruit, meat, and milk involves the following components:

- direct intake of airborne radioactivity by plants and animals via absorption through leaves and fruits or by inhalation
- indirect uptake from radioactivity deposited onto soil via root uptake or, for animals, the ingestion of soil or contaminated feed

Aquatic foods, for example fish, crustaceans, and molluscs, may become contaminated as a result of the animals ingesting radioactivity present in the water or sediment in which they live, or from consuming other organisms that have already taken in radioactivity.

There is potential for public and private water supplies to be contaminated either as a result of direct deposition to surface waters (rivers, reservoirs), run-off from surrounding catchments, or movement through soils and underlying rocks to ground water.

1.7.2.3 Inadvertent ingestion of contaminated soils and dust

Inadvertent ingestion of contaminated materials such as soils and dust by humans may require consideration for some scenarios. In particular, where those implementing remedial protective actions are working closely with the handling of contaminated soils, for example digging or topsoil removal, or during the management of waste materials.

1.8 Environments

This handbook considers 3 main types of environment: food production; drinking water; and inhabited areas. These are broken down further into categories of food production, for example: agricultural, domestic, wild; types of drinking water supply; and types of surfaces present in inhabited areas. The principal pathways of exposure are highlighted for each type of environment.

1.8.1 Food production systems

1.8.1.1 Agriculture (intensive, extensive)

Contamination of land used for food production may result in radiation exposure to members of the public via a number of pathways. These exposure pathways include external irradiation to someone spending time on the land from deposited activity (for example, a farmer) and the ingestion of activity which has been incorporated into food produced on the land.

Contamination of foods can occur relatively quickly, for example via direct deposition onto fruits or green vegetables or the inhalation by animals, or relatively slowly, for example via root uptake by plants or consumption of pasture by animals.

Most agricultural production in the UK is carried out under intensive management systems. However, there are a few cases (for example, meat and fish production) where extensive systems make an important contribution to the diet. Table 4 gives an overview of the types of agricultural food products for which the handbook can be applied to develop a remediation strategy. Food produced from organic farming systems must meet requisite standards to maintain organic status, when selecting protective actions.

Table 4. Classification of agricultural products in UK

Production system	Food product	Examples
Intensive	Milk and other dairy	Dairy cattle, sheep and goat
	Meat	Beef cattle, sheep, lamb, deer, pig, poultry
	Eggs	Hen’s eggs
	Cereal	Wheat, barley, oats, rye, maize
	Vegetables and horticultural crops	Roots, tubers, onions, legumes, brassicas, salad vegetables
	Industrial crops	Oil seeds, pulses, sugar beet, hops
	Fodder plants	Silage, hay and root vegetables
	Fruit	Orchard, bush, canes, herbaceous and grapes
	Honey	Commercial beehive
	Fish	Fish farm (salmon and trout)
Extensive	Meat	Hill lamb and hill beef
	Fish	Marine fish, freshwater fish, mussels, oysters, scallops, crabs and lobsters

1.8.1.2 Domestic production and the gathering of foods from the wild

Table 5 gives an overview of the types of domestic and free foods for which the handbook can be applied to develop a remediation strategy. Domestic food production includes all food that is produced by individuals in private or kitchen gardens or allotments; free foods are those that are collected from the wild.

Table 5. Classification of domestic food production and food collected from the wild

Source	Food product	Examples
Domestic	Meat	Sheep, goat, pig, duck, turkey, chicken
	Milk	Sheep, goat
	Vegetables	Carrot, courgette, lettuce
	Tree fruit	Apple, plum, cherry
	Berries	Strawberry, gooseberry, raspberry
	Herbs	Mint, parsley, sage, fennel
	Nuts	Hazelnut, chestnut, walnut, beech nut
	Freshwater fish	Private lake
	Honey	Private beehive
	Eggs	Domesticated fowl, for example, duck, goose, hen
Wild foods	Meat	Waterfowl, wildfowl, game fowl, ground game
	Mushrooms	Field mushrooms, chanterelle, puffball, oyster
	Tree fruit	Apple, damson, and sloe
	Berries	Elderberry, blackberry, and rosehips
	Herbs	Horseradish, dandelion root, garlic, and nettle
	Aquatic plants	Seaweed, watercress
	Nuts	Hazelnut, chestnut, walnut, beech nut
	Marine fish	Cod, haddock, plaice, herring, and mackerel
	Marine shellfish	Clam, scallop, cockle, mussel, winkle, crab, lobster, prawn, shrimp
	Freshwater fish	Trout, carp, eel, perch, pike, and salmon
	Freshwater shellfish	Crayfish
	Honey	Feral beehive

1.8.2 Drinking water supplies

Drinking water supply can be classed as public or private. Both involve abstraction of water from the environment. Ingestion of activity in the water is the main exposure pathway from contaminated water although those working in the abstraction, treatment and distribution of contaminated water may also be exposed via external irradiation during times spent near to large volumes of water.

1.8.2.1 Public water supplies

Public water supplies are those delivered by statutorily appointed water companies to the majority of properties including private houses, commercial and public buildings, industrial premises, and other properties. Public water supplies come from both surface water and ground water sources. Surface water sources include reservoirs, lakes, and rivers, while ground water sources are from aquifers, which are underground geological formations that store rainwater. The ground water is drawn through wells or boreholes drilled into the aquifers by the water companies. Ground water can also supply impounding reservoirs (these are formed by placing a dam across a natural watercourse causing water to build up behind it).

The water supplies delivered by water companies are subject to strict regulation regarding their quality. To comply with the water quality regulations, the water is treated at water treatment works prior to being delivered. The water companies take regular samples of the water throughout the treatment process to ensure the provision of high-quality water that meets the required standards.

1.8.2.2 Private

Private water supplies are defined as any supply of water, intended for human consumption, which is not provided by a statutorily appointed water company and where the responsibility for its maintenance and repair lies with the owner or person who uses it. Private water supplies can come from a variety of sources including wells, boreholes, springs, streams, rivers, and lakes. The majority of private supplies are likely to be for dwellings and farms situated in remote, rural areas. However, there may be some private supplies in urban areas, particularly those used for industrial purposes such as brewing and food and drink manufacturing. Private water supplies may also supply places such as hospitals, hotels, schools, or campsites. It is important to note however, that less than 1% of the population of the UK obtain their water from an entirely private supply either on an individual or multiple property basis.

Regulatory powers require private water supplies meet the same standards as water from a mains water supply. With the exception of private water supplies to single domestic dwellings, the relevant local authority is required to carry out a risk assessment for each supply every 5 years and carry out periodic sampling of the water to assess its microbiological and chemical quality.

1.8.3 Inhabited areas

Inhabited areas are places where people spend their time, either to live (residential), work (non-residential, industrial) or relax (recreational). External irradiation by gamma-emitting radionuclides present on various surfaces is often a significant exposure pathway. However, depending on individual behaviours, intake of activity via the inhalation and inadvertent ingestion of contaminated dusts may also be significant, especially if the contamination is composed of mainly alpha-emitting radionuclides.

Table 6. Surfaces in inhabited areas

Surface	Description of surface
Buildings – external surfaces and objects	External hard surfaces (for example, walls, roofs, windows, doors), and garden furniture, play equipment, signs, post boxes
Buildings – indoor surfaces and objects	Indoor building surfaces (for example, walls, floors, ceilings, soft furnishings, furniture)
Vehicles	All vehicles used for public transportation (for example, cars, lorries, trains, buses, trams, boats, aircraft)
Roads and paved areas	All roads, pavements, large paved or asphalt areas (for example, playgrounds, yards, car parks)
Soil and vegetation	Lawns, flowerbeds, parks, playing fields, other green areas Trees, shrubs, bushes

Inhabited areas are characterised by different surfaces such as buildings (external, internal, objects), roads and pavement, soils, and vegetation. A brief description of these surfaces is given in Table 6. Each surface is made of different materials each with their own characteristics in relation to how readily radionuclides absorb or become attached to them and how quickly those radionuclides can be removed from them via weathering (for example, concrete, glass, metal). In addition, some surfaces have properties that make certain remedial protective actions more or less viable (biodegradable surfaces such as soil, wood and vegetation are quite different from metal surfaces for example).

1.8.3.1 Importance of different surfaces in influencing radiation exposure

The amount of contamination deposited onto a surface and how long it is retained there, depends on a number of factors including: the physical and chemical forms of the radionuclides; the properties of the surface (such as its material, geometry and whether it is rough or smooth); and weather conditions during and after deposition.

In the case of an airborne release, radioactive material is more likely to be retained on external, horizontal, rough surfaces with cracks and crevices that ‘trap’ particulates. Should it be raining at the time of deposition, some contamination will be washed off building surfaces, leading to a greater proportion of material on the ground, particularly grassed areas, and soil. Some contamination can deposit on indoor surfaces, typically smaller and/or lighter particles that can migrate through openings such as windows and doors or cracks in buildings, particularly during dry weather. Human activity can also lead to transfer of contamination on footwear from the ground outside to indoor surfaces.

As well as a radiological half-life, radioactive material also has a physical half-life on surfaces, that is, time taken for removal by physical processes such as weathering, including the intensity of removal processes, for example, heavy rain versus drizzle. This is affected by the chemical form of the radionuclide and its tendency to react or fix to the surface, as well as physical characteristics of the surface itself, for example, whether it is hard like varnished wood or soft like fabric furnishings.

Doses will depend on the level of contamination on different surfaces, the time spent near those surfaces and the distance, the geometry of the surfaces and the presence of any shielding. For example, a member of the public who spends 90% of their time indoors will receive a greater level of exposure from a certain amount radioactive material on the indoor surfaces (the flooring and furnishings in their home) than they will from the same activity per unit area on the road outside (from which they are shielded by the brick walls of their house for the majority of the time, and at a greater distance). In estimating doses to the public, it is therefore necessary to carefully evaluate the contribution to the total dose an individual may receive from radionuclides present on each surface, taking into account their occupancy in different parts of their environment.

1.9 Other guidance

More guidance of relevance to recovery is listed below:

National Nuclear Emergency Planning and Response Guidance. Part 3 Recovery (12) (currently under review)

Building a framework for post nuclear accident recovery preparedness (40)

Public health protection in radiation emergencies (53)

Strategic National Guidance (19). The decontamination of buildings, infrastructure and open environment exposed to chemical, biological, radiological substances or nuclear materials (noting that this document has out-of-date references to legislation and organisations and departments).

2. A framework for recovery

2.1 Introduction

Recovery is the process of rebuilding, restoring and rehabilitating the community following an emergency, as described in the National Nuclear Emergency Planning and Response Guidance (12). The most obvious demonstration of successful return to normal lifestyles would be the full reinstatement of pre-emergency conditions. Unfortunately, where contamination is widely distributed and long lasting, this would rarely be a practicable option. Many radionuclides can readily be detected at extremely low levels which, despite having a negligible impact in terms of physical health, may lead to other negative effects on psychological health and wellbeing. Unless the contaminated area is very limited, removal of all detectable contamination would have very damaging societal and environmental consequences, as well as incurring significant monetary costs. Therefore, a framework for managing recovery is required to develop an inclusive, optimised, and sustainable strategy.

2.2 Recovery framework

Recovery is an iterative process involving a series of 7 well-defined steps, summarised in Table 7.

Table 7. Stepwise process to manage recovery

Step	Aim	What is involved
1	Define the situation	Establish a picture of what and who has been affected, and to what extent
2	Assess impacts	Use data and models to assess projected doses to people living and working in the affected area
3	Agree goals of recovery	Engage stakeholders [note 1] in establishing recovery goals
4	Identify and evaluate options	Identify protective actions and engage stakeholders [note 1] in evaluating options
5	Make decisions on the recovery strategy	Establish a decision-making process that is open, transparent, and flexible
6	Implement the strategy	Put the agreed strategy into practice by breaking it down into the ‘who, what, where, when, and how’ the various recovery goals will be met
7	Monitor and evaluate progress	Establish a long-term monitoring programme (food, environment, and public health) to evaluate success of the recovery strategy

Notes

[note 1] ‘Stakeholders’ includes government agencies, other technical experts, and members of the local community who have local knowledge and expertise.

This 7-step framework was first proposed by the U.S. National Council on Radiation Protection and Measurements (NCRP) (34), and later adopted in the UK in National Nuclear Emergency Planning and Response Guidance (12) and other UK public health guidance for radiation emergencies (53). For clarity, step 3 and step 4 have been further developed for this publication to differentiate between the setting of recovery goals (step 3) and the identification and evaluation of protective actions (step 4). As each accident or malicious event is likely to be different in terms of its radiological composition, impact, and duration, it is not possible to recommend a generic strategy.

Step 1. Define situation: establish a picture of what and who has been affected, and to what extent

Establishing an accurate and detailed characterisation of the contamination and presenting it in an understandable manner is an important element to defining the situation. This includes identifying:

- the radionuclides present and their physical and chemical form (for example, solubility will affect mobility)
- the heterogeneity of deposited radionuclides, including areas of enhanced activity caused by variations in, for example, deposition, weathering
- the extent of the contamination and size of the affected area (this will influence the size and complexity of the recovery effort), noting that contamination may occur in several discrete geographical areas, potentially affecting several types of land use
- mobile versus fixed contamination to inform how the radionuclide profile may change with time

Defining the situation relies on extensive monitoring and surveillance of the contaminated areas including buildings, pavements, infrastructure, parks, surface waters, ground water, soils, produce, livestock, and commodities. The most current data need to be made available, and the point in time that the data represent should be clearly stated. This is particularly important in situations where the concentration of a radionuclide is changing rapidly (for example, as a result of radioactive decay or build-up).

During recovery, the monitoring subgroup of the Recovery Co-ordination Group would co-ordinate the monitoring programme, calling on a range of government departments and agencies as well as private contractors.

Other important factors in defining the situation include land use and occupancy, demographics (population size, age, ethnicity, and details of displaced people), and the availability of critical infrastructure and essential services.

Step 2. Assess impacts: use data and models to assess projected doses to people living and working in the affected area

Environmental monitoring data coupled with assessment models may be used to calculate projected doses to representative persons living and/or working in the affected area, taking into account the various exposure scenarios, habits, and prevailing environmental conditions. The situation can be complex due to the involvement of multiple radionuclides, multiple surfaces and media, and multiple exposure pathways. Various UK government departments and agencies, including UK Health Security Agency, have responsibility for carrying out dose assessments during the recovery phase.

When assessing impacts, the focus should be on lowering doses from the various exposure scenarios, not specifically activity concentrations on (or in) environmental media, noting that derived concentrations can be used as proxy indicators of dose in the early and intermediate phases (for example, maximum permitted levels (MPLs) in foodstuffs, see section 3.2.2.1.). This is because the time and effort required for removing contamination below certain levels from everywhere does not automatically lead to a reduction in doses and can add significantly to the decontamination workload and economic costs, while generating unnecessarily large amounts of waste. The assessments must be realistic and consider prevailing environmental conditions. Assessments of non-radiological impacts of the radiation emergency on all aspects of life including psychosocial health, environment, business, economy, and society also need to be considered. Where other physical and chemical hazards are present, an all-hazards approach is recommended (39).

Once doses have been assessed, it will be important to compare them to the reference level that has been set by the Secretary of State for recovery (with advice from others), using powers in the Ionising Regulations (Basic Safety Standards) (Miscellaneous Provisions) Regulations 2018. The value selected is likely to reflect a balance of many interrelated factors and the views of the local community and other stakeholders. Realistic calculations should be carried out to derive measurable activity concentrations in the environment that would lead to exposure to a dose equating to the reference level selected. For contaminated food production systems and drinking water supplies, secondary criteria have been established in advance for application in the early and intermediate phases of the response (section 3.2.2). In the longer term, an approach using reference levels is likely to be more appropriate.

Step 3. Agree goals for recovery: engage stakeholders in establishing recovery goals

For a radiation emergency, the primary goal of recovery is to return areas affected by the emergency to a state as close as possible to that existing before the release of radioactivity and the population to a lifestyle where the accident is no longer a dominant influence. It is important that the public participate fully in establishing the goals for recovery. There are a variety of goals that could be considered, including reduction in dose, maintenance of health and wellbeing, re-opening of critical infrastructure and utilities, support for the economy, and protection of the environment. Interim milestones should be developed to judge progress on, and effectiveness of, the work being done.

Step 4. Identify and evaluate options: identify protective actions and engage stakeholders in evaluating options

Once the land use and exposure pathways have been clarified, protective actions to reduce external doses, and doses from the ingestion of contaminated food and drinking water supplies, need to be identified. There are many options to consider (section 4) including controlling access, modifying individual behaviours, land and livestock management, treatment of drinking water and decontaminating the open and built environment within inhabited areas. Identification and selection of the most appropriate actions for use in any area will depend on site specific conditions as well as the goals set for recovery. In meeting different recovery goals, it will be necessary to balance the costs and benefits of the different options so that the overall recovery strategy can be optimised (section 3.1.2). In some circumstances, the best course of action may be to rely on the natural decay of activity over time accompanied by an appropriate monitoring strategy.

Having identified potential protective actions, they then need to be evaluated. Evaluation involves scrutinising their key attributes to decide whether the agreed goals for recovery can be met. Key attributes include the following:

- costs (direct and indirect)
- doses to those involved in implementation
- effectiveness
- radionuclide type and form
- technical constraints (for example, availability of materials)
- timescales for implementation
- waste generation

Section 6 provides a decision-aiding framework for selecting and combining protective actions. To support this process, a compendium of comprehensive datasheets have been produced for each protective action to systematically record information on key attributes (Annexe A).

The development of a recovery strategy will rely on input from a wide range of stakeholders, including those with local knowledge and expertise. It is likely that the Recovery Co-ordination Group will establish various sub-groups to help develop the protective action strategy, including:

- environment and infrastructure sub-group to identify and evaluate remedial protective actions
- health and welfare sub-group to address any health implications arising from the emergency including impact of protective actions

- business and economic recovery sub-group to assess and mitigate the economic implications of the emergency and any protective actions that are implemented
- communications sub-group to co-ordinate messages relating to protective actions to ensure the public are kept fully informed

The involvement of a wide range of stakeholders, including those with local knowledge and expertise should ensure that the recovery strategy is optimised, effective, acceptable, and sustainable.

Step 5. Make decisions on the recovery strategy: establish a decision-making process that is open, transparent and flexible

This step is where the final decisions are made on the recovery strategy, by those held responsible and accountable. It is informed by the evaluation process undertaken in step 4. The decision-making process should be open, transparent, and sufficiently flexible to allow changes to the recovery strategy, if necessary. This will build trust and credibility among the affected population, and ensure acceptance and sustainability of the decisions made. No matter how robust the science, or valid the recovery strategy, it will fail if it is not accepted and understood by those affected by the decisions.

Step 6. Implement the strategy: put the agreed strategy into practice by breaking it down into the 'who, what, where, when, and how' the various recovery goals will be met

Once decisions have been reached regarding the recovery strategy, implementation must be accompanied by publicly assessable information that explains the basis for those decisions using clear and easily understandable language. In addition, that information should describe all factors associated with the selected strategy including timescales, costs, resources and equipment, doses to members of the public living and working in the affected area and to those responsible for implementing protective actions, conditions for success, and key factors that may lead to a review, for example, prompted by changes in meteorological conditions, monitoring data and so on. The entire decision-making process and resulting recovery plan must maintain transparency throughout. Communication must be able to reach all stakeholders to convey consistent messages that are timely, accurate, credible, and clear. Every available communication channel should be used wisely to disseminate and share information in order to confirm data from multiple sources. Strategies for countering misinformation and disinformation should be considered in advance.

The recovery plan needs to be sufficiently flexible to allow adjustments and improvements to be made during implementation. This iterative process is likely to continue for an extended period during which baseline conditions may evolve. Sometimes technologies are new or under development and will have to be trialled on a small scale before consideration and approval given for their wider application.

Step 7. Monitor and evaluate progress: establish a long-term monitoring programme (food, environment, and public health) to evaluate success of the recovery strategy

A long-term monitoring program is a key element to evaluating the success of the recovery strategy. Measurable milestones for recovery, established at step 2, should be regularly reviewed, and updated. These targets provide a means of monitoring and evaluating progress and may assist in deciding when specific recovery activities can be scaled down. In addition, the long-term monitoring of residual contamination in the environment, as well as other public health objectives (for example, for psychosocial impacts), economic indicators (for example, employment statistics, agricultural production) or environmental targets (volumes of waste) should also be evaluated.

In the longer-term, exposures will fall below the reference level due to the combined effects of protective actions and natural process, including radioactive decay. However, vigilance will still be necessary as human activities or natural disasters, such as flooding, can lead to remobilisation or enhanced availability of radioactive contamination, which may increase doses. Therefore, an appropriate long-term monitoring programme and communication strategy should be maintained, even when protective actions are terminated.

3. Radiological protection principles

3.1 Overarching guidance

In emergency and existing exposure situations, the objectives of radiological protection are achieved using the fundamental principles of 'justification of decisions' and 'optimisation of protection' (30, 31). These objectives should be pursued considering the potential adverse effects not only from radiation exposure, but also from any protective actions that might be implemented – for example, anxiety, disruption, societal stress, waste production. This means preserving, to the extent possible, the health and wellbeing of all affected individuals, decent working conditions, good quality of life in affected communities, and the safeguarding of the environment for future generations.

3.1.1. Justification of decisions

All decisions that aim to reduce the impact of radiation exposure in the event of a radiation emergency inevitably introduce additional constraints on living and working in affected areas, and these must be taken into account when justifying the decision. The principle of justification ensures that decisions regarding the implementation of protective actions to avoid or reduce exposures, result in a net benefit for the affected people and environment. Furthermore, the justification of decisions is not a one-off process, and should be reassessed regularly as the situation evolves to ensure that the protection strategy continues to do more good than harm in the broadest sense.

Responsibility for making decisions on the justification of protection is usually the role of authorities and responsible organisations. However, experience has demonstrated the importance and benefit of involving stakeholders in these decisions, particularly representatives of local authorities, professionals, and inhabitants of affected communities.

3.1.2 Optimisation of protection

The principle of optimisation is applied with the selection of reference levels of dose to limit the inequity in the distribution of individual exposures, and to maintain or reduce all exposures to as low as reasonably achievable, taking into account societal, economic, and environmental factors. As optimisation requires balancing positive (dose reduction) and negative (economic, societal, and environmental) factors it does not automatically equate to either the complete elimination or minimisation of exposure. Instead, optimisation should ensure selection of the best strategy under the prevailing circumstances to maximise the margin of good over harm, and to meet key recovery goals.

Unlike emergency exposure situations, where there is a need to take urgent action, the optimisation process during recovery can be implemented step by step. Due to its reliance on judgements by individuals or groups, the process of optimisation needs transparency and direct involvement of the relevant stakeholders. This transparency assumes that all available and relevant information, assumptions, and judgements about the radiological and non-radiological impacts are provided to affected people and communicated in such a way as to assist understanding of the risks.

3.2 Radiological criteria

3.2.1 Reference levels

For the protection of people following a radiation emergency, reference levels of residual dose, expressed in terms of individual effective dose (mSv) are recommended to reduce inequity in the distribution of exposures, and to maintain or reduce all exposures to as low as reasonably achievable (31, 53). This residual dose corresponds to the remaining dose added by the radiation emergency after the emergency exposure situation has ended, without including natural background.

In preparedness planning, reference levels are used as guiding values to select and scale protective actions according to a range of accident scenarios. At the planning stage, reference levels are exposures that should not be exceeded. Following a radiation emergency, reference levels become a benchmark for evaluating the effectiveness of protective actions. As the best protective actions are always site- and scenario-specific, it is not relevant to determine, in advance, a reference level of dose for use in recovery, below which the requirement for further dose reduction can be relaxed.

ICRP and UKHSA recommend that the reference level for the optimisation of protection of people living in contaminated areas during the recovery phase, should be selected from the dose band of 1 to 20 mSv with an emphasis on selecting a value from the lower half of that range if possible, depending on the prevailing circumstances (31, 53). The process for selecting a reference level should result from a careful balance of many factors, including the sustainability of living and working conditions, business and trade, and quality of the environment. The reference level selected should also take into account the views of all relevant stakeholders. For radiation emergencies affecting large areas, management of the situation may need to deal simultaneously with response (emergency exposure situation) and recovery (existing exposure situations) affecting different geographic areas, each with their own reference level. The evolution of a reference level is a matter of choice and stakeholder views should be taken into account. A time variable reference level may help to improve the situation progressively. For context Table 3 illustrates how the magnitude of doses in the reference level band compare to doses received from exposure to naturally occurring sources of radiation and from the medical use of radiation.

3.2.2 Secondary criteria

Secondary criteria in the form of maximum permitted levels in marketed foodstuffs and action levels in drinking water have been developed for use in the UK following a radiation emergency. No such criteria have been developed for application to contamination of surfaces in inhabited areas. Nevertheless, it is possible to derive such operational criteria (for example, Operational Intervention Levels (27)), based on surface dose rate for example. However, any criteria derived for such purposes must account for relevant characteristics of the contamination which depend, in turn, on the relative importance of each exposure pathway. For example, if inhalation of resuspended dusts is an important exposure pathway, individual criteria may need to be developed for fixed and non-fixed components of the contamination.

3.2.2.1 Maximum permitted levels (food)

The maximum permitted levels (MPLs) of radionuclides in marketed foods and animal feed are set within UK legislation (The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). These regulations are binding on foods marketed within the UK whether the contamination is as a result of an accident in the UK or abroad. The levels in the current UK legislation match those in the current EU legislation which covers the European Union (9). In the UK, the Food Standards Agency and Food Standards Scotland are responsible for implementing these regulations. The MPLs represent a judgement on the optimum balance between the beneficial and detrimental consequences of introducing food restrictions; they do not represent a boundary between safe and unsafe levels. If the MPLs should prove inappropriate under the specific circumstances of a future accident, the MPLs could be revised but only by an amendment to legislation.

The MPLs that would initially apply following a radiation emergency are set out in Table 8. The MPLs for foods are divided into 4 groups of radionuclides (radiostrontium, radioiodine, alpha-emitting radionuclides, and other radionuclides with relatively long half-lives) and 5 food categories (baby foods, dairy foods, other major foods, minor foods, and liquid foods). For radionuclides not covered by this legislation (for example, ^{14}C, ^{3}H and ^{40}K), alternative food legislation can be applied (that is, General Food Law (assimilated Regulation (EC) 178/2002)). There are also MPLs for animal feed that apply to radioisotopes of caesium only and are specified for feed intended for pigs, poultry, lamb and calves, and other (see Table 9). By using these groupings, the MPLs are kept to a manageable number, while, at the same time, important differences in the behaviour of radionuclides and people’s dietary habits are taken into account.

Within each food group, the sum of the activity concentrations for the associated radionuclides are to be compared with the MPL. For example, if both ^{134}Cs and ^{137}Cs are present within a consignment of meat, then the activity concentrations of the individual radionuclides should be added together before comparison with the MPL of 1,250 becquerels per kilogram (Bq/kg).

The MPLs are intended to be applied independently of one another; if the combined activity concentration level for one radionuclide group in a given food category is exceeded, then restrictions on food will be imposed, regardless of the concentration of other radionuclides in that food, or of the concentration of radionuclides from that group in other foods. Similarly, if no individual MPL is exceeded, regardless of how much activity is present as a function of any MPL, then the food will not be subjected to restrictions under these controls. UKHSA has explored the range of doses that might result from applying food restrictions at the levels of the MPLs and advises that the current MPLs are adequately protective and optimised (53). Consumption of food at these concentrations would result in an effective dose of between a few hundredths of a mSv to about half of a mSv committed over a year, depending on the food type and radionuclide involved. Reduction of the MPLs to more restrictive levels is therefore unlikely ever to be justified on the grounds of reducing radiation risk.

Although MPLs are useful for controlling activity concentrations in foodstuffs in the early and intermediate phases following a radiation emergency, an approach using reference levels is preferable in the recovery phase.

Table 8. Maximum permitted levels of radioactive contamination of food

Radionuclide	Maximum permitted levels (Bq/kg) [note 1]				
	Baby foods	Dairy produce [note 2]	Minor foods	Other foods	Liquid foods
Sum of isotopes of strontium, notably ^{90}Sr	75	125	7,500	750	125
Sum of isotopes of iodine, notably ^{131}I	150	500	20,000	2,000	500
Sum of alpha-emitting isotopes of plutonium and transplutonium elements, notably ^{239}Pu and ^{241}Am	1	20	800	80	20
Sum of all other radionuclides of half-life greater than 10 days, notably ^{134}Cs and ^{137}Cs [note 3]	400	1,000	12,500	1,250	1,000

Notes

[note 1] The level applicable to concentrated or dried products is calculated on the basis of the reconstituted product as ready for consumption.

[note 2] Milk and cream only.

[note 3] ^{14}C, ^{3}H and ^{40}K are not included in this group.

Table 9. Maximum permitted levels of radioactive contamination of animal feed

Feed for	Maximum permitted levels (Bq/kg) [note 1]
Pigs	1,250
Poultry, lambs and calves	2,500
Other	5,000

Notes

[note 1] MPLs are for ^{134}Cs and ^{137}Cs only.

3.2.2.2 Action levels (drinking water)

The EU Regulations (Council of the European Union, 2016) on MPLs in marketed foods and animal feed do not specify criteria for drinking water supplies for application during a radiation emergency. Nevertheless, these Regulations do state that EU Member States may refer to the MPLs for liquid food to manage the use of water for human consumption. Based on this, UKHSA has recommended UK action levels (ALs) for radionuclide activity concentrations in drinking water, following an emergency, as set out in Table 10. These ALs apply to all drinking water (both public and private supplies) after an incident, regardless of the distance away from the source of the incident. UKHSA advises that these ALs for drinking water supplies represent a balance between the harms and benefits likely to arise from restrictions; they do not represent a boundary between safe and unsafe levels. The typical consumption, bathing and washing clothes in water at the AL over the course of one year would result in a dose of at most a few mSv's (45).

The ALs should be used to indicate whether any protective actions are needed to protect public health, such as the provision of alternative drinking water or additional water treatments. It is emphasised that if individuals were to drink water contaminated in excess of these ALs for limited periods, for example, a few weeks, this need not pose a significant radiological hazard. Thus, the immediate withdrawal of drinking water supplies is unlikely to be essential on the basis of radiological protection. However, it may be necessary in order to prevent whole networks becoming contaminated in the longer term.

In general, if it is not possible to reduce the activity concentrations of radionuclides in drinking water below the ALs, every effort should be made to provide alternative supplies within a few weeks to maximise the dose reduction achieved. In circumstances where replacement of supplies is extremely difficult, relaxation of the ALs over the longer term may be justified but would need specific consideration of the harms and benefits according to the prevailing circumstances.

Table 10. Recommended UK action levels for drinking water supplies [note 1] [note 2]

Radionuclide	Action levels (becquerels per litre, Bq/l)
Sum of isotopes of strontium, notably ^{90}Sr	125
Sum of isotopes of iodine, notably ^{131}I	500
Sum of alpha-emitting isotopes of plutonium and trans-plutonium elements	20
Sum of all other radionuclides of half-life greater than 10 days, notably ^{134}Cs and ^{137}Cs [note 3] [note 4]	1,000

Notes

[note 1] Source: NRPB, 1994 (45).

[note 2] These action levels refer to all water supplies that are intended, at least in part, for drinking and food preparation purposes.

[note 3] For ^{235}U, action would be taken based on the chemical toxicity of uranium, since this is of more concern to health than the radioactive content of the water (57).

[note 4] ^{14}C, ^{3}H or ^{40}K are not included in this group.

4. Protective actions

Protective actions are taken during a radiation emergency or malicious event to reduce or prevent exposures. The action can be taken at source, at points in the exposure pathway, or occasionally by modifying the location and habits of the exposed individuals. Protective actions are described in more detail below, in the context of food production systems, drinking water supplies, and inhabited areas. The information provided has undergone extensive review to make sure it reflects current practice. This has resulted in some changes to the previous classification and range of protective actions considered. For example, compared to version 4 of the handbook (50), a few new protective actions have been introduced, others have been combined, and some have been excluded where evidence suggests they would not be applicable in UK.

4.1 Food production systems

Many protective actions for use in food production systems have been developed since the accidents at the Chornobyl NPP in 1986, and the Fukushima Dai-ichi NPP in 2011. However, not all of these are applicable for implementation in the UK, due to a variety of reasons including acceptability, effectiveness, and practicability.

The 24 protective actions described in this handbook encompass many types of activities that can be carried out over various phases of the response to reduce the impact of radioactive contamination of food (Table 11). While many protective actions are of a technical nature, involving some form of physical or chemical intervention to reduce transfer of radionuclides in the food chain, there are a few options that simply provide advice, reassurance monitoring and information, and support the public to undertake 'self-help' actions. The protective actions listed in Table 11 are grouped together according to their purpose, for example, land management, livestock management.

4.1.1 Preventing contamination of food before release

Some protective actions can be implemented prior to a release of radioactive material, provided sufficient warning is given in advance. These actions prevent radionuclides reaching food products by for example, the closing of air intake systems in greenhouses and at food processing plants, the covering of harvested food and fodder crops, and the sheltering of livestock. These options are radionuclide independent.

4.1.2 Restrict, prevent, or reduce consumption of contaminated food

As there are only limited options to prevent food products from becoming contaminated after a nuclear accident, other approaches to restrict, prevent or reduce consumption need to be considered. Firstly, the Food and Environment Protection Act 1985 (FEPA) prohibits the harvesting, movement, sale, and processing of food from areas where radionuclide concentrations in produce exceeds MPLs. Restrictions can also be placed on hunting and fishing. Where foods above MPLs have entered the food chain, products can either be withdrawn prior to the point of sale or recalled from consumers after purchase.

Table 11. List of protective actions for food production systems

Objective	Protective action
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) [note 1]
	Select alternative land use (non-edible products)
	Slaughter and suppress lactation
Monitoring and dose assessment	Consumer access to monitoring equipment
	Derestriction surveys and dose assessment
	Live monitoring (Mark and Release) [note 2]
	Natural attenuation with monitoring
Land management	Application of NPK fertilisers and/or lime to soils [note 3]
	Ploughing options
	Remove topsoil
Livestock management	Addition of AFCF to concentrate ration [note 4]
	Addition of calcium to concentrate ration
	Addition of clay minerals to concentrate ration
	Administer AFCF boli to ruminants [note 4]
	Clean feeding
	Manipulate slaughter times
	Selective grazing

Notes

[note 1] FEPA: Food and Environment Protection Act.
[note 2] Applicable to sheep and cattle.
[note 3] NPK: Nitrate, phosphate and potassium.
[note 4] AFCF: Ammonium iron hexacyanoferrate.

In situations where it is not possible to adequately reduce concentrations of radionuclides in live animals (see livestock management), slaughter and disposal should be considered. Furthermore, land contaminated with radioactivity can be used for non-food production by selecting alternative land uses assuming any proposed new use meets all relevant regulatory requirements, for example, sugar beet for bioethanol, perennial grass or coppice for biofuel, or for recreational use or forestry.

If permitted and practical (that is, taking into account volumes and biodegradability of product), commercial food processing and storage can be used to reduce the activity in food prior to consumption, especially where significant amounts of short-lived radionuclides are present. In the domestic setting, where FEPA does not apply (that is, gardens, allotments) the provision of dietary advice, including culinary preparation techniques, can reduce radionuclide levels in home grown foods, and help consumers make informed choices.

It should be noted that the placing of statutory restrictions, on the marketing of crops, milk, and meat, in conjunction with withdrawal and recall of products, has the potential to generate considerable volumes of contaminated biodegradable waste. Therefore, it is essential that appropriate routes of disposal for such material are identified as part of planning and preparedness (see section 8) in advance of future accidents or incidents. These waste disposal options range from relatively simple in-situ methods (ploughing in, composting and landspreading) to offsite commercial treatment facilities (that is, landfill and incineration).

4.1.3 Monitoring and/or dose assessment

Once there is a good understanding of the variation in radionuclide concentrations according to season, soil type and so on, protective actions can focus on monitoring and dose or risk assessment to maintain consumer confidence and in so doing, sustain food production in affected areas. In some situations, where the radionuclide has a short half-life, it may be appropriate to allow activity concentrations to decrease without active implementation of protective actions other than monitoring (that is, natural attenuation with monitoring). In other circumstances, live monitoring (that is, Mark and Release) can establish activity concentrations of gamma-emitting radionuclides in livestock before slaughtering. This can provide reassurance to consumers and other stakeholders that contaminated foodstuffs are not entering the food chain. Where activity concentrations exceed MPLs, the animals can be marked and held on the farm, until levels fall below the MPL (through implementation of other protective actions). Over time, areas subject to the placing of statutory restrictions (that is, FEPA (1985) Orders), can be permanently released from restrictions, by carrying out rigorous derestriction surveys (monitoring) accompanied by realistic dose assessment.

The provision of monitoring equipment together with suitable training and education to local communities enables individuals to monitor radiation levels in food grown in private gardens and allotments, and food gathered from the wild. This type of self-help protective action enables consumers to adapt their dietary habits to reduce intake of contaminated home grown produce and wild foods. It was used widely following the NPP accidents at Chornobyl and Fukushima Dai-ichi.

4.1.4 Land management

Protective actions can involve changes to land management, to reduce the transfer of radionuclides from soil to plants (that is, crops, pasture). The options include removal of topsoil, and the implementation of physical or chemical techniques such as ploughing options and the application of fertilisers and lime to the soil.

4.1.5 Livestock management

Protective actions directed at livestock fall into 2 main categories: those that involve a change in husbandry practice (for example, clean feeding, selective grazing) and are radionuclide independent and, secondly, those that require the use of additives to prevent or reduce the uptake of specific radionuclides into animals (for example, addition of ammonium-ferric-cyano-ferrate (II) (AFCF) to animal feeds to reduce uptake of caesium).

4.2 Drinking water supplies

There are 4 protective actions to provide uncontaminated or less contaminated drinking water supplies, and one that flushes the distribution system so that it can be used to supply clean drinking water, in the weeks following the radiation emergency. The protective actions for drinking water supplies are listed in Table 12.

Table 12. List of protective actions for drinking water supplies

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

4.2.1 Provision of uncontaminated drinking water

The 2 protective actions that provide uncontaminated water are dependent on alternative supplies being provided. This is either a) through provision of bottled water, tankers, bowsers, static tanks, direct water injection into mains or service reservoirs; or b) abstraction of water upstream of any contamination or a change from surface water abstraction to bore hole supplies.

4.2.2 Provision of less contaminated drinking water

The 2 protective actions that provide less contaminated drinking water involve some form of treatment or controlled blending. Normal water treatment involving for example, primary filtration, flocculation, and coagulation, clarification, secondary filtration, and ion exchange can be highly effective at removing radioactive contamination from drinking water supplies. Blending, on the other hand, relies on the mixing of contaminated water with uncontaminated or less contaminated supplies. This approach is already used for other contaminants such as nitrates, heavy metals, and pesticides. In all cases, there is a legal obligation for monitoring to ensure that the treated or blended drinking water meets the normal quality standards.

4.3 Inhabited areas

Many protective actions for use in inhabited areas have been developed since the accidents at the Chornobyl NPP in 1986, and the Fukushima Dai-ichi NPP in 2011. Most are applicable for implementation in the UK.

The 17 protective actions described in this handbook encompass many types of activities that can be carried out to reduce the impact of radioactive contamination on different surfaces. They can be implemented in the days, weeks, months and even years after the radiation emergency. The protective actions listed in Table 13 are grouped together according to their purpose, for example shielding, physical removal, chemical removal.

Table 13. List of protective actions for inhabited areas

Objective	Protective action
No active remediation	Natural attenuation with monitoring
Restrict access	Prohibit public access
	Temporary relocation
Shielding	Store and cover personal and precious objects
	Cover contaminated soil and grass
	Ploughing methods and mechanical digging techniques
	Tie down
Physical removal	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)

Objective	Protective action
Chemical removal	Reactive liquids (domestic chemicals)
	Water-based cleaning

Due to the range of surface types and materials, only a subset of techniques will be applicable according to what is affected. The protective actions involving physical or chemical removal have the potential to produce large volumes of contaminated waste. Therefore, it is essential that appropriate waste management options are identified both locally and nationally, as part of planning and preparedness (see section 8).

4.3.1 No active remediation

The development of a remediation strategy should give careful consideration to the 'no active remediation' alternative. In some circumstances, remediation may not be justified, due to harms outweighing benefits, for example, where doses to people are low and the potential for disruption is high. In these situations, the optimised course of action might be to not implement any protective actions. If this approach is adopted, it should be accompanied by monitoring and an effective communication strategy.

4.3.2 Restrict access

Reduction in external exposure can be achieved by restricting access to contaminated areas either by temporary relocation, or the emplacement of cordons. Such options are very effective against all types of contaminants while they are in place and provided the contamination does not spread outside the restricted areas.

4.3.3 Shielding

If the primary aim is to reduce the dose rate from radionuclides located outside of the body, then placing a shielding material between the source and the person is required, for example by storing and covering of objects, covering the contaminated soil and grass, or diluting the contamination by ploughing or digging techniques. In general, these types of protective actions are more effective in reducing external dose rates from gamma-emitting radionuclides. If the primary aim is to reduce inhalation doses from resuspension, then shielding is about fixing the contamination to the surface to restrict its mobility for example, tie down.

4.3.4 Physical removal

Physical removal of radioactive contamination from surfaces involves physical processes, which can be divided into surface cleaning techniques and surface removal techniques. Surface cleaning (as opposed to washing, see section 4.3.5 on chemical removal), which keeps the surface intact as the contamination is mechanically dislodged, includes high pressure washing including water jetting, strippable coatings, and vacuum cleaning. Surface removal, which removes contamination by virtue of the removal of an entire layer of the surface, includes removal and replacement of road and paved surfaces, as well as removal of building surfaces (external and internal) using various types of blasting, grinding and scabbling techniques. In addition, topsoil and turf can be removed manually or mechanically, grass can be removed by mowers, and other plant material by chainsaws or smaller scale pruning equipment.

4.3.5 Chemical removal

Chemical removal of radioactive contamination from surfaces involves a wide spectrum of chemicals, ranging from mild detergents to strong mineral acids. Those included in the handbook are at the milder end of the spectrum that is, water-based cleaning techniques using detergents, and more reactive liquids such as domestic or light industrial chemicals. The handbook specifically excludes any chemicals that might be classed as moderately or very aggressive cleaners. This is because such chemicals are not suitable for use on most surfaces likely to be encountered in the types of urban or rural setting considered in this handbook (that is, they would only be used to target a few specialised surface types).

4.4 Factors influencing implementation

There are a number of factors that need to be considered when developing a remediation strategy. The most widely applicable are:

- timing
- location
- effectiveness of protective actions
- doses received during implementation of protective actions
- waste disposal
- legal constraints
- environmental impact, including secondary contamination
- economic cost
- disruption, societal impacts, and acceptability of protective actions

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

4.4.1 Timing

The consequences of a radiation emergency not only depend on timing of the release, for example, day or night, and season of the year, but also on the variation in activity concentrations of the deposited radionuclides over time, due to radioactive decay and physical movement in the environment.

Timing also has an impact on the spread of contamination in the environment. In general, the earlier that protective actions are implemented, the less spread or secondary contamination there is to the rest of the environment, for example decontamination of outdoor surfaces can reduce the amount of contamination transferred indoors by the movement of people and this will be more effective if implemented sooner.

Furthermore, timing affects practicality of implementing protective actions. In the early phase, relatively straightforward protective actions are likely to be the most appropriate, as they can be implemented quickly, using available local resources, and applied over a wide area. More complicated actions that require training or gathering of resources, would likely be most appropriate for use in the intermediate to longer term phase. For example, in the short-term, the sheltering of livestock may be possible but provision of clean feed or preparation and distribution of feed additives, may take weeks to organise and transport to the affected area. Similarly, cutting grass can be done quickly as municipal mowing equipment is available in most areas. In contrast, the removal of turf and topsoil would take more time to organise as specialist equipment may not be available locally.

Where protective actions are likely to cause significant disruption or have a significant negative impact on the environment or economy, it is important to allow enough time (months) for full engagement with local communities and other stakeholders before implementation.

4.4.2 Location

The location and size of the affected area, as well as existing land use (that is, inhabited areas, agricultural land, or water supplies), influences the applicability of protective actions. Some protective actions are only practicable on a small scale, for example application of strippable coatings, reactive liquids, whilst others can be implemented on a wide scale, for example ploughing options, restrictions on terrestrial or aquatic foods. In addition, some locations are highly sensitive, for example critical national infrastructure or schools, and may afford a higher priority in terms of remediation.

4.4.3 Effectiveness of protective actions

Protective actions generally aim to reduce: a) ingestion dose from the consumption of contaminated foodstuffs and drinking water; b) external dose rates from deposited radionuclides; and c) inhalation dose from breathing in resuspended radioactive material. In addition, there are a few protective actions, for example natural attenuation and monitoring, and live monitoring, that are carried out for the purpose of reassurance. As such, these measures do not directly reduce exposures, but can be helpful in demonstrating the effectiveness of other protective actions.

Information on the effectiveness of protective actions is generally expressed in terms of a reduction factor (RF) or percentage reduction in the radionuclide concentration in the target medium (that is, soils, crops, building surfaces, roads) after implementing the protective action. This reduction factor is often directly related to the decrease in dose. The term decontamination factor (DF) is also a reduction factor but used specifically for protective actions involving decontamination, that is, removal of contamination from the target medium.

Effectiveness is influenced by several factors, including how quickly the action can be carried out after deposition, the duration of treatment, physical and chemical form of the radionuclide, radiological half-life, and compliance with carrying out the procedure.

4.4.4 Doses received during implementation of protective actions

Additional doses can be received by those responsible for implementing protective actions, for example farmers, remediation workers, monitoring personnel. Several factors influence the magnitude of the doses received, including the radionuclides released, level of contamination, exposure time, wearing of personal protective equipment (PPE), and management strategy for any waste arisings.

4.4.5 Waste disposal

Some protective actions, for example the placing of food restrictions and techniques involving the physical and chemical removal of contamination from surfaces, generate waste products that need to be carefully managed. These wastes include solids and liquids, including biodegradable materials. Routes for transportation, segregation, storage, treatment, and disposal of waste must be considered at the time the protective action is being evaluated.

There are a range of disposal options available to manage wastes generated during recovery, some of which can be carried out in situ (for example, landspreading of milk, composting), whilst others require off-site facilities (for example, landfill, incineration). To provide suitable control of any waste arising during recovery operations, a number of factors need to be considered when forming a recovery plan including:

- identification of appropriate areas to store wastes on either a short or long-term basis, accounting for weather and physical and chemical characteristics of the waste (for example prevention of rain ingress into the waste, prevention of liquid wastes contaminating the wider environment)
- how waste is to be characterised, including techniques to be employed and the location of any facilities that may be required (for example laboratories for radiochemistry analysis)
- how specific types of wastes will be disposed of (for example by landfill or incineration), the location of suitable facilities and any specific acceptance criteria required by disposal facility operators
- how and by what route waste will be transported between its source and each site identified by the management plan

It is important that these factors are considered in a holistic way, together with any other factors that may influence how waste may be managed (for example, legal requirements, stakeholder perceptions and so on). More information on waste management is given in section 5.

4.4.6 Legal constraints

The implementation of protective actions is influenced by a patchwork of different legislation designed to protect for example, food safety, farmland, animal welfare, environmentally sensitive and protected areas, fisheries, drinking water supplies, historic buildings, radiation exposure of the public and remediation workers, non-radiological health and safety, health protection, access, liability, and management of waste. A systematic review of the legislative framework for recovery from a radiological incident has been conducted (13) and is summarised in Annexe B. Relevant aspects have been captured in the protective action datasheets, described in section 4.5. When deciding on a remediation strategy, appropriate legal, regulatory, and professional advice should be sought (for example, radiation protection adviser).

4.4.7 Environmental impact, including secondary contamination

Protective actions can lead to positive and negative impacts on the environment, although negative impacts are likely to be the more common. For example, ploughing or mechanical digging, turf and topsoil removal may lead to changes in biodiversity, soil fertility and structure, and enhanced soil erosion. The fire hosing of buildings can lead to secondary contamination of the wider environment if the water is not contained and disposed of appropriately. Protective actions can also indirectly affect the quality of the environment through negative changes to the landscape, for example by siting of new buildings for storage of waste, erection of fencing or cordons, or to the social and economic value placed on the environment by restricting access to the countryside or traditional pursuits such as hunting, fishing, and walking.

4.4.8 Economic cost

There are various economic costs associated with the implementation of protective actions. Direct costs include labour, equipment and consumables, and waste management. Indirect costs include loss of business and economic activity, loss of market share, reduction in tourism, and blight on the value of land and properties. It is difficult to estimate the costs of any protection strategy as numerous factors have an influence, for example time of year, scale, duration, public perception, and behaviour.

4.4.9 Disruption, societal impact and acceptability of protective actions

The implementation of protective actions can be disruptive and cause anxiety and stress to those affected, and may impact health and wellbeing, and the economic stability of the affected area. Those particularly susceptible are elderly people, parents with young families, pregnant women, and small businesses. Conversely, protective actions may also provide reassurance and have a positive impact by making an area look cleaner or by improving infrastructure. In practice, the choice of protective action will almost always involve a balance between health, economic and societal impacts, as well as trade-offs between the interests of different stakeholders. Such complexity means that it is difficult, if not impossible, to predict the way in which these factors may impact on the situation. Therefore, building a process to discuss the issues at stake with all affected people is an important part of the remediation strategy.

4.5 Protective action datasheets

4.5.1 Datasheet template

A datasheet template was designed to systematically record information in a standardised format, taking into account the technical criteria that decision makers might wish to consider when evaluating different protective actions (Table 14). This template updates previous versions to reflect extensive discussion with stakeholders and end-user requirements. The template includes a short description of the protective action, its key attributes, physical and legal constraints, effectiveness, feasibility, the waste generated, possible pathways of exposure, impacts, and practical experience of implementation. Potential societal impacts have not been included, due to complexity and dependence on site and incident-specific factors.

Table 14. Datasheet template

Name of protective action	
General	**Provides general information about the protective action**
Objective	Primary aim of the protective action (for example, reduction of ingestion dose, external dose, or resuspension dose).
Other benefits	Secondary aims of the action (if any).
Protective action description	Short description of what the protective action does and how to implement it.
Target	Type of production system, surface, or water supply. Where protective action is to be implemented.
Targeted radionuclides	Radionuclides or categories of radionuclides (for example, alpha emitters, short-lived or long-lived radionuclides) that the protective action is aimed at. Information is given as appropriate on one or more of the following categories: Known applicability: Radionuclides for which there is evidence that the option will be effective. Probable applicability: Radionuclides for which there is no direct evidence the option will be effective but for which it could be expected to be so. Not applicable: Radionuclides for which there is evidence that the option will not be effective. Reasons for this are given.

Name of protective action	
Scale of application	An indication of whether the option can be applied on a small or large scale. Small = less than 1 km^2. Medium = 1 to 10 km^2. Large = over 10 km^2. Parameters of scale will be different for drinking water (volume-based) and food production systems (larger areas potentially contaminated).
Timing of application to optimise effectiveness	Time relative to the emergency when the action is applied. For food can be implemented pre-deposition. Otherwise, early phase (days), intermediate phase (weeks-months), or long-term phase (months-years)
Constraints	**Provides information on the constraints that should be considered before applying the protective action. These may limit application of the action**
Legal	Laws referring to, for example, regulation of foodstuffs, protection of the environment, cultural heritage protection, liabilities for property damage, protection of workers. Primary legislation only.
Physical environment	Constraints of a physical nature that prevent or restrict implementation or access such as weather (snow, frost, rain,) soil type and slope. Environmentally sensitive habitats may also preclude application of some actions.
Effectiveness	**Provides information on the effectiveness of the protective action and factors affecting effectiveness**
Reduction in activity concentrations in foods, drinking water or on surfaces	Expressed in terms of a reduction factor (RF), decontamination factor (DF) or percentage reduction in contamination. In all cases, effectiveness refers to the reduction in activity concentration in or on the target surface after applying the protective action. A DF is used specifically for protective actions involving decontamination. RFs and DFs are indicative values based on studies. Actual results may vary depending on site specific situation (including form of the radionuclide) and when the action is implemented relative to deposition.
Reduction in surface dose rates	The reduction in the dose rate above a surface.
Reduction in resuspended activity in air	The reduction in the resuspended activity concentration in air above the surface. This is particularly important for implementers.
Technical factors influencing effectiveness of protective action	Technical factors include surface material, evenness or slope of surface, weather conditions, soil type, scale, as well as chemical and physical characteristics of the contamination.

Name of protective action	
Resourcing	**Provides information on the equipment, infrastructure and skills required to carry out the protective action**
Specific equipment	Primary equipment for carrying out the protective action.
Ancillary equipment	Secondary equipment that may be required (for example, monitoring equipment).
Utilities and infrastructure	Utilities (for example, water and power supplies) and infrastructure (for example, buildings and distribution networks such as road and rail links).
Consumables	Consumables such as fuel, sorbents, fertiliser, PPE, waste disposal bags, containers, and bunds.
Skills	Skills and the type of training that might be required.
Work rates and operator time	Time required to implement the option per unit of the target that is treated. Operator times are subject to many variables including the terrain, weather conditions, the skills and equipment available, and whether workers are wearing PPE.
Waste	**Some protective actions create waste, the management of which must be carefully considered at the time the protective action is selected**
Type	Nature of waste (solid or liquid).
Transport	Options available to transport waste (for example, road, rail, sea). If road, type of vehicle required. Proximity to and capacity of storage, treatment, and/or disposal sites needs to be considered.
Treatment	Requirement to treat waste *in situ* or at an offsite facility.
Storage	Options for storing waste.
Disposal	Options for disposal.
Pathways of exposure to implementers and the public	**Provides information about relevant exposure pathways**
Exposure pathways	Exposure pathways to implementers. Indicate pathways that may be significant. Exposure pathways to members of the public.
Impact of protective action	**Provides information about side effects of implementing the protective action**
Environmental impact	Impact that a protective action may have on the environment (for example, with respect to pollution, land use).

Name of protective action	
Practical experience	**State-of-the-art experience in carrying out the protective action. Some options have only been tested on a limited scale, while others are standard practices.**
Key references	**References to key publications leading to other sources of information**
Comments	**Any further comments not covered by the above**

4.5.2 Catalogue of datasheets

Datasheets have been produced for each protective action (Table 15). In total there are 46 datasheets: 24 for food production systems (numbered 1 to 24), 5 for drinking water supplies (numbered 25 to 29), and 17 for inhabited areas (numbered 30 to 46). The datasheets are listed in alphabetical order for each land use category.

This index of protective actions also contains hyperlinks to individual datasheets presented in Annexe A. The user is guided back to this index from a link that is provided at the bottom of each datasheet. The complexity of legislation relating to remediation of inhabited areas is captured in Annexe B, rather than within individual protective action datasheets.

Table 15. Index to protective actions with hyperlinks to datasheets

Number	Protective actions: Foods
1	Addition of AFCF to concentrate ration
2	Addition of calcium to concentrate ration
3	Addition of clay minerals to concentrate ration
4	Administer AFCF boli to ruminants
5	Application of NPK fertilisers and/or lime to soils
6	Clean feeding
7	Close air intake in greenhouses and food processing plants
8	Consumer access to monitoring equipment
9	Derestriction surveys and dose assessment
10	Dietary advice, including culinary preparation
11	Live monitoring (Mark and Release)
12	Manipulate slaughter times
13	Natural attenuation with monitoring
14	Ploughing options
15	Processing and storage (commercial)
16	Product withdrawal and recall

17	Protect harvested crops from deposition
18	Remove topsoil
19	Restrictions on hunting and fishing
20	Restrictions on terrestrial or aquatic foods (FEPA orders)
21	Select alternative land use (non-edible products)
22	Selective grazing
23	Shelter livestock
24	Slaughter and suppress lactation
	Protective actions: Drinking water
25	Alternative drinking water supply
26	Changes to water abstraction point
27	Controlled blending
28	Continue normal water treatment
29	Flush distribution system
	Protective actions: Inhabited areas
30	Cover contaminated soil and grass
31	High pressure washing including water jetting
32	Natural attenuation with monitoring
33	Ploughing methods and mechanical digging techniques
34	Prohibit public access
35	Reactive liquids (domestic chemicals)
36	Remove and replace road and paved surfaces
37	Remove building surfaces
38	Remove grass after cutting
39	Remove plant material
40	Remove topsoil (and turf)
41	Store and cover personal and precious objects
42	Strippable coatings
43	Temporary relocation
44	Tie down
45	Vacuum cleaning (indoor and outdoor)
46	Water-based cleaning

4.5.3 History of datasheets and acknowledgements

The datasheets have a long history of development (49) that predates the publication of the first version of the UK Recovery Handbook for Radiation Incidents (21). Over the intervening years, the datasheets have been reviewed and updated, with each new version of the UK Recovery Handbook (22, 23, 50), and the European counterpart (2, 41, 43). The reviews have included input from experts outside of UKHSA including regulators, industry practitioners and specialists working on decommissioning and recovery projects within the UK and internationally.

5. Management of waste

Large volumes of radioactive waste can arise from the management of food production systems, drinking water supplies and inhabited areas (land, buildings, roads and so on) following contamination of the environment after a radiation emergency. The types and volumes of radioactive waste produced will be determined by the specific nature of the radiological or nuclear emergency, the protective actions taken during the response and recovery phases and the reference level selected. For example, due to the selection of different reference levels and remediation strategies the volume of waste generated after the Chornobyl accident was, at 30,600 m^3, approximately 500 times less than the amount of waste removed by decontamination works in the Fukushima prefecture (29).

Radioactive waste management during emergencies will typically require plans and arrangements for activities including waste collection and staging at a secure site pending characterisation, segregation, treatment, storage, transport, and disposal. In a radiation emergency, the scale and surge in demand for materials, infrastructure, vehicles, and skilled workers is likely to be beyond the normal radioactive waste management capacity of the UK nuclear industry. Therefore, proposals for the management of radioactive wastes should be pragmatic, aim for simple solutions that can be adapted to the prevailing circumstances, and at all times be optimised. When deciding on a waste management strategy, it is important to consider the impact of the contaminated waste on the public, workers handling the waste, and on the environment. This will be part of a holistic approach that also accounts for any relevant non-radiological characteristics of the waste, available resources, and regulatory requirements. A waste management strategy should be agreed prior to carrying out remediation and decontamination. Ideally an outline plan for managing radioactive waste in emergencies should be developed in the preparedness phase (section 8.5). This builds upon the experience from the Fukushima Dai-ichi accident in 2011 and requirements or guidelines provided in IAEA General Safety Requirements Part 7: Requirement 15 (25) and IAEA TECDOC 1826 (26). In the case of Fukushima, remediation efforts started without the necessary identification of storage or disposal sites for remediation wastes. As a result, the wastes generated were stored adjacent to the areas being cleaned or transported and stored within the vicinity of the affected community, in so called temporary storage sites (TSS), subsequently referred to by IAEA (26) as 'staging areas'. The result of the remediation works meant waste was held in over 150,000 different locations. The lack of waste management strategy put in place prior to remediation led to a delay in moving the waste to suitable storage or disposal facilities. Temporary incineration facilities were constructed in locations to deal with the excess incinerable waste and reduce the time taken to remove waste from the affected communities (29).

5.1 Legislation and regulations

In line with current legislation, any radioactive waste storage or disposal activities associated with a radiological emergency will require regulatory control. Within England and Wales, the

Environmental Permitting Regulations 2016 specify activities, including accumulation and disposal of wastes, which require an environmental permit from the Environment Agency (EA) or Natural Resources Wales (NRW). Similar provisions are given with respect to the management of radioactive waste in Scotland in the Environmental Authorisations (Scotland) Regulations 2018 and for Northern Ireland in the Radioactive Substances Act (RSA 93) (1993) respectively. The regulatory authorities in Scotland and Northern Ireland are the Scottish Environment Protection Agency (SEPA) and the Environment and Heritage Service of the Department of the Environment in Northern Ireland respectively. In addition, storage of waste material on a nuclear licensed site will require adherence to the conditions of the license held by the responsible organisation.

For nuclear and radiological emergencies that generate waste beyond the UK's capacity for routine operations, it is likely that legislation will need to be applied flexibly or amended to temporarily facilitate the rapid increase in demand for waste management resources (sites, equipment, personnel and so on), for example, in establishing TSS. It will, however, be important that the management of this waste is brought under regulatory control as soon as possible, and any amendments to legislation are seen as temporary measures. Government and regulators should be prepared to act quickly if the legislation needs to be amended or regulatory tools applied, to deal with the prevailing circumstances of emergencies that generate large volumes of radioactive waste. For smaller-scale nuclear and radiological emergencies, the legislation should be complied with as written.

Wherever possible, existing storage and disposal routes should be used before considering new or alternative disposal options. The permitting of new facilities or varying the limits and conditions of existing permits can be a lengthy process which may lead to delays in remediation. Where no suitable permitted facility can be identified, the relevant environment agency will have to agree some form of regulatory control which may require direction from the Secretary of State or relevant Scottish Minister.

Consent for waste management activities (storage, transportation), the acquisition of land for waste management facilities from local authorities and landowners and addressing concerns of residents were key challenges identified in the review of the Fukushima Dai-ichi recovery effort (29). The waste management strategy should therefore consider such issues as a priority and ensure that the regulatory framework facilitates an optimised approach.

5.2 Principles and considerations

Waste that has been contaminated with radioactivity in emergencies is likely to be far more heterogeneous, voluminous, and complex than waste arising from routine operations. These large volumes of waste could quickly exceed or overwhelm the available capacity in the UK. Therefore, following an accident, a bespoke strategy to manage any waste arising is likely to be required. This strategy which should be underpinned by the fundamental radiation protection principles of justification, optimisation, and dose limitation. Any plans and strategies to deal with radioactive waste from emergencies should consider international guidance (25, 26, 40). In addition, the proximity principle should be adhered to as far as practical, that is, the wastes should be managed as close to the source as possible (see section 5.2.1). Where transport of wastes is required, any packaging used is subject to numerous regulatory requirements for which advice from the ONR should be sought.

Data management of the locations, quantities and properties of waste is necessary. Waste packages should be indelibly labelled with a unique identifier to allow the relevant data to be linked to the waste package. Systems should be put in place to allow for the collection, review, organization, and retention of the data as well as allowing prompt access to, and dissemination of the data.

5.2.1 Collection of waste at or near the scene

This section is written in the context of large nuclear and radiological emergencies where there is no existing storage or disposal route for waste. This will result in waste needing to be collected in areas near the point of origin. For example, if a decision is taken to remove large areas of topsoil, a nearby area will be needed to collect the topsoil that has been removed before it can be moved for onward storage and disposal. The area where waste is collected is referred to as a ‘staging area’ (section 5.2.1.1). Certain waste management activities may take place in the staging area, including characterisation (section 5.2.3), segregation (section 5.2.4) and volume reduction (section 5.2.5).

5.2.1.1 Establishing staging areas

From the first few days after the onset of an emergency, it is crucial to consolidate waste in staging areas so that it does not hinder the emergency response or recovery activities. Staging areas represent a first step in the waste management process for major nuclear and radiological emergencies. It is here that waste can be collected for initial characterisation, segregation and temporary storage including packaging. For emergencies that lead to wide-area contamination, there may need to be several staging areas set up to collect the waste before more established waste management facilities and resources can be secured. IAEA TECDOC 1826 (26) provides details of the main attributes of staging areas, but in summary they should:

- be of sufficient size to facilitate characterisation and segregation by waste type to avoid the mixing of incompatible materials; waste needs to be segregated on the basis of radiological, chemical, and physical properties
- have sufficient management controls in place
- have a records management process in place noting the radiological, chemical, and physical properties
- use durable containers to hold bulk materials (for example, concrete or metal boxes, reinforced fabric bags, suitable plastic containers)
- have drainage systems and bunding to control potential releases
- have monitoring systems in place

- use concrete or other low permeability hard surfaces on which to place the waste or containers
- have security measures in place (for example, security fencing, surveillance) to prevent fly-tipping or uncontrolled access
- be operated by trained radiological safety and security personnel to perform activities, such as:
    - segregation of waste based on gamma dose rates
    - supervision of all activities including labelling of waste
    - recording of waste within packaging
    - accepting packaged waste
    - surveillance of temporary storage

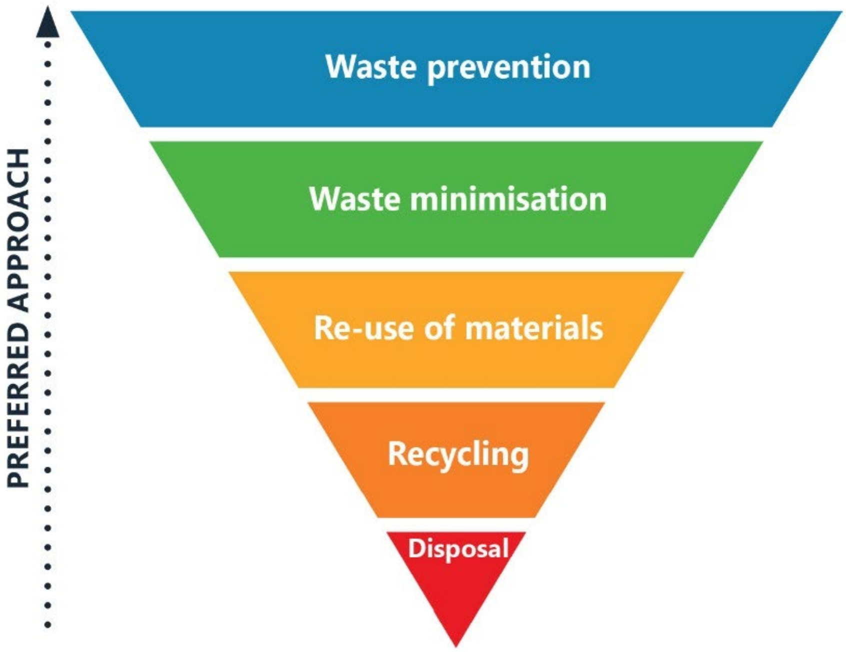
Managing personnel dosimetry programmes and identification of potential staging areas will be a key consideration for nuclear and radiological emergencies that generate wide-area contamination, and should be considered either in preparedness or early in the response as part of the waste management strategy. The attributes listed above, should be considered when identifying potential sites, including, how resources (people, packaging and so on) will be sourced to operate the staging area. Close collaboration with the respective regulator will be required to ensure the safety of the site for workers, the public and the environment. Information on how staging of waste was conducted after the Fukushima Dai-ichi accident is available from the Ministry of the Environment in Japan (33).

5.2.2 Minimise volumes of waste requiring disposal

The waste management hierarchy should be applied as far as practical weighed against the time, cost, and societal restoration constraints for recovery. This sets out the priority order for managing waste (see Figure 5). Top priority is to prevent or minimise waste being produced. In this context, the criteria agreed for decontamination will have a large impact on the volume of waste generated and this should be considered when setting reference levels. For any waste that is produced, options for reuse, recycling, and volume reduction (for example, incineration, compaction, evaporation) prior to disposal, are recommended. However, the deliberate dilution of contaminated waste in order to release that waste from regulatory control should be avoided, although such dilution may be permitted if it aids the reuse or recycling of that material and prior approval from the regulator has been obtained.

Volume reduction is a key tool in the management of waste, which helps with the handling of the waste and reduction in capacity required for storage and disposal. Application of the waste hierarchy will help to prevent and minimise the creation of waste from which the remaining waste can then be reduced further by various methods, including incineration, compaction, and evaporation. Incineration was one of primary methods of volume reduction used in the Fukushima Dai-ichi clean-up (29). The need to construct or re-purpose incineration facilities will need to be considered as part of the waste management strategy.

Figure 5. Application of the waste hierarchy and sustainability (36)



Some other practical examples of how waste was reduced in the clean-up of the Fukushima Dai-ichi accident, included:

- crushing: used to crush branches and other vegetation
- chipping: used to reduce the size of branches and other vegetation using woodchippers
- compression: vacuum compression of organic material
- drying: used to dry out contaminated municipal sewage sludge

5.2.3 Develop a plan to characterise waste

Waste characterisation is essential to provide information about the levels of radioactivity present in the waste as well as its physical, chemical, and biological properties. This information will be used to inform the categorisation of the waste (section 5.2.4) and provide assurance that wastes can be accepted by treatment, storage or disposal facilities or inform the adaptation of existing facilities and the design and development of new facilities. Monitoring and characterisation requirements should be considered at an early stage. Guidance on good practice in solid radioactive waste characterisation has been produced by the Nuclear Decommissioning Authority (35). It is likely that characterisation will need to occur in stages, to facilitate different steps in the waste management process, that is, beginning with crude assessments to facilitate movement and storage, progressing to more detailed characterisation to facilitate disposal.

When characterising waste, for example when estimating the average activity concentration present, care should be taken to manage the level of conservatism applied. This is because excessive conservatism could result in the unnecessary classification of waste as radioactive or wrong choices being made about how to dispose of or manage the waste.

5.2.4 Apply criteria to categorise radioactive waste

Radiological criteria for the categorisation of waste are important to support efficient management of waste arising from emergencies. In the UK, radioactive wastes from normal operations are classified according to the type and quantity of radioactivity they contain and if heat is produced (Table 16). In the event of a large radiation emergency, there are likely to be large volumes of very low-level waste and low-level waste.

Table 16. Waste categorisation

Category	Description
Out of scope	Waste that has levels of radioactivity that are below those noted in the regulations and hence, for regulatory purposes, is not considered to be radioactive waste. Subject to it not having any other hazardous properties, waste that is out of scope of the regulations can be managed as normal household waste, for example by disposal to landfill or incineration facilities.
Exempt waste	Material that should be managed as radioactive waste but which, due to the low level of activity present, poses a low level of risk and hence its management is exempt from some of the requirements of the regulations. Subject to it not having any other hazardous properties, exempt waste can be disposed of with regular household waste.
Very low-level waste (VLLW)	Material that is a sub-category of low-level waste with specific activity limits. VLLW can sometimes be disposed of with regular household or industrial waste at permitted landfill facilities.
Low-level waste (LLW)	Material that contains relatively low levels of radioactivity (not exceeding 4 giga becquerel (GBq) per tonne of alpha activity, or 12 GBq per tonne of beta or gamma activity) with more limiting criteria for chemical form and specific radioisotopes. LLW can be accepted at some landfill and incinerator facilities although the quantity allowed may be limited. Disposal to the Low-Level Waste Repository may be permitted. The disposal of LLW must be discussed with regulators and disposal facility operators at the earliest opportunity.
Higher activity waste (HAW)	This category includes wastes that have levels of activity above those of LLW and includes material classed as intermediate level waste (ILW) and high-level waste (HLW). HAW requires specialised handling, treatment processes and storage or disposal. In the UK, HAW is currently stored on nuclear licensed sites until facilities for its final disposal are constructed. It is unlikely that recovery following an accident will involve the generation of significant volumes of HAW.

Category	Description
Plutonium contaminated material (PCM)	Specific type of radioactive waste requiring additional security controls and special management due to the presence of PCM. Depending on inventory of nuclear material, the PCM could be LLW or ILW but will need specific management.

These categories of wastes will need to be applied in a nuclear or radiological emergency as they inform how the waste should be managed. In the unlikely event that these categories would need to be amended to specifically deal with increased volume and complexity of waste generated by wide-area contamination, close collaboration with the respective regulator will be essential.

Several factors were considered as part of the categorisation of waste following the Fukushima Dai-ichi accident (29), including:

- the geographical area where the waste was generated (that is, the waste must have originated as a result of the emergency or subsequent protective actions)
- the activity concentration of radioactive caesium, specifically ^{134}Cs and ^{137}Cs, as part of the clearance level. For example, in response to Fukushima, wastes were dealt with depending on the activity concentration present, as presented in Table 17
- the type of waste (combustible, non-combustible including soil)
- source of the waste (for example, demolition, cleansing and so on)

Table 17. Classification of waste in response to Fukushima Dai-ichi incident

Activity	Disposal route
Less than 8,000 Bq/kg	Conventional waste disposal (municipal landfill) – recycled where possible
8,000 to 100,000 Bq/kg	Designated landfills equipped with radiation monitoring and leachate treatment system
Over 100,000 Bq/kg	Stored in the interim storage facility in specially designed concrete storage facilities

5.2.5 Avoid mixing waste

Segregation of waste by radioactive content or on physical or chemical characteristics allows each waste type to be managed appropriately. For example, if VLLW soil becomes contaminated with oil it would prevent its disposal at a permitted landfill site. Therefore, soil contaminated with oil should be separated from soil that is uncontaminated. Similarly, segregating waste containing radionuclides with short half-lives from that containing longer-lived radionuclides may allow options such as decay storage prior to disposal to be used.

5.2.6 Identify appropriate storage and disposal options and sites

Treatment, packaging, and temporary storage of wastes are likely to be required prior to final disposal. It is essential that these steps are considered when deciding on protective actions. Where possible, existing facilities and resources used in routine operations should be used for waste generated in a radiological or nuclear emergency. However, where information about waste characterisation is limited, storage in temporary locations may be appropriate pending the gathering of such data. In addition, in some situations it may be necessary to consolidate waste temporarily in 'staging sites' as discussed in section 5.2.1.1. Some flexibility within the regulatory regime will be necessary for the establishment of short-term storage options (that is, staging areas lasting weeks or months). However, as the waste is moved into existing or more orthodox facilities for longer-term storage (for example, up to decades), then full regulatory controls will be needed. This will be the case for the construction of new longer-term storage facilities. A checklist for setting up facilities for temporary storage can be found in Table 18. The list is not exhaustive, and other considerations may apply.

When considering storage requirements, the chemical and physical properties of the waste and of the containing medium (that is, steel drums versus builders' bags for control of dispersion of activity) should be considered, as well as its radioactivity content. A suitable secure storage facility should be easy to decontaminate, made of non-combustible materials and not contain, or be located close to, any corrosive, explosive or flammable materials. Furthermore, water ingress (for example, rain) should be minimised and water egress (for example, leachate) should be controllable at such sites.

Where solid waste is stored, especially if that area has not previously been used for such purposes, an assessment of risk should be carried out and, following discussion with appropriate experts and regulators, appropriate measures taken to control those risks enacted. ONR, the police and the relevant environment agency should be notified immediately if any radioactive waste is lost or stolen. Packaging and treatment of wastes to enable storage must not rule out or prevent any future disposal route.

Table 18. Checklist for temporary storage of solid radioactive waste

Potential issue	Factors to consider
Water infiltration	Requirement to store waste in watertight drums or containers. Adequacy of a tarpaulin to prevent infiltration of containers. Requirement to place containers inside a building.
Containment	Requirement for containers to be chemically stable; to provide shielding; to be mechanically robust (impact, thermal); and portable.
Leachate and atmospheric emissions	Requirement for sloped concrete floor with isolated drainage system for leachate collection. Leachate removal from site, for example tanker.

Potential issue	Factors to consider
	Location of leachate treatment disposal facilities. Requirement for a gas extraction and collection system, and/or a heat removal system.
Monitoring	Requirement for routine monitoring of storage facility and local environment. Requirement for a leakage detection system, with alarm in case of release of activity. Requirement for personal monitoring. Arrangements for reporting monitoring results to regulators.
Waste conditioning	Requirement for waste conditioning prior to storage, for example will storage of waste in its natural form compromise future disposal, for example, grass decomposition? Presence of unconditioned organic waste that may generate methane and carbon dioxide; and reactions involving metals will generate hydrogen. These gases could contain traces of radionuclides and lead to exposures to workers and members of the public.
Type of storage site or facility used	Requirement to use non-combustible materials in construction of storage facility. Requirement to decontaminate facility after use. Management of any residual contamination.
Incident response	Risk of integrity of storage facility being breached (for example fire or incident involving radioactive waste material). Appropriate planning for such incidents.
Location of storage facility	Consideration of natural hazards that could affect integrity of stored waste (for example flooding). Consideration of any corrosive, explosive or flammable materials, onsite or close by. Consideration of sensitive environments, water sources (for example reservoirs) or areas of high public occupancy (for example near to residential, educational, or industrial buildings).
Radiation protection Doses to workers and the public	Consideration of regulatory obligations and requirements for example, permitting, worker and public dose control and so on Requirements for controlled access. Assessment of risk to the public and requirements for appropriate radiological protection measures for wastes with elevated activities.
Security	Adequacy of controls needed to manage acts of vandalism, terrorist attacks and other threats.

Potential issue	Factors to consider
Transport	Access to site, transport routes, proximity to final disposal facility and other aspects.

Figure 6 shows the indicative viability of different waste management routes for different categories of waste. This can be used as an early screening tool to inform a waste management plan. However, there is no guarantee that any specific route is available or has capacity, as this is incident specific and may require emergency legislation or changes to the regulations.

Figure 6. Indicative viability of different waste management routes according to waste management hierarchy

Reuse

Process	Waste type
Controlled reuse of land or property	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Not credible)
	VLLW (Minor changes)
	Exempt (Minor changes)

Reduce

Process	Waste type
Incineration	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Minor changes)
	VLLW (Minor changes)
	Exempt (Minor changes)

Recycle

Process	Waste type
Process contaminated metals	PCM (Not credible)
	HLW (Not credible)
	ILW (Potential)
	LLW (Minor changes)
	VLLW (Minor changes)
	Exempt (Established)

Store & Dispose

Process	Waste type
Existing nuclear facilities on licenced sites	PCM (Minor changes)
	HLW (Minor changes)
	ILW (Minor changes)
	LLW (Established)
	VLLW (Established)
	Exempt (N/A)

Disposal

Process	Waste type
Uncontrolled landfill	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Not credible)
	VLLW (Potential)
	Exempt (Established)

Reuse

Process	Waste type
Uncontrolled release	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Not credible)
	VLLW (Potential)
	Exempt (Established)

Reduce

Process	Waste type
Decontamination (to reclassify waste)	PCM (Potential)
	HLW (Not credible)
	ILW (Potential)
	LLW (Established)
	VLLW (Established)
	Exempt (N/A)

Recycle

Process	Waste type
Release of bulk material (e.g. lightly contaminated concrete, soils)	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Potential)
	VLLW (Minor changes)
	Exempt (Established)

Store & Dispose

Process	Waste type
Existing nuclear facilities Controlled use (e.g., new construction)	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Potential)
	VLLW (Minor changes)
	Exempt (Established)

Disposal

Process	Waste type
Hazardous landfill	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Potential)
	VLLW (Established)
	Exempt (Established)

Reduce

Process	Waste type
New processing / conditioning facility (to make waste suitable for an existing disposal route)	PCM (Potential)
	HLW (Potential)
	ILW (Potential)
	LLW (Minor changes)
	VLLW (Minor changes)
	Exempt (Established)

Store & Dispose

Process	Waste type
Existing secure site storage	PCM (Minor changes)
	HLW (Minor changes)
	ILW (Minor changes)
	LLW (Established)
	VLLW (Established)
	Exempt (N/A)

Disposal

Process	Waste type
In situ disposal (e.g. ploughing of soils, burying of material on affected site)	PCM (Not credible)
	HLW (Not credible)
	ILW (Not credible)
	LLW (Potential)
	VLLW (Minor changes)
	Exempt (Established)

Legend
Not credible
Potential
Minor changes
Established
N/A

Waste type and primary organisation

PCM (NDA - Sellafield and/or Atomic Weapons Establishment); HLW (NDA - Sellafield); ILW (NDA - Sellafield); LLW (Nuclear Waste Services (NWS) and/or NDA - Sellafield); VLLW (Supply chain and/or NWS); Exempt (Supply chain or local authority)

Figure 6 distinguishes 4 levels of viability as follows:

1. Not credible: there are significant and disproportionate costs, technical constraints, or future timing issues, that prevent the partial or widespread use of this waste management route for this type of waste classification.
2. Potential: in principle this waste management route could be considered, subject to resolution of constraints that are currently beyond the intention of the existing facilities or organisations. This might require modification or granting of a licence (ONR) and permit (environment agencies) under emergency measures.
3. Minor changes: involving small changes at an existing waste management facility or expansion of capacity that can be achieved within weeks or months. Receipt and/or processing of material would not significantly increase the hazard or consequence to the local population if implemented.
4. Established: the process is available for the waste classification, although there may still be other issues associated with logistics and capacity.

If no permitted disposal route can be identified, then emergency options will need to be considered. Emergency storage and disposal options might include:

- making use of conventional waste transfer stations for storage of radioactive waste
- using conventional landfills for disposal of large volumes of low activity wastes
- using anaerobic digestion plants for cut vegetation
- composting of organic wastes (for example, turf, leaves, plants)
- creating new disposal or storage sites
- varying the limits or conditions of existing radioactive waste disposal sites so they can accept a wider range or wastes
- on-farm burial of radioactively contaminated carcasses
- decay storage of material which retains contamination well
- reuse of contaminated materials in another application, with or without decay storage

The relevant environment agency would have to consider any proposals for the use of emergency storage and disposal options as they would not be permitted in normal circumstances. The resultant contamination of any facilities must also be considered as well as any potential for radioactive liquid run-off from using these facilities.

The advice of accredited Radioactive Waste Advisors and Radiation Protection Advisors should always be sought when pursuing any waste management activities.

5.2.7 Consider non-radiological properties of waste

The non-radiological properties of radioactive waste, such as physical form, organic content and the presence of other hazardous contaminants may restrict options for treatment, storage, and disposal. Therefore, their determination should form part of the characterisation plan.

5.3 Management of solid radioactive wastes from decontamination

The protective action datasheets (Annexe A) provide information on the likely types of waste that will be generated, as well as suitable treatment, storage, and disposal route for the different radioactive wastes.

5.3.1 UK infrastructure for managing solid radioactive wastes

There are several sites in the UK which are permitted for the disposal and treatment of radioactive wastes. These sites include landfills, incinerators, metal treatment facilities, supercompaction and disposal facilities. Existing waste disposal or treatment sites use waste acceptance criteria (WAC) which specify the types and volumes of wastes which they can accept in accordance with their environmental permits. WAC include limits on the types, volume, and activity levels of the waste, as well as limits on other non-radioactive contaminants that the waste might contain (for example, asbestos or lead).

During smaller or localised incidents, it should be possible to make use of existing suitably permitted waste management facilities to store, treat, or dispose of radioactive wastes generated when undertaking remedial protective actions. Larger incidents which generate high volumes of radioactive waste are likely to exceed the capacity of existing radioactive waste infrastructure in the UK. Hence alternative emergency storage and disposal options will be needed (sections 5.2.1.1 and 5.2.6). It is also possible that waste generated during recovery will have properties that mean it is not suitable for sending to a disposal route used for waste generated during routine operations. For such wastes, an emergency disposal solution will need to be identified and bespoke permit granted by the relevant authority.

5.3.1.1 UK waste management services

Defra operates a private sector remediation capability framework. This capability is available for use by local authorities as well as Defra. If contractors under this framework are used, they would be expected to manage any waste arisings from decontamination activities they carry out. The Recovery Co-ordination Group, which is set up following a radiation emergency, should be consulted on any decisions made by the selected contractor regarding waste storage or disposal routes.

Nuclear Waste Services (NWS), which is a division of the Nuclear Decommissioning Authority (NDA), can advise on the treatment and disposal of nuclear waste and provide nuclear waste management services across the UK. In the event of a nuclear or radiological emergency, NWS have confirmed they would be able to utilise their existing Waste Acceptance Procedure to provide advice on whether wastes generated could be disposed of using existing UK infrastructure. NWS on-call staff should be contacted to initiate this process and the relevant environment agency can support discussions. Plutonium contaminated material and higher activity waste are likely to be sent to Sellafield.

5.4 Management of liquid radioactive wastes from decontamination

Some protective actions will generate liquid wastes. If water has been used for decontaminating surfaces, for example, pressure hosing, there is potential for generating large volumes of radioactively contaminated wastewater. Contaminated wastewater should be contained and collected wherever possible. It may then undergo treatment prior to storage or disposal. Temporary storage for the goal of reducing the activity present in the waste is particularly suited to wastewater containing short-lived radionuclides. Table 19 gives a list of factors to consider for the management of wastewater.

Several decontamination options involve the use of water to physically wash off radionuclides associated with particulate material. These particles normally retain the contamination well and can be collected along with the wash-water. Simple filtration through an inexpensive polymer fibre textile with a pore size of approximately 0.14 mm has been found to be highly effective in isolating the solid particles. Subject to approvals, the water may then be disposed of via sewers and the filters disposed of separately as solid waste.

Some contaminants may be dissolved in the liquid waste and not removable by filtration. Alternative methods include evaporation, precipitation, ion exchange and reverse osmosis. For small volumes of contaminated wastewater, zeolite blocks can be used to remove specific radionuclides (for example, radiocaesium).

Sewage treatment works (STW) typically use a combination of physical and biological methods to treat wastewater. During these treatments, concentrations of some radionuclides in the aqueous phase are reduced to a level that can be discharged to rivers or sea. However, filtration membranes can become highly contaminated and require special disposal, with potential radiological contamination of pipework and equipment at the STW requiring specialist cleaning. Sewage sludge is also produced when treating wastewater and will need suitable management given its radiological, chemical, and biological properties.

Unfortunately, the collection and storage of large volumes of wastewater can be challenging. Therefore, discharge to sewers and surface water drains may be unavoidable. If contaminated run-off enters the sewer system, the relevant environment agency must be consulted as this activity would not be permitted under normal circumstances. Identification of the surface water drains, and location of the affected STW should be a priority action. Once facilities with the potential to be affected by any discharge of radioactive liquids have been identified, a suitable risk assessment should be performed and submitted to the appropriate regulatory body (and possibly facility owner).

Factors to consider when disposing of contaminated wastewater are presented in Table 20.

Table 19. Checklist for management of wastewater

Issue	Factors to consider
Collection of wastewater	Method for collecting and containing wastewater and other decontamination liquids. Method for controlling wastewater that normally goes to soak-aways. Method for storing collected wastewater, especially that with different radiological or chemical properties. Location for storage prior to treatment and disposal.
Monitoring	Radionuclides present and detectors required. Monitoring process (for example, in situ dose rate measurements from stored bulk material). Location of monitoring sites, and laboratories for sample analysis. Adequate representation of the bulk material by sampling (for example, volume and location). Archiving of monitoring results (format, units, quality assurance, access, viewing permissions and so on).
Treatment of wastewater	Methods for volume reduction from decontamination activities. Methods for treatment, for example, simple screening of suspended contaminants at a public sewage treatment works (STW). Location of treatment facilities and capacities, local versus specialised facilities. Re-use of treated water for other clean-up options (for example, sandblasting). Options for transferring waste if public sewer system cannot be used.
Doses to workers and public	Requirement to meet regulatory limits and constraints for members of the public and those who might be occupationally exposed when managing and disposing of wastewater. Methodology to estimate doses consistent with published guidance, for example, by Environment Agency and others (15) and guidance notes from NDAWG (such as those on performing a tiered assessment (37) and how to account for short duration discharges of activity (38)). Noting that these literature sources are being updated.
Disposal	See Table 20.

Table 20. Checklist for disposal of contaminated wastewater

Issue	Factors to consider
Environmental impact	Impact on controlled waters, for example potable sources of water. Impact on sensitive environments, for example, sites of special scientific interest (SSSI); special areas of conservation (SAC); special protection areas (SPA).
Monitoring	Radionuclides present and detectors required. Monitoring process (for example, in situ dose-rate measurements from stored bulk material). Location of monitoring sites, and laboratories for sample analysis. Adequate representation of the bulk material by sampling (for example, volume and location). Archiving of monitoring results (format, units, quality assurance, access, viewing permissions and so on).
Doses to workers and public	Requirement to meet regulatory limits and constraints for members of the public and those who might be occupationally exposed when managing and disposing of wastewater. Methodology to estimate doses consistent with published guidance, for example, by Environment Agency and others (15) and guidance notes from NDAWG (such as those on performing a tiered assessment (37) and how to account for short duration discharges of activity (38)). Noting that these literature sources are being updated.
Acceptability	Two-way communication with stakeholders to find the most acceptable solution. Even if impact is assessed to be small, a perceived lack of control and deliberate contamination of STWs and environment may not be acceptable to the public.

6. Decision-aiding framework for remediation

In the event of a radiation emergency, decision makers will need to develop a remediation strategy involving one or more protective actions. As each accident or malicious event is likely to be different in terms of its radiological composition, impact, and duration, it is not possible to recommend a generic strategy. Section 2 describes a 7-step iterative process to frame decisions on recovery to:

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

Step 4 is the most relevant when it comes to identifying appropriate remedial protective actions and applying key attributes to evaluate them to inform decisions. Using the data and information provided in this section, it is possible to guide decision makers to the most appropriate subset of options, according to the specific characteristics of the radiation emergency. To aid navigation, this section is divided into 3 parts according to the different land uses that might be impacted by a radiation emergency:

- Part 1. Food production
- Part 2. Drinking water supplies
- Part 3. Inhabited areas

For each land use, a series of 3 look-up tables is provided. These tables help to refine option selection according to the 3 main criteria:

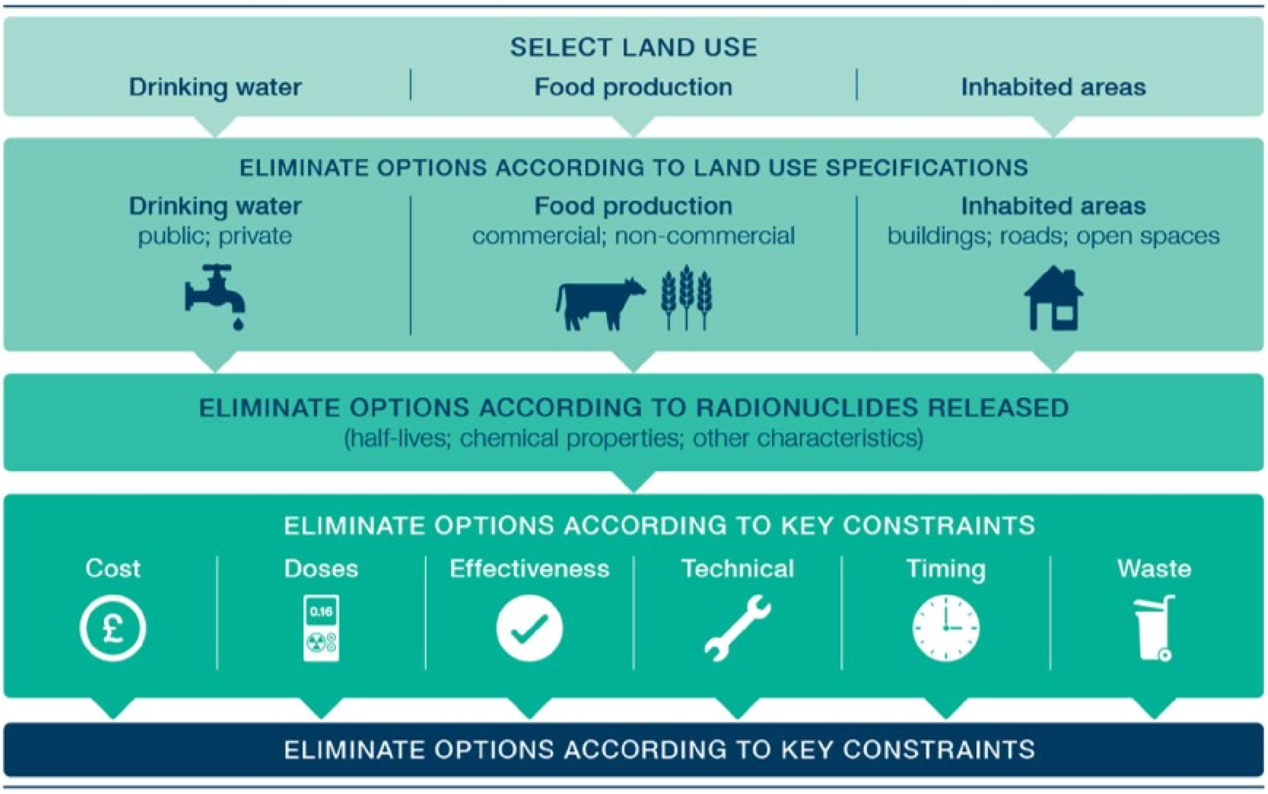
- specifics of the land use affected
- the radionuclides released
- key constraints

Quick links to the relevant tables are given in Table 21. A diagram illustrating the option selection and evaluation process is given in Figure 7. This figure guides the user through a series of steps that eliminate unsuitable protective actions on the basis of land use specifics, the radionuclides present, and various site-specific constraints including technical aspects and waste management.

Table 21. Navigation to look-up tables

Elimination criteria	Food	Drinking water	Inhabited area
Types or surfaces	Table 22	Table 25	Table 28
Radionuclides	Table 23	Table 26	Table 29
Constraints	Table 24	Table 27	Table 30

Figure 7. Overview of process to select and evaluate remedial protective actions



6.1 Part 1. Food production systems

6.1.1 Identifying options

There is a wide range of food production systems in the UK for which many protective actions can be applied (section 4). The first step in fine-tuning the selection of protective actions is to check for applicability according to what type of foods may have been impacted by the radiation emergency. Table 22 shows the applicability of 24 protective actions for commercial and non-commercial food production systems, according to food type, that is, milk, meat (extensive and intensive), fish, crops and grassland, domestic produce, and foraging, hunting, and fishing.

6.1.2 Evaluating options

The applicability of each protective action can be evaluated according to the radionuclides of concern and a series of key situational and contextual constraints. In this way, a subset of protective actions can be identified for each specific scenario or situation.

6.1.2.1 Identify key radionuclides

It is important to identify which of the radionuclides released during the radiation emergency contribute most to dose over time, noting that the relative contributions from different radionuclides and exposure pathways will change over time. Once the most important radionuclides have been identified it is then possible to check whether the protective actions are applicable.

Table 23 shows applicability of protective actions for food production systems according to radionuclide. Some protective actions are not applicable for radionuclides with short half-lives (less than a few weeks), whilst conversely others are not applicable for radionuclides with long half-lives (more than 2 years). Furthermore, some protective actions are radionuclide specific. These characteristics are helpful in eliminating unsuitable protective actions.

6.1.2.2 Consider constraints

In addition to identifying the radionuclides present, it is important to identify key situational or contextual constraints that will influence the applicability of each protective action. This will vary on a site and incident specific basis. Six major constraints have been identified:

1. Waste generation and subsequent waste management. Do the protective actions generate waste? Is there an established waste management route for any potential waste arisings?
2. Effectiveness of the protective action, some options are more effective than others. What level of effectiveness is required?
3. Doses to those implementing protective actions or managing waste arisings. Are doses to those implementing protective actions or managing waste suitably understood and controlled or managed from both legal and practical perspectives? Might additional doses be received by members of the public?
4. Technical limitations when applying the protective action, for example availability of feed additives or equipment. Does the protective action require specific environmental conditions, for example no snow, certain depth of soil, no rain and so on?
5. Timing issues. Does the protective action need to be implemented soon after deposition to be effective? Does the protective action take time to organise or manufacture?
6. Costs. What are the direct costs of resourcing the protection strategy? Are there indirect costs associated with consequences of implementing the protective action, such as disruption, stigma or environmental impact?

Table 24 provides details of major and minor constraints for each protective action for food production systems. These data can aid in the evaluation of options and help to eliminate impractical and unsuitable protective actions. More information on constraints can be found in the datasheets for each protective action (Annexe A1). These should be consulted before confirming the elimination of protective actions, based on site and incident specific constraints and local knowledge.

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	Applicable	Applicable	Not applicable	Applicable	Applicable	Not applicable	Not applicable
Protect harvested crops from deposition	Not applicable	Not applicable	Not applicable	Not applicable	Applicable	Not applicable	Not applicable
Shelter livestock	Applicable	Applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Restricting, preventing or reducing consumption of contaminated food							
Dietary advice, including culinary preparation	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Applicable	Applicable
Processing and storage (commercial)	Applicable	Applicable	Applicable	Applicable	Applicable	Not applicable	Not applicable
Product withdrawal and recall	Applicable	Applicable	Applicable	Applicable	Applicable	Not applicable	Not applicable
Restrictions on hunting and fishing	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Applicable
Restrictions on terrestrial or aquatic foods (FEPA orders)	Applicable	Applicable	Applicable	Applicable	Applicable	Not applicable	Applicable
Select alternative land use (non-edible products)	Applicable	Applicable	Applicable	Not applicable	Applicable	Not applicable	Not applicable
Slaughter and suppress lactation	Applicable	Applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Monitoring and dose or risk assessment							
Consumer access to monitoring equipment	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Applicable	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
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 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 23

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 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

Category or option	Major constraints	Moderate constraints
Restrictions on hunting and fishing	None	**Technical** • ability to predict times during the season when radionuclide levels will be below MPLs • 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)

Category or option	Major constraints	Moderate constraints
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 **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)

Category or option	Major constraints	Moderate constraints
		Effectiveness • potassium is most effective when exchangeable potassium status is less than 0.5 milli equivalents per 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

Category or option	Major constraints	Moderate constraints
		Doses to implementers • from external exposure and, to a lesser extent, inadvertent ingestion and inhalation while ploughing
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

6.2 Part 2. Drinking water supplies

6.2.1 Identifying options

There are 2 types of regulated drinking water supply in the UK and relatively few protective actions that can be applied (section 4). Table 25 shows the applicability of 5 protective actions according to drinking water supply type (public and private) noting that all options are applicable for public supplies.

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 25

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.

6.2.2 Evaluating options

The applicability of each protective option can be evaluated according to the radionuclides of concern and a series of key situational and contextual constraints. In this way, a subset of protective actions can be identified for each specific scenario or situation.

6.2.2.1 Identify key radionuclides

It is important to identify which of the radionuclides released during the radiation emergency contribute most to dose over time, noting that the relative contribution to the total dose to a representative person from different radionuclides and exposure pathways will change over time. Once the most important radionuclides have been identified it is then possible to check the applicability of all relevant protective actions. Table 26 shows applicability of protective actions for drinking water supplies according to radionuclide, noting that some protective actions are not applicable for radionuclides with short half-lives (less than a few weeks).

6.2.2.2 Consider constraints

In addition to identifying the radionuclides present, it is important to identify key situational or contextual constraints that will influence the applicability of each protective action. This will vary on a site and incident specific basis. Six major constraints have been identified:

1. Waste generation and subsequent waste management. Do the protective actions generate waste? Is there is an established waste management route for any potential waste arisings?
2. Effectiveness of the protective action. Some of the protective actions are more effective than others. What level of effectiveness is required?
3. Doses to those implementing protective actions or managing waste arisings. Are doses to those implementing protective actions or managing waste suitably understood and controlled or managed from both legal and practical perspectives. Could additional doses be received by members of the public?
4. Technical limitations when applying the protective action, for example, availability of alternative supplies. Does the protective action require specific environmental conditions for example, no drought?
5. Timing issues. Does the protective action need to be implemented soon after deposition to be effective? Does the protective action take time to organise or manufacture?
6. Costs. What are the direct costs of resourcing the protection strategy? Are there indirect costs associated with consequences of implementing the protective action, such as disruption, stigma or environmental impact?

Table 27 provides details of major and minor constraints for each protective action for drinking water. These data can aid in the evaluation of options and help to eliminate impractical and unsuitable protective actions. More information on constraints can be found in the datasheets for each protective action (Annexe A2). These should be consulted before confirming the elimination of protective actions, based on site and incident specific constraints and local knowledge.

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 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

<table>
<tr><th>Option</th><th>Major constraints</th><th>Moderate constraints</th></tr>
<tr><td>Controlled blending</td><td>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</td><td>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</td></tr>
<tr><td>Continue normal water treatment</td><td>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</td><td>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</td></tr>
</table>

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

6.3 Part 3. Inhabited areas

6.3.1 Identifying options

Table 28 shows the applicability of 17 protective actions for inhabited areas, according to surface type, that is, internal, and external building surfaces, roads and paved surfaces, and open spaces.

6.3.2 Evaluating options

The applicability of each protective action can be evaluated according to the radionuclides of concern and a series of key situational and contextual constraints. In this way, a subset of protective actions can be identified for each specific scenario or situation.

6.3.2.1 Identify key radionuclides

It is important to identify which of the radionuclides released during the radiation emergency contribute most to dose over time, noting that the relative contribution to the total dose to a representative person from different radionuclides and exposure pathways will change over time. Once the most important radionuclides have been identified it is then possible to check the applicability of all relevant protective actions. Table 29 shows applicability of protective actions for inhabited areas according to radionuclide. Some protective actions are not applicable for radionuclides with short half-lives (less than a few weeks), others are more suitable for long-lived radionuclides (more than 2 years), and a few radionuclides are difficult to detect.

6.3.2.2 Consider constraints

In addition to identifying the radionuclides present, it is important to identify key situational or contextual constraints that will influence the applicability of each protective action. This will vary on a site and incident specific basis. Six major constraints have been identified:

1. Waste generation and subsequent waste management. Do the protective actions generate waste? Is there is an established waste management route for any potential waste arisings?
2. Effectiveness of the protective action. Some options are more effective than others. What level of effectiveness is required?
3. Doses to those implementing protective actions or managing waste arisings. Are doses to those implementing protective actions or managing waste suitably understood and controlled or managed from both legal and practical perspectives? Could additional doses be received by members of the public?
4. Technical limitations when applying the protective action for example, availability of infrastructure, equipment. Does the protective action require specific environmental conditions for example, no snow, certain depth of soil, no rain, presence of leaves on trees and so on?
5. Timing issues. Does the protective action need to be implemented soon after deposition to be effective? Does the protective action take time to organise or manufacture?

6. Costs. What are the direct costs of resourcing the protection strategy? Are there indirect costs associated with consequences of implementing the protective action, such as disruption, stigma or environmental impact?

Table 30 provides details of major and minor constraints for each protective action for the range of surface types found in inhabited areas. These data can aid in the evaluation of options and help to eliminate impractical and unsuitable protective actions. More information on constraints can be found in the datasheets for each protective action (Annexe A3). These should be consulted before confirming the elimination of protective actions, based on site and incident specific constraints and local knowledge.

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				

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

Key to Table 28

a - Large buildings only.

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

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											

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

Key to Table 29

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 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)	**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
	• availability of drivers and transport to aid relocation, especially for those unable to drive themselves • 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	**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
	effluent may be collected in tanks or temporary bunded areas for subsequent disposal	**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

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, 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

Category or option	Major constraints	Moderate constraints
Remove topsoil (and turf)	**Waste** • large quantities of contaminated soil and vegetation	**Technical** • rocky, uneven, frozen, and waterlogged soils restrict machinery • 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	**Waste** • potential for high levels of contamination on indoor vacuum cleaner filters (low volume); larger

Category or option	Major constraints	Moderate constraints
	Technical • only of value for loose particulates or dusty contamination • outdoor vacuuming of large areas requires specialist equipment	volumes of dust and sludge from outdoor vacuuming **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

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
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

7. Applying decision-aiding framework to previous emergencies affecting the UK

Historically, 3 radiation emergencies have seriously affected the UK:

- the fire at Windscale in Cumbria in 1957, leading to high levels of ^{131}I in milk (4, 10, 14, 55)
- the accident at the Chornobyl Nuclear Power Plant in 1986, leading to high levels of radiocaesium in sheep in Cumbria and North Wales (16, 42)
- the poisoning of Alexander Litvinenko with ^{210}Po, in 2006, leading to contamination of parts of central London (56)

These emergencies can be used as worked examples to illustrate how the decision-aiding process (section 6) can be applied to real scenarios. They are not intended to be used to judge the remediation strategy implemented at the time.

7.1 Windscale fire (1957)

The following sections step through the process to aid decisions on remedial protective actions for agricultural areas contaminated by ^{131}I following the Windscale fire. The focus is on how the handbook could be used to develop a strategy if the same accident happened today. The final section provides information on which protective actions were selected at the time and why.

7.1.1 Define the situation (step 1)

Windscale was the site of a plutonium production factory that was constructed on the coast of Cumbria in north-west England in the early 1950s (now known as Sellafield). On 10 October 1957, uranium fuel and the graphite reactor caught fire and released an estimated 900 to 3,700 TBq of ^{131}I to atmosphere (18). Ground deposition was dominated by ^{131}I, with deposits of over 4 kBq/m^2 extending approximately 75km east-north-east and 140 km south-south-east of the site, covering an area of approximately 12,000 km^2 (3).

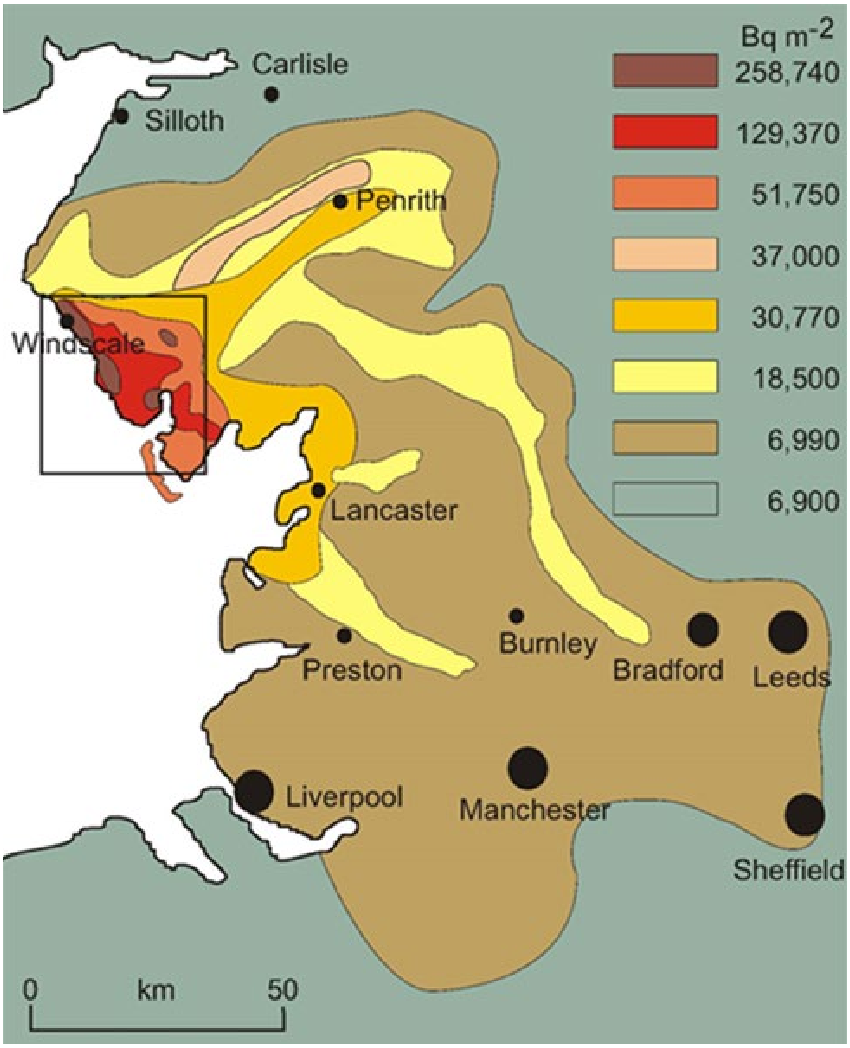
7.1.2 Assess impacts (step 2) and agree goals of recovery (step 3)

During the accident, radiation exposure of the public was assessed to be below the level that warranted the evacuation of communities in the vicinity of the Windscale site. The areas affected by deposition from the Windscale Fire consisted of mainly rural communities where dairy farming was a common agricultural practice.

Hasty but effective consultations and calculations led to the conclusion that distribution of milk at concentrations of ^{131}I in excess of 3,700 Bq/l should be prevented (this was the radiological protection goal established in 1957). Subsequent analysis showed that implementation of this ban on milk sales resulted in no individual receiving an equivalent thyroid dose greater than 200 mSv (8). The duration of milk bans in 1957 was of the order of 44 days.

The MPL in milk developed in 1957 (3,700 Bq/l) is well above the current MPL of 500 Bq/l (today's radiological protection goal). Using published deposition data (32, 44, 46), NRPB produced a deposition map (Figure 8) (46). Some manipulation of the data was necessary to resolve the 6,990 Bq/m^2 deposition contour corresponding to an activity concentration of 500 Bq/l in milk.

Figure 8. Deposition map of ^{131}I



The duration of restrictions on milk within each deposition contour is presented in Table 31. The total quantity of contaminated milk produced was estimated using the duration of milk restrictions and agricultural production data for the affected area. Applying an MPL of 500 Bq/l, the area subject to milk bans would have been 11,200 km^2 (1,120,000 ha). This would have resulted in about 86 million litres of milk requiring disposal, assuming no protective actions were implemented to reduce ^{131}I transfer to milk.

Table 31. Estimated areas and duration of restrictions on milk within each deposition contour, based on exceedance of the current MPL in milk (46)

Deposition level (Bq/m^2)	Area (thousand hectares)	Duration of restrictions (days)	Milk requiring disposal (thousand litres per day)	Total milk requiring disposal (thousand litres)
6,990	680	11	6,600	72,000
18,500	240	14	2,500	7,400
30,770	87	16	1,100	2,200
37,000	40	17	590	590
51,750	39	23	380	380
129,370	22	26	170	170
258,740	11	44	59	59
Total	1,100	-	-	86,000

7.1.3 Identify and evaluate options (step 4)

7.1.3.1 Identify options

The applicability of protective actions for different food products is shown in Table 22. Of the 24 potential protective actions, only 12 are relevant to milk production, as follows.

Prevent contamination before release

- close air intake in greenhouses and food processing plants
- shelter livestock

Restricting, preventing or 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

Livestock management

- addition of AFCF to concentrate ration
- addition of calcium to concentrate ration
- addition of clay minerals to concentrate ration
- clean feeding
- selective grazing

7.1.3.2 Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclide of concern is ^{131}I. The applicability of protective actions for ^{131}I is presented in Table 23. Of the remaining 12 protective actions listed above, a further 6 can be eliminated, due either to the short half-life of ^{131}I precluding the implementation of several options that take too long to organise (that is, selective grazing, slaughtering, and alternative land use); or are specific for other radionuclides (that is, adding AFCF or clay minerals to concentrate ration is specific for ^{134}Cs and ^{137}Cs, and adding calcium to concentrate ration is specific for ^{90}Sr).

In summary, the evaluation of options at this stage suggests:

- eliminate: 'select alternative land use'; 'selective grazing'; 'slaughter and suppress lactation', 'addition of AFCF to concentrate ration', 'addition of clay minerals to concentrate ration', 'addition of calcium to concentrate ration'
- retain: 'close air intake in greenhouses and food processing plants', 'shelter livestock', 'processing and storage (commercial)', 'product withdrawal and recall', 'restrictions on terrestrial or aquatic foods (FEPA orders)', 'clean feeding'

Consider key constraints

Key constraints (major and moderate) that may reduce the applicability of protective actions are presented in Table 24. The constraints relevant to the remaining 6 options are discussed below.

a) Prevent contamination before release

Options to be implemented before arrival of the plume (that is, short-term sheltering of dairy animals, closing air intake systems at processing plants) depend on the period of notification given. In the case of the Windscale accident in 1957 there was no advance warning and hence neither of these 2 protective actions are applicable.

b) Restricting, preventing or reducing consumption of contaminated food

There are 3 protective actions to consider in this category (restrictions on entry of contaminated milk into the food chain, product withdrawal and recall, processing and storage). Restrictions on entry of contaminated milk into the food chain would be possible by the placing of FEPA orders (1985) by the Food Standards Agency and Food Standards Scotland. They are legally binding, irrespective of any constraints. Where there is uncertainty that contaminated milk products may have entered the food chain before restrictions had been put in place, product withdrawal and recall is a possible option. For milk with activity concentrations of ^{131}I above the maximum permitted level, some types of processing and/or storage could be used to reduce ^{131}I levels in milk products so that they could enter the food chain. Whilst technically feasible, the acceptability of processing contaminated milk is likely to be low, unless supplies of uncontaminated milk are limited.

c) Livestock management

In terms of producing less contaminated milk, clean feeding of livestock over a period of weeks would likely result in milk with activity concentrations of ^{131}I below the MPL. Constraints such as availability of suitable housing and supplies of alternative clean feeds for the livestock are unlikely to exist. For instance, dairy livestock in north-west England are brought indoors during the winter (mid-October until the end of March) suggesting that housing would be available. Furthermore, as the Windscale scenario is based on an October accident, there should be no shortage of stored clean feed, harvested earlier in the year.

In summary, the evaluation of options at this stage suggests:

- eliminate: ‘close air intake in greenhouses and food processing plants’, ‘shelter livestock’
- retain: ‘restrictions on terrestrial or aquatic foods (FEPA orders)’, ‘product withdrawal and recall’, ‘processing and storage’, ‘clean feeding’

7.1.4 Make decisions (step 5), implement strategy (step 6), and monitor and evaluate progress (step 7)

By working through step 4 (identify and evaluate options), it is possible to propose a remediation strategy for managing high levels of ^{131}I in milk (Table 32). The decision-making process must be transparent, involving representatives from the local community and farmers, milk processors, the retail trade and various government agencies. The rationale for remediation and the timescales should be clearly communicated. Implementation of this strategy would significantly reduce the volume of milk requiring disposal. Any milk unable to enter the food chain could be managed locally by storage (to allow for decay) and subsequent disposal on farms by landspreading at appropriate times of the year, guided by the relevant environment agency.

Table 32. Proposed remediation strategy for Windscale fire scenario

Timeline (phase)	Protective action
Pre-deposition phase	None: no advance warning.
Early phase	Restrictions on terrestrial or aquatic foods (FEPA orders). Product withdrawal and recall.
Intermediate phase (in this scenario, there was no long-term phase, as all milk restrictions were removed after 44 days)	Clean feeding. Processing and storage (only if supplies of uncontaminated milk are limited).

A long-term monitoring programme would be established to evaluate the success of the remediation strategy, identifying when to stop protective actions.

7.1.5 Protective actions taken at the time of the Windscale fire

In 1957, there were few, if any, contingency plans for accidental releases of radionuclides. All that could be done was the imposition of a milk ban (restriction on entry of milk to the food chain, similar to a FEPA order (1985)) and subsequent disposal of the contaminated milk into sewers and rivers.

7.2 Chornobyl accident (1986)

The following sections step through the process to aid decisions on remedial protective actions for UK upland areas contaminated by ^{134}Cs and ^{137}Cs following the Chornobyl accident in 1986. The focus is on how the handbook could be used to develop a strategy if the same accident happened today. The final section provides information on which protective actions were selected at the time and why.

7.2.1 Define the situation (step 1)

Radiocaesium originating from the accident at the Chornobyl nuclear power plant in the Ukraine was deposited across the UK on 2 to 4 May 1986. The highest levels of radiocaesium deposition, in the range of 20 to 40 kBq/m^2, occurred in the uplands of western Britain, where extensive sheep farming is an important agricultural activity (7). Due to the particular chemical and physical properties of the peaty soil types present in the upland areas of the UK, the radiocaesium is able to pass easily from soil to grass and hence accumulate in sheep.

7.2.2 Assess impacts (step 2) and agree goals of recovery (step 3)

A countrywide programme of sampling carried out after the accident, identified lamb as the foodstuff of most concern. To protect consumers at the time, a maximum limit of radiocaesium in food of 1,000 Bq/kg was imposed, under powers provided in the Food and Environment Protection Act 1985 (FEPA). This resulted in approximately 9,000 farms, with about 4 million sheep, having restrictions placed on them to control movement and sale of sheep. These farms were in parts of Cumbria, North Wales, Scotland, and Northern Ireland. The current MPL (1,250 Bq/kg) is slightly higher than the limit used at the time, so if the accident occurred today, there might be fewer farms and sheep impacted.

7.2.3 Identify and evaluate options (step 4)

7.2.3.1 Identify options

The applicability of protective actions for different food products is shown in Table 22. Of the 24 potential protective actions, only 11 are relevant to extensive meat production, as follows:

Restricting, preventing or 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 or risk assessment

- derestriction surveys and dose assessment

- live monitoring
- natural attenuation and monitoring

Livestock management

- administer AFCF boli to ruminants
- clean feeding
- manipulate slaughter times
- selective grazing

7.2.3.2 Evaluate options

Eliminate options according to radionuclides of concern

The principal radionuclides of concern are ^{134}Cs and ^{137}Cs. The applicability of protective actions for ^{134}Cs and ^{137}Cs is presented in Table 23. Of the remaining 11 protective actions listed above, one option can be eliminated as it is only applicable for short-lived radionuclides (that is, natural attenuation and monitoring).

In summary, the evaluation of options at this stage suggests:

- eliminate: 'natural attenuation and monitoring'
- retain: 'processing and storage (commercial)', 'product withdrawal and recall', 'restrictions on terrestrial or aquatic foods (FEPA orders)', 'select alternative land use', 'live monitoring', 'derestriction surveys and dose assessment', administer AFCF boli to ruminants', 'clean feeding', 'manipulate slaughter time', 'selective grazing'

Consider key constraints

Key constraints (major and moderate) that may reduce the applicability of protective actions are presented in Table 24. The constraints relevant to the remaining 10 options are discussed below.

a) Restricting, preventing or reducing consumption of contaminated food

Of the 4 protective actions available to restrict, prevent or reduce consumption of contaminated food, restrictions on the entry of contaminated lamb into the food chain is enforceable by the Food Standards Agency and Food Standards Scotland by the placing of statutory food restriction orders (FEPA, 1985); these are legally binding, irrespective of any constraints. Where there is uncertainty that contaminated lamb products may have entered the food chain before restrictions had been put in place, product withdrawal and recall is a possible option. Selection of alternative land use would only occur if the land could not support food production on a reasonable timescale. The option for processing and storage of meat to reduce activity concentrations in marketed products, whilst technically feasible, could face challenges from processors unwilling to accept contaminated products. As less radical protective actions are available for restricting and reducing consumption of contaminated lamb, the selection of an alternative land use, and the processing and storage of meat, can all be eliminated for this scenario.

b) Monitoring and dose or risk assessment

There are 2 options to be considered in the 'monitoring and dose or risk assessment' category: live monitoring, and derestriction surveys with dose assessment. Both would be constrained by the availability of NaI detectors and trained personnel, which would take time to manufacture and organise, on the scale required. Therefore, both these protective actions should be considered as intermediate to long-term options. Live monitoring is carried out initially to establish activity concentrations of gamma-emitting radionuclides in livestock before slaughtering. If the activity concentration is above the MPL the animals must not be sold or slaughtered for a specified period of time. During this time other protective actions can be used to lower the activity concentration in animal tissues before they are monitored again.

Derestriction surveys are carried out where routine monitoring indicates that activity concentrations of gamma-emitting radionuclides in grazing livestock have decreased and are unlikely to exceed the MPLs. This is accompanied by a probabilistic assessment of doses to consumers, based on the range of contamination levels in food and the habits of those consuming that food. Decisions to remove FEPA orders and to lift restrictions are then made according to whether individuals are likely to receive doses below the reference level.
Both options in the 'monitoring and dose or risk assessment' category are applicable in this scenario.

c) Livestock management

In terms of livestock management, there are 4 protective actions to be considered (administer AFCF boli to ruminants; clean feeding; manipulate slaughter time; selective grazing). The administration of AFCF boli to ruminants in the upland areas requires a supply of AFCF which may not be readily available in the UK, furthermore, manufacturing plants that could produce AFCF boli would need to be identified. These constraints would make it an intermediate to long-term option, and the organic status of some farms may preclude its use.

Clean feeding is constrained by the availability of alternative clean feeds and suitable areas (either fenced areas or barns) in which to provide a supply of clean feed. The Chornobyl accident happened early in the growing season so it is unlikely that any stored feed would be available. Furthermore, there are no barns in the affected upland areas and the erection of fences would not be permitted in national parks and areas of outstanding natural beauty. The clean feeding option can be eliminated.

Manipulation of slaughter times in conjunction with selective grazing can significantly reduce radiocaesium concentrations in lamb. Selective grazing requires the availability of less contaminated pasture nearby. In this case, improved lowland pasture can be found in close proximity to the upland areas where, in some cases, it is already used by farmers to 'finish' the lambs prior to them being sent to market. Live monitoring provides valuable information on how long slaughtering should be delayed and the period of selective grazing required.

In summary, the evaluation of options at this stage suggests:

- eliminate: ‘select alternative land use’, ‘processing and storage’, ‘clean feeding’
- retain: ‘product withdrawal and recall’, ‘restrictions on terrestrial or aquatic foods (FEPA orders)’, ‘live monitoring’, ‘derestriction surveys and dose assessment’, ‘administer AFCF boli to ruminants’, ‘manipulate slaughter time’, ‘selective grazing’

7.2.4 Make decisions (step 5), implement strategy (step 6), and monitor and evaluate progress (step 7)

In terms of a strategy, 7 protective actions can be selected to assist in the management of contaminated sheep in Chornobyl restricted areas (Table 33).

Table 33. Selection of protective actions along the timeline

Timeline	Protective action
Early to intermediate phase	Restrictions on terrestrial or aquatic foods (FEPA orders). Product withdrawal and recall.
Intermediate to long-term phase	Live monitoring of animals. Administer AFCF boli to ruminants (on farms without organic status). Selective grazing. Manipulate slaughter times. Derestriction surveys and dose assessment.

The decision-making process must be transparent, involving representatives from the local community, sheep farmers, meat processors, the retail trade and various government agencies. The rationale for remediation and the timescales should be clearly communicated. Implementation of this strategy would significantly reduce the numbers of sheep with activity concentrations in excess of the MPL, thus allowing more sheep to enter the food chain. Derestriction surveys and dose assessments would be carried out to evaluate the success of the remediation strategy and would be invaluable in the approach to lifting all restrictions.

7.2.5 Protective actions taken at the time to manage Chornobyl contaminated upland areas

It was not possible to implement protective actions to reduce levels of radiocaesium in vegetation in the restricted areas due to the physical limitations of the terrain and the environmentally sensitive nature of these areas. It was also not practicable to provide housing and clean feed. The availability of AFCF boli was limited and those boli that were commercially available were too large to be given to the small hill lambs grazing the uplands of the UK. Restrictions on entry of contaminated lamb to the food chain remained in place from 1986 to 2012. There were no requirements for withdrawal and recall of products. The situation was managed through the development of a very well-designed live monitoring programme, selective grazing of lambs on less contaminated lowland pasture, and manipulation of slaughter times. These protective actions enabled lamb production to be sustained and the livelihoods of sheep farmers to be protected. Furthermore, consumer confidence in lamb was maintained. The restrictions were able to be lifted following intensive surveys and dose assessments that indicated the risk to consumers was very low and below any legal criteria.

7.3 Litvinenko (2006)

The following sections step through the process to aid decisions on remedial protective actions for inhabited areas in London contaminated by ^{210}Po. The focus is on how the handbook could be used to develop a strategy if the same incident happened today. The final section provides information on which protective actions were selected at the time and why.

7.3.1 Define the situation (step 1)

On November 23, 2006, Alexander Litvinenko died in London as a result of poisoning with ^{210}Po. He suddenly fell ill on 1 November 2006 and was hospitalized until his death. As a result of Litvinenko's movements after being poisoned, as well as the movements of those carrying out the poisoning, contamination was found to be present at some 47 locations throughout London including Mr Litvinenko's family home, hospitals where he was treated, hotels, offices, restaurants, bars, cars, buses, and even aircraft. Except for his home, members of the public had access to all the contaminated locations. Only Mr Litvinenko's family were exposed to contamination at his home. Of those 47 locations, most were either found to have traces of polonium (less than 10 Bq/cm^2), or low to medium levels of polonium (a few tens to a few hundreds of Bq/cm^2). However, a few venues, which were visited or used by those directly involved in the poisoning, were shown to be much more heavily contaminated (up to several hundred thousand Bq/cm^2). The potential for intakes of ^{210}Po from the contamination therefore posed a public health risk and generated considerable public concern (11).

Examples of the types of surfaces that were contaminated, and the extent of the contamination are:

- office chairs (15 to 400 Bq/cm^2) and table cover (hot spots of 500 to 100,000 Bq/cm^2)
- hotel bathroom pedal bin (much more than 1,500 Bq/cm^2)
- hotel bathroom sink plug hole trap (up to 150 Bq/cm^2)
- hotel hand towel (up to 17,000,000 Bq/cm^2) and bath towel (up to 6,500 Bq/cm^2)
- hotel bathroom floor (up to 500 Bq/cm^2) and wall (up to 625 Bq/cm^2)
- hotel bedroom wall, floor, and furniture (from less than 10s to 100s of Bq/cm^2)
- hotel valuable artefacts in tea room (from less than 10s to 100s of Bq/cm^2)
- tearoom seats (over 500 Bq/cm^2), teapot and cup (up to 100,000 Bq/cm^2)
- restaurant bench (up to 30 Bq/cm^2)
- nightclub cushions, table (from less than 10s to 100s of Bq/cm^2)
- Mr Litvinenko's home (from less than 10s to 100s of Bq/cm^2)

Due to the aggressive cleaning practices employed by the hospitals looking after Mr Litvinenko, contamination of hospital wards (bedding and so on) as well as medical equipment, tended to be present at low levels. Doses to staff were further reduced using personal protective equipment (PPE).

Polonium-210 is essentially a pure alpha-particle emitting radionuclide. Due to the very short range of alpha particles (that is, less than a few tens of microns in soft tissue), ^{210}Po does not pose a hazard when external to the body. The only hazard is if the radionuclide enters the body via inhalation, ingestion, or contaminated wounds. It follows that detecting ^{210}Po on surfaces such as floors or furniture does not in, and of itself, mean that there is a risk to health: the ^{210}Po has to be unbound from physical surfaces and sufficiently mobile to be transferable into the body. For example, when someone touches the contaminated surface, transferring ^{210}Po to their hands, which are then used to eat.

7.3.2 Assess impacts (step 2) and agree recovery goals (step 3)

Some 752 people living in the United Kingdom were tested by the Health Protection Agency (HPA) to see whether they had been exposed to ^{210}Po used in the poisoning. The urine tests showed that 137 of those tested had been exposed to ^{210}Po and, of those exposed, 17 would have received an effective dose greater than 6 mSv. While the magnitude of dose these individuals may have received is not high enough to cause immediate health problems, it was considered by the authorities at the time to represent an unacceptable level of risk of long-term health effects such as cancer. This group included a family member caring for Mr. Litvinenko and a number of people who either worked or visited the hotel bar where Mr Litvinenko was poisoned. The highest assessed effective dose (approximately 100 mSv) was for the family member (11).

HPA recommended a value of 10 Bq/cm^2 as a reference level for fixed surface contamination with ^{210}Po (11) – this reference level was developed at the time of the incident. This value is based on conservative calculations to estimate levels of dose that might be received from exposure to contamination at this level. A number of scenarios were considered involving people of different ages engaged in a range of behaviours, from inhalation of resuspended material, direct entry of contamination into wounds, or ingestion of material. Based on these assessments, anyone exposed to ^{210}Po present as surface contamination at or less than 10 Bq/cm^2 was not expected to receive doses exceeding 1 mSv. This was the agreed radiation protection goal adopted in 2006.

Polonium-210 has a physical half-life of 138 days, decaying to a stable isotope of lead. Therefore, for the initial levels of ^{210}Po detected on many surfaces, that is, 400 to 10,000 Bq/cm^2, it would take a period of between 2 to 4 years respectively, for radioactive decay to reach the 10 Bq/cm^2 reference level.

7.3.3 Identify and evaluate options (step 4)

7.3.3.1 Identify options

Polonium-210 contamination in London mostly affected the inside of buildings, including residential and commercial properties, businesses, and several hospitals. Polonium-210 is not one of the specific radionuclides considered in the handbook, as this type of threat (poisoning of an individual) falls outside the scope of typical accident scenarios. However, it has been chosen as a worked example to highlight how the handbook can be used even where the radionuclides of concern are not explicitly included. The decision-aiding steps can still be followed taking into account what is known about the behaviour of ^{210}Po in the environment (information provided in step 1).

The applicability of protective actions for different surface types is shown in Table 28. Some protective actions are applicable to all surfaces, whilst others are more specific in their applicability. In this scenario, the predominant surface of interest is the interior of buildings. Of the 17 potential protective actions, there are 11 that are most relevant as follows.

No active 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

- store and cover personal and precious objects (applicable to the interior of large public buildings)
- tie down (applicable to all surfaces)

Physical removal techniques

- high pressure washing including water jetting (applicable to interior of large public buildings)
- remove building surfaces
- strippable coatings (applicable to interior of buildings)
- vacuum cleaning (applicable to interior of buildings)

Chemical removal techniques

- reactive liquids (domestic chemicals) (applicable to interior of buildings)
- water-based cleaning (applicable to interior of buildings)

7.3.3.2 Evaluate options

Eliminate options according to radionuclides of concern

The radionuclide of concern in this scenario is ^{210}Po. For the higher levels of contamination, it would take several years of natural attenuation and monitoring before activity concentrations reduced to below the 10 Bq/cm^2 reference level. Given the public nature of most of the affected venues (that is, hospitals, hotels, restaurants), their high footfall, and commercial focus, this would not be an acceptable option for businesses or members of the public. In contrast, the option of prohibiting public access on a short-term basis, to allow other remedial protective actions to be carried out, needs further consideration.

In summary, the evaluation of options at this stage suggests:

- eliminate: ‘natural attenuation and monitoring’
- retain: ‘prohibit public access’, ‘temporary relocation’, ‘store and cover personal and precious objects’, ‘tie down’, ‘high pressure washing including water jetting’, ‘remove building surfaces’, ‘strippable coatings’, ‘vacuum cleaning’, ‘reactive liquids’, water-based cleaning’

Consider key constraints

Key constraints (major and moderate) that may reduce the applicability of protective actions are presented in Table 30. The constraints relevant to the remaining 10 options are discussed below in the context of a) managing the population at different venues by restricting access; and b) management of the affected building interiors.

a) Restricting access

There are 2 protective actions to consider:

- prohibit public access
- temporary relocation

Contamination above 10 Bq/cm^2 was found at several locations including: Mr Litvinenko’s home, various hotels, restaurants, offices, and nightclubs. In all cases, where monitoring indicates a potential public health concern, a venue should be secured and public access prohibited, pending decisions on further protective actions. In some situations, it may be appropriate to prohibit access to an area of the premises (for example, by locking doors to bathrooms or bedrooms, and establishing a cordon) rather than the whole venue. This minimises disruption to the rest of the venue. Cooperation between owners and/or operators of venues means that breaches of legislation (for example, Health and Safety at Work Act) can be avoided.

Restricted access and temporary relocation of Mr Litvinenko’s family would be applicable while monitoring of his home was carried out and the risks assessed. There should be no constraints on implementation, as only a few people were affected. Furthermore, given the malicious nature of the poisoning, the family might wish to be temporarily housed elsewhere. If the period of relocation can be extended, physical decay of ^{210}Po will reduce the need for costly remediation.

In summary, the evaluation of options to manage the population suggests to:

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

b) Management of contaminated internal building surfaces

There are 8 protective actions relevant to contaminated internal services, 2 for shielding, 4 for physical removal, and 2 for chemical removal.

Polonium-210 only poses a health risk when it is mobile. Therefore, protective actions that might remobilise fixed contamination (that is, physical removal techniques) should only be considered when other options (shielding, chemical removal) are not available or judged inappropriate. There were a range of internal surfaces found to be contaminated with ^{210}Po and different protective actions may be applicable according to:

- whether the contamination was fixed or mobile (all mobile contamination should be removed)
- for fixed contamination, whether reference level of 10 Bq/cm^2 was exceeded and by how much
- nature of contamination: patchy (discrete items); widespread
- nature of the surface: porous or non-porous; hard or soft
- likelihood of contact with item
- whether hard surfaces can be removed
- whether items have a high economic or sentimental value
- implications for waste
- stakeholders' views

For very heavily contaminated, discrete, low cost and easily replaceable smaller items such as towels, teapot, table cover, pedal bin and sink plug hole trap it would be appropriate for specialists to bag items and arrange disposal. For other items with lower levels of contamination the following protective actions can be considered.

i) Shielding

- store and cover personal and precious objects
- tie down

The relatively short half-life of ^{210}Po, suggests that some discrete items of value could be covered, and removed to temporary storage to allow for radioactive decay. Items might include upholstered furniture, and valuable artefacts such as paintings and ornaments from the affected hotels and restaurants. This option requires appropriate storage facilities with adequate capacity and the potential for retaining goods until monitoring shows levels of contamination have reduced to acceptable levels, a process that may take several years, depending on the initial activity.

For large areas with contaminated hard surfaces such as walls, the application of tie down materials such as paint or varnish could be considered, once any mobile contamination has been removed (see below for water-based cleaning and reactive liquids). This would fix the contamination in place and provide a barrier to future resuspension. Inevitably, there would have to be some sort of agreement with the owner to prevent damage to the treated walls (for example, drilling) for a limited period of time (approximately a few years). Other than that, there should be no physical or legal constraints on implementation, although the owner may be reluctant to accept this course of action.

ii) Physical removal techniques

- high pressure washing including water jetting
- strippable coatings
- remove building surfaces (in this case, enamelled bathroom suites)
- vacuum cleaning

The physical removal techniques listed are unlikely to be preferred options for decontaminating hard surfaces because the act of removal is likely to remobilise ^{210}Po (that is, transferring it onto other surfaces that present a resuspension or inhalation hazard). Exceptions might be made for the porous enamel surfaces found on highly contaminated sinks and bathtubs. In this situation, decontamination specialists with appropriate PPE (resuspension hazard) might be employed to physically remove and dispose of the contaminated enamel layer, rather than the entire bathroom suite. This would significantly reduce the volume of waste needing to be managed.

iii) Chemical removal techniques

- reactive liquids (domestic chemicals)
- water-based cleaning

The use of water-based cleaning methods or application of reactive liquids are best carried out as soon as possible after contamination, when maximum levels of contamination are on the surface. Depending on their value and level of contamination, soft furnishings such as curtains, can undergo thorough washing to remove the contamination. Higher value solid objects can be wiped and washed using various water-based cleaning techniques, and depending on the amount of contamination removed, can either be used straight away or stored for a set period of time. Smooth surfaces will be more effectively cleaned than those that are rough or uneven. Reactive chemicals such as strong detergents are particularly well suited to decontaminating solid, non-porous surfaces like varnished wooden furniture and painted walls, although care should be taken when managing any waste arising.

In summary, the evaluation of options to manage contaminated internal building surfaces suggests:

- eliminate: ‘high pressure washing including water jetting’, ‘strippable coatings’, ‘vacuum cleaning’
- retain: ‘store and cover personal and precious objects’, ‘tie down’, ‘remove building surfaces (bath enamel)’, ‘reactive liquids’, ‘water-based cleaning’

7.3.4 Make decisions (step 5), implement strategy (step 6) and monitor and evaluate progress (step 7)

In terms of a strategy, 2 protective actions for managing the population and 5 remedial protective actions for managing contaminated internal surfaces might be selected following the contamination of an urban area with ^{210}Po (Table 34).

The decision-making process must be transparent, involving representatives from the local community, including commercial businesses as well as government agencies. The rationale for remediation and the timescales should be clearly communicated. Implementation of this strategy would significantly reduce the numbers of venues that would need to be closed as well as the quantities of waste requiring disposal. A long-term monitoring programme would be established to evaluate the success of the remediation strategy and clearance of venues.

Table 34. Selection of protective actions

Target	Protective actions
Restricting access	Temporary relocation (of Mr Litvinenko's family). Prohibit public access (venues or parts of venues, for monitoring and remediation).
Buildings (internal surfaces)	Store and cover personal and precious objects (including upholstered furniture, ornaments, paintings). Tie down (of fixed contamination on walls, non-carpeted floors, varnished furniture). Water-based cleaning (to remove mobile contamination from soft furnishings, carpets, other discrete items). Reactive liquids (domestic chemicals) (non-porous varnished wooden furniture and painted walls). Remove building surfaces (enamel from sinks and bathtubs).

7.3.5 Protective actions taken at the time to manage contamination arising from Litvinenko poisoning

A full description of the remediation framework is given in a report by Westminster City Council (56). Public access was prohibited to sites requiring remediation. In the case of Litvinenko's home in London, the family were temporarily relocated for a period of 2 years, to initially allow radioactive decay of ^{210}Po, and subsequent remediation of any remaining contaminated surfaces.

In general, it was the mobile component of ^{210}Po that presented the main radiological hazard and areas could not be declared safe for public access until that component had been removed. Options for removal included wiping, washing, and bagging of contaminated objects, followed by their removal to safe temporary storage to await appropriate decontamination or disposal. The removal of mobile contamination was carried out by specialists. On solid, non-porous surfaces (for example, varnished wooden furniture and painted walls) a strong detergent was used. Soft furnishings were either bagged, removed, and stored prior to disposal, or where there was emotional value or historical significance, it was advised that the item could be covered to prevent the spread of contamination and removed for safe storage until the ^{210}Po had decayed away.

Only surfaces with fixed contamination greater than 10 Bq/cm^2 required decontamination from a radiological protection perspective. In some cases, it was sufficient to provide reassurance that the contamination was truly fixed (for example, by applying a coat of paint). In other cases, particularly if the item was portable and of low value, the optimal solution was removal and disposal. Porous surfaces posed the greatest challenge, for example, where ^{210}Po had penetrated the surface of enamel coated bath tubs and basins in some of the London hotels used by those handling the poison. In these cases, the enamel was removed, bagged, and disposed of. The hotel where Mr Litvinenko was poisoned was one of the most contaminated venues and took 19 days to remediate.

The ownership of the waste remained with the owner or occupant of the venue, who had to meet the costs for its transport, storage, and disposal. Contractors undertaking remediation acted as consignors of the waste and had to prepare and suitably package the waste and arrange for transport, storage, and disposal. The Environment Agency proposed 3 categories of waste. Category 1 waste with activity less than 0.37 Bq/g was classified as uncontaminated and could be disposed of via the normal route appropriate for the material involved. Category 2 waste with activity more than 0.37 Bq/g and less than 14.8 Bq/g was classified as ‘exempt’ radioactive material and such material could be disposed of in a suitable landfill with the full understanding and agreement of the landfill operator. Category 3 included all other contaminated material, which needed to be fully characterized. An emergency exemption order (2006) was used for Category 3 waste so that items could be disposed of without authorization. Most of the waste arising from the Litvinenko incident fell under categories 1 and 2 (56).

8. Preparedness and planning

8.1 What is at stake?

Past experiences from radiation emergencies and other types of severe accidents and natural disasters have highlighted the difficulties that may be encountered if there is a failure to prepare adequately for recovery. In recovery, the effectiveness of the adopted strategy will be highly dependent on the resources that can be mobilised as well as the organisation of those resources. If resilience is not built during preparedness, the ability to deliver the best possible outcomes (health, society, environment, economy) will be undermined. It should be recognised that the financial cost of recovery can be 10 to 100 times higher than the cost of response, highlighting the need for adequate planning and preparedness for recovery. Expediency is key and requires a co-ordinated plan to be available in advance. For medium to large-scale radiation emergencies, experienced personnel may be required to deliver low technology remediation solutions, using credible high volume waste management routes, identified in advance.

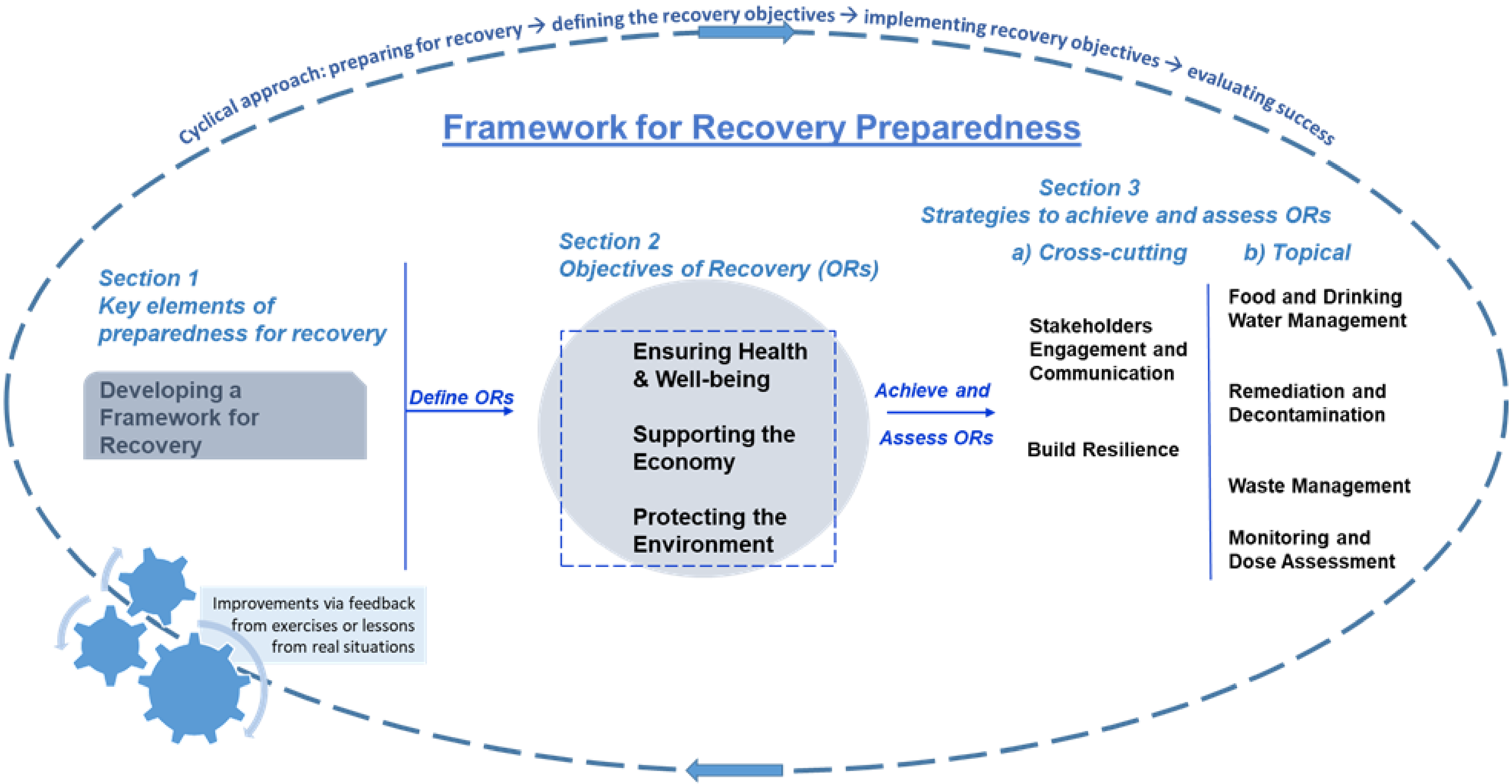
8.2 Framework for recovery preparedness

A process for establishing a framework for recovery preparedness has been published by the Nuclear Energy Agency (40), and a figure illustrating the cyclical process is reproduced here (Figure 9).

The generic recovery preparedness framework shown below follows a cyclical approach, starting with the creation of a national framework and definition of recovery objectives to ensure health and well-being, support for the economy, and protection of the environment. Strategies are then developed to address cross cutting issues (that is, stakeholder engagement, communication and building resilience) as well as topical challenges (that is, food and drinking water management, remediation and decontamination, waste management and monitoring and dose assessment). The cycle is completed by improving preparedness based on feedback from emergency exercises and lessons from the response to real emergencies.

In terms of preparedness, the scope of the UKRHRIv5 is focused on food and drinking water management, remediation and decontamination, and waste management. These are elaborated in the sections that follow.

Figure 9. The cyclical process of building a framework for recovery preparedness (reproduced from NEA document 'Building a framework for post-nuclear accident recovery preparedness' (40))



8.3 Preparedness: food and drinking water management

8.3.1 What is at stake?

One of the major concerns of people living in areas affected by radiation emergencies is food and water safety. Internal doses to the affected population can be averted by taking protective actions to either restrict the sale of contaminated food or reduce the transfer of radioactivity to food products. However, a food management system based solely on activity concentrations does not necessarily prevent stigma or negative attitudes from consumers or retailers, leading to the potential for major economic consequences for agricultural businesses in the affected area. Furthermore, food restrictions can lead to large volumes of biodegradable, contaminated waste, which have to be managed.

8.3.2 What can be done in preparedness?

The 3 major goals of a food and drinking water management strategy are to:

- ensure the quality of product
- maintain consumer confidence
- and ensure economic sustainability of the affected areas

To address these challenges in the preparedness phase, there is a need to:

- develop radiological criteria for maintaining food safety in the days, weeks, months or even years after the radiation emergency
- produce an outline monitoring strategy for national and local authorities
- collect and collate information on applicable protective actions
- develop a mechanism for engaging with stakeholders and the local community

8.3.2.1 Radiological criteria

In preparedness, it is important to evaluate the various radiological criteria that might be applied at different stages of response and recovery. The fixing of radiological criteria needs to balance many considerations, including the interests of producers, retailers, and consumers at the local, national, and international level. MPLs, expressed in terms of Bq/kg or Bq/l, are important criteria used in the emergency phase for identifying food products subject to restrictions. The values are generic and are not readily adaptable on a site-specific basis, as the underlying rationale for deriving the individual values is complex. MPLs can be perceived as providing a single point denoting safe and unsafe. However, an activity concentration below a particular level is not necessarily risk free, as increased levels of artificial radioactivity are still present in the diet. Conversely, an activity concentration above an MPL is not always harmful, as this will depend on the composition of the diet. Furthermore, the numerical values of the MPLs can be refined following a radiation emergency. Producers have requested that a graded approach should be taken in the management of contaminated foodstuffs, based on a process of continual improvement. Regaining credibility and trust of consumers depends on the proactive and transparent implementation of protective actions during the recovery phase, and the selection of relevant radiological criteria by the food standards agencies.

In addition to MPLs, other dose criteria such as reference levels, expressed in terms of residual effective dose, should be considered when planning for recovery. Reference levels (RLs) apply across all exposure pathways, including ingestion. The value of RLs should be selected in conjunction with all affected stakeholders, and considering the appropriate timeframe, individual dose distribution within the affected population, and the tolerability of risk in the circumstances (31). RLs can be refined according to the prevailing circumstances, based on reductions in activity concentrations in foodstuffs and the results of monitoring and dose assessments. RLs were used, for example, in the UK to lift restrictions on the marketing of sheep meat after the Chornobyl accident and were accepted by farmers, the food sector, and consumers (see section 7.2). RLs were also used in the UK more recently for the removal of import restrictions of Japanese foodstuffs. The risk assessment showed that food imported from Japan, in the aftermath of the Fukushima Dai-ichi accident, resulted in doses well below the 1 to 20 mSv/y RL for an existing exposure situation (17).

8.3.2.2 Food monitoring strategy

The UK has routine programmes for monitoring of foodstuffs as part of normal operations, but these will need considerable expansion and adaptation to cope with the post-accident situation. Clearly, it is not practical to monitor each and every food sample. Consequently, responsible authorities need to identify sensitive foodstuffs likely to be present in an affected area (for example, milk, free-ranging livestock) for prioritised monitoring after an accident. When developing plans for post-accident monitoring it is important that the temporal and spatial heterogeneity in radionuclide distribution in the environment, as well as different uptake rates by pasture and other crops, are accounted for.

Small-scale domestic produce (for example, garden, or wild products) are foods typically not covered by the authorities' control systems, but which may be important for the public. It would be useful if these products could be measured before consumption. Self-help actions carried out by individuals are a key factor in empowering the public to gain an understanding of the range of activity concentrations they might encounter in home grown produce, and whether these levels are of concern or not. This citizen science has proven to be invaluable in the monitoring of contamination after both the Chornobyl NPP accident in 1986 and the Fukushima Dai-ichi NPP accident in 2011 (1). Preparedness must consider how complementary but independent measurements taken by various groups, such as NGOs, businesses and cooperatives, can be integrated into databases to expand the information available to members of the public.

8.3.2.3 Plans for protective actions

There are a wide range of protective actions to reduce activity concentrations in food products and drinking water that can be implemented in the days, weeks, months, and years following a radiation emergency. Early phase protective actions mainly involve precautionary restrictions on the consumption of agricultural and fishery products and drinking water, as well as the banning of hunting and the gathering of wild foods. Monitoring of the affected areas enables food restrictions to be more accurately defined in terms of location and types of produce. It is in these areas that subsequent protective actions should be implemented to reduce the radioactivity in products and to sustain food and drinking water supplies and economic activities. Without good planning, unnecessary controls may be imposed which are likely to make the situation worse, due to perception of blight and wasting of resources. Preparedness should include:

- ensuring access to, and familiarisation with, databases and information on protective actions that can be applied by the authorities as well self-help actions (that is, this handbook)
- planning to involve local communities and affected stakeholders in the evaluation of protective actions to identify feasible options and those for which capacity might be limited; for planning purposes, some indication of the volumes of waste that could be generated by a protective action will be an important consideration
- developing experimental approaches for refining or adapting protective actions under local conditions
- growing UK monitoring and analytical capability across public or private supply chain
- developing a prepared outline communications plan to present the rationale for protective actions, including timescale, technologies, uncertainties and so on
- developing an approach to compensate producers for loss of production or adaptation to new practices or procedures
- agreeing on factors to be included in defining ‘end state’ or success criteria that allow protective actions to be withdrawn; this will require the availability of measurement devices and provision of up-to-date information

8.4 Preparedness: remediation and decontamination

8.4.1 What is at stake?

A remediation and decontamination strategy should be developed in the preparedness phase to ensure it can be implemented efficiently and effectively during an emergency or post-emergency situation. Past accidents have shown that authorities can be overwhelmed during the emergency phase, resulting in delays in initiating remedial protective actions. For example, human, technical and financial resources that are required for remediation may not be available on the timescales required resulting in reduced levels of protection and additional, long-term costs being incurred.

Remediation and decontamination can have positive and negative impacts on the health and well-being of affected people, the food chain, the environment, economy, and society. Positive impacts of remediation include reduced radiation exposure of those living and working in affected areas, reassurance for the public that contamination is reduced or removed, reassurance that food is safe to eat and reinstatement of businesses and trade. Negative impacts of remediation include additional doses received by remediation workers, disruption to lifestyle and livelihoods whilst remediation work is being carried out, disruption to food supplies, the generation of waste, and the economic cost of the remediation efforts. All these issues at stake can be addressed in the preparedness phase.

8.4.2 What can be done in preparedness?

When preparing remediation plans, it is important to ensure that they are risk-based, proportionate, flexible, scalable, open to lessons from previous events, inclusive and co-ordinated (12). They also need to be supported by appropriate legislative frameworks. Remediation planning comprises 3 main aspects: infrastructure and resource requirements; the remediation process; and the collection and compilation of data and information in advance.

8.4.2.1 Anticipate infrastructure and resource requirements

Infrastructure requirements involve identifying the services that might be needed, the businesses or organisations that can supply them (government, universities, and private suppliers) and the processes that would facilitate procurement. In terms of services, it is important to ensure that a critical level of remediation expertise and decontamination specialists will be available on demand. Furthermore, infrastructure requirements should be able to indicate how this remediation workforce capability could be expanded to support remediation over several weeks, months or years, perhaps bringing in public and private contractors along with the appropriate level of radiation protection support. Previous experience suggests that contamination may persist for years or decades, so the remediation strategy must be sustainable at local, regional, and national levels. Opportunities for supporting self-help protective actions in the community should be considered to complement those remedial actions provided by the authorities. The remediation infrastructure should also identify community representatives and other stakeholders with local knowledge who could help develop the remediation plans.

8.4.2.2 Establish a process to carry out remediation

Decisions on remediation need to be part of a holistic decision-making process that considers a broad perspective of recovery issues (for example, business continuity, trade, public acceptance environmental impacts). The 7-step iterative process has already been described in section 2. For each step, several actions can be taken in advance to enhance remediation preparedness. These are further elaborated in Table 35.

Table 35. Preparedness aspects of the recovery process, relating to remediation

Step	Aim	What can be done in preparedness
1	Define the situation	Develop an outline environmental monitoring strategy and sampling programme, and a process to validate, collate and share information about the distribution of contamination.
2	Assess impacts	Ensure that habit data and dose assessment models are available and up to date.
3	Agree goals of recovery	Establish a process to agree the goals of recovery. Agree how reference levels will be selected and applied.
4	Identify and evaluate options	Ensure access to, and familiarisation with databases of information on remedial protective actions (for example, the datasheets in Annexe A) and ensure familiarity with new and emergent technologies. Consider volumes of waste that might be produced. Ensure access to up-to-date information on waste management plans.
5	Make decisions on the recovery strategy	Identify community representatives and affected stakeholders who can help inform decisions. Consider how to present information on the remediation strategy and identify requirements for recording decisions and how to inform the wider community of the decisions.
6	Implement strategy	Develop a template for subdividing the strategy into manageable tasks, by identifying the 'who, what, where, when, and how' it will be implemented.
7	Monitor and evaluate progress	Identify appropriate measurable milestones for remediation. Establish mechanisms for adapting the strategy if it is ineffective or causes harm.

8.4.2.3 Collect important and relevant data and information in advance

Preparedness should involve the collection and compilation of relevant data and information that will support decision-making on remedial protective actions. This may be achieved through the production of templates for compiling information about the area around nuclear facilities to assist in prioritising remediation needs (for example, infrastructure, schools, nurseries, sites of special scientific interest, historic monuments, listed buildings). Some of this information can be gathered in advance to identify who or what may be impacted, and who may be able to support remediation. Examples include:

- population: distribution, size, demography; sensitive and vulnerable groups based on age, health social or ethical considerations; institutionalised people
- business: industrial, commercial, retail, food, and other activities
- types of buildings: multi-storey, detached, terrace; and building materials.

- critical infrastructure: water and sewage treatment plants, energy networks, roads, railways, schools, medical practices, and hospitals
- waste storage and disposal sites
- sensitive habitats such as sites of special scientific interest
- food production: location of milk and meat producers, supply chains; location of gardens and allotments and areas for gathering of wild plants and animals
- drinking water: sources, abstraction points, monitoring points, and alternative supplies

8.5 Preparedness: waste management

8.5.1 What is at stake?

Radiation emergencies have the potential to generate large volumes of radioactive waste, coming predominantly from the implementation of remedial protective actions, and the creation of secondary waste from further treatment and processing. Activity concentrations may be low, moderate, or high depending on the initial level of contamination and treatment method, although large volumes of lower activity waste are likely to be more prevalent.

Managing waste is a key component of recovery and can incur considerable costs and delays if executed poorly. Many activities, such as transport or setting up staging areas, are difficult to establish without prior planning and may require legal and political backing to be implemented. Without prior approvals or plans which cover such activities, it will be difficult to avoid delays and the associated impacts on people and the environment. Routine radioactive waste management arrangements will come under extreme pressure after large emergencies. Experience from previous incidents has shown that a lack of preparedness resulted in arrangements for managing waste being developed at the time of the incident rather than in advance. This has led to multiple economic, environmental, and social challenges, which could most likely have been reduced if there was greater preparedness (26).

8.5.2 What can be done in preparedness?

Specific arrangements need to be put in place to deal with the increased volume and types of waste. This should include a critical evaluation of national policy, strategy, and legislation as well as the adoption of a proportionate approach to waste management preparedness. Information to support decisions and inform plans for the management of wastes should come from established science and evidence sources, including appropriate environmental modelling that accounts for dispersion and build-up of radioactivity in the environment over time, and practical experience gained under routine operations or recovery activities in other areas. Radiological criteria for waste management should be evaluated and treatment and storage plans established. A recovery preparedness plan should also include preparations for staging and defining endpoints.

8.5.2.1 Critical evaluation of national policy, strategy, and legislation

The volume and complexity of waste generated in a radiation emergency could overwhelm national capabilities and resources. It is therefore important that national policy, strategy, and legislation for radioactive waste management is prepared in a way that adequately covers the surge in capacity that is likely to be required in the aftermath of large emergencies (28). Recovery preparedness plans and regulatory approaches should allow for flexibility in dealing with wastes from a range of emergency scenarios, whilst at all times prioritising the safety of people and the environment according to the requirements set out in IAEA GSR Part 5 (24).

8.5.2.2 Use models to inform decisions

Several modelling tools such as CONDO (47, 48), ERMIN (5, 6) and WEST (54), have been developed to help users estimate the types and volumes of waste that could be generated as a result of implementing various remedial protective actions. These models also estimate the activity concentrations in the waste. These models need to be kept up to date and reflect UK-specific conditions.

8.5.2.3 Adopt a proportionate approach to waste management preparedness

It is important to take a proportionate approach to preparedness by concentrating on the issues where preparedness has the greatest potential to reduce the impacts on society, the environment, and the economy. To help with this, preparedness for waste management during recovery should be broken down into phases, with the greatest emphasis placed on preparing for the early phases where the maximum benefits can be achieved. This primarily covers how to prepare for the pre-disposal of wastes, including characterisation, staging, transport, and temporary or interim storage. Advice on disposal will be limited as it is expected that disposal options for large volumes of waste will need careful consideration at the time of an incident.

8.5.2.4 Develop plans for staging, treatment, and temporary storage

During the early response and recovery, it is crucial to consolidate waste in collection locations known as staging sites, located close to the source of the waste. Detailed information on the attributes of staging areas is provided in IAEA TECDOC 1826 (26).

Existing infrastructure and equipment should be used to treat the waste wherever possible. Otherwise, non-radiological waste facilities may need to be requisitioned to treat radiological waste, such as sewage treatment works for aqueous waste, or new facilities constructed. Sending waste to be treated, packaged, or disposed of at facilities not designed to handle radioactive waste may increase risks to both those occupationally exposed and members of the public due to work practices and equipment not being on par with those facilities purpose built for such wastes. In addition, such facilities may require decontamination before they are allowed to return to normal operations and the costs and practicalities of such action should be considered, together with dose levels and any legal constraints, prior to any radioactive waste being sent to them.

Storage of waste will be needed, either for the purpose of radioactive decay, or before onward treatment, reuse, recycling or disposal. Storage can be short-term, that is, within a staging area for weeks to months, or long-term (for example, up to decades) to allow for permanent disposal solutions to be constructed. Due to uncertainties relating to the potential volumes of waste arising, IAEA promotes the use of “modular and scalable” storage designs (26). The modular concept means that storage facilities can be increased in size according to the needs for recovery. It is recommended that such designs are considered, and ideally approved by the waste regulators, in the preparedness phase so that they can deployed quickly at the time of an incident.

9. Future challenges and next steps

The UKRHRIv5 is a state-of-the-art document in terms of the knowledge and information it provides on protective actions. However, on its own, it cannot be used to develop a recovery strategy as it is only one of several tools in the 'response and recovery tool-box'. As with the other tools, it is of most value when used as an instrument for dialogue and debate with stakeholders and end users.

In the future, it may be possible to create some interactive tools to support users through the decision-aiding framework, provided in the handbook. Previously, a radiation recovery record form was developed in Excel, to complement UKRHRIv4 (50). The spreadsheet was designed to record decisions made at each stage of the decision-making process. This allowed a clear record to be made of how the process was followed; where and why protective actions were eliminated; and what issues were noted that might influence the final choice of options. In this way, the radiation recovery record form provided a transparent audit trail allowing decisions to be reviewed in the future. With a worksheet tab for each environment (that is, food production, drinking water supply, inhabited area), it is possible to use the one record form for multiple affected environments. Development of such a spreadsheet, or alternative software tool, is an obvious next step following publication of this handbook.

Other complementary tools for supporting decisions on protective actions, include the UK model 'Consequences of Decontamination Options' (CONDO) (47, 48), the European Model for Inhabited Areas (ERMIN) (5, 6) and the US Waste Estimation Support Tool (WEST) (54). These models can perform some of the assessments required during recovery. However, CONDO and ERMIN contain old data, and the range of protective actions included in these models is not consistent with those in UKRHRIv5. WEST is a powerful tool for estimating waste from clean-up, however several aspects (for example, building types) would need to be customised for UK conditions, before being applicable (20). Future work may involve bringing existing models up to date and customised for use in the UK.

Two capability reviews, one looking at UK nuclear recovery capability (51), the other specifically at monitoring capability (52) highlighted a few key areas where improvements could be made to enhance capability in the future. Since these reviews were carried out, work within government has been undertaken to address some of these gaps in capability, for example, by developing a model for the future provision of UK remediation capability, including surge capacity, through using public and private suppliers. Work is also underway to develop an operational plan outlining how the UK will manage waste arising from radiation emergencies. However, one area for future improvement, that was identified in the 2 capability reviews, relates to the future provision of monitoring, sampling, and analytical capabilities. Whilst models form one important component of the decision-making process, without the timely provision of reliable and representative monitoring data, model outputs cannot be validated. Consequently, a policy is required for the coordination of monitoring, sample collection, and sample analysis during response and recovery from a radiation emergency. This may entail better use of existing resources, improving capability for rapid monitoring of large areas, and enhancing laboratory analysis capability.

Finally, one other area that may impede a smooth and effective recovery from a large-scale radiological or nuclear emergency, is the challenge posed by the existing and complex patchwork of legislation, particularly for the remediation of inhabited areas. Either a new overarching legislative framework analogous to REPPIR would have to be developed, or extensive amendments would need to be made to the current framework. Both options would require a significant legal resource but nevertheless this challenge should be seen as a high priority.

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11. Acknowledgements

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Annexe A. Datasheets of protective actions

Annexe A1. Datasheets for food production systems

Index to datasheets for food production systems

Three links are provided at the bottom of each datasheet: one that returns the user to the main datasheet index in section 4, one that returns the user to the decision-aiding look-up tables in section 6.1, and one that returns the user to the datasheet index in this annexe.

1. Addition of AFCF to concentrate ration	
General	
Objective	To reduce activity concentrations of radiocaesium in meat, milk and eggs to below maximum permitted levels (MPLs).
Other benefits	Reduces quantities of animal products requiring disposal. Normal animal management and/or grazing regimes can be maintained.
Protective action description	Ammonium-ferric hexacyano-ferrate (AFCF, Giese-salt, Prussian Blue) is an effective radiocaesium binder, which may be added to the diet of dairy cows, sheep and goats as well as meat or egg producing animals to reduce radiocaesium transfer to milk, meat and eggs by reducing absorption in the gut (1, 2). It can be added to the diet of animals as a powder or incorporated into pelleted feed. Toxicological studies have shown that AFCF has no adverse effects on animal or human health (6). Dairy animals are generally fed a concentrate ration when they are milked (usually twice daily) - incorporation of AFCF into the concentrate ration would allow administration daily. Meat producing animals would only need to be fed AFCF-concentrates for a suitable period prior to slaughter.
Target	Meat, milk and egg producing animals, especially those handled daily as part of normal farming practice, that is, dairy livestock. Inappropriate for free grazing livestock unless they can be confined in enclosures.
Targeted radionuclides	Known applicability: specific to ^{134}Cs, ^{137}Cs.
Scale of application	Large.
Timing of application to optimise effectiveness	Early application is best. However, AFCF is not manufactured in the UK. The requirement to obtain and distribute AFCF and incorporate into feed, makes it more likely be applied in the intermediate to long-term.
Constraints	
Legal	The sale of milk, meat and other animal products intended for human consumption is subject to maximum permitted levels (MPLs). MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019).

<table>
<tr><th colspan="2">1. Addition of AFCF to concentrate ration</th></tr>
<tr><td></td><td>On 14 October 2001 permanent authorisation was given by the European Communities for AFCF to be used as a feed additive for the purposes of binding radiocaesium. AFCF is an authorised feed additive in the UK.
AFCF may not be permitted under some organic production regimes.
Standards of animal husbandry and welfare regulations would need to be observed (Animal Welfare Act (2006)). The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals.</td></tr>
<tr><td>Physical environment</td><td>None.</td></tr>
<tr><td colspan="2">Effectiveness</td></tr>
<tr><td>Protective action effectiveness</td><td>A review of effectiveness is given in IAEA TRS 475 (5) and summarised below.
<table>
<tr><th>Livestock</th><th>AFCF application rate (g/d)</th><th>Reduction factor</th><th>% reduction</th></tr>
<tr><td>Sheep</td><td>1</td><td>5 to 8</td><td>80 to 88</td></tr>
<tr><td>Goats</td><td>1.5</td><td>3 to 4</td><td>67 to 75</td></tr>
<tr><td>Dairy cows
Beef cattle</td><td>3
3</td><td>3 to 5
4 to 5</td><td>67 to 80
75 to 80</td></tr>
<tr><td>Pigs
Chickens</td><td>1.5 to 2.0
1.5</td><td>4 to 6
3 to 5</td><td>75 to 83
67 to 80</td></tr>
</table></td></tr>
<tr><td>Technical factors influencing effectiveness of protective action</td><td>Amount of AFCF ingested by each animal daily.
The use of commercially prepared concentrates tends to be more effective than mixing as a powder into home produced rations.
Initial activity concentration and the biological half-life of radiocaesium in the animal.
Period of adaptation to pelleted feed may be required.</td></tr>
<tr><td colspan="2">Resourcing</td></tr>
<tr><td>Specific equipment</td><td>None.</td></tr>
<tr><td>Ancillary equipment</td><td>None.</td></tr>
<tr><td>Utilities and infrastructure</td><td>Concentrate manufacturing plants with the ability to add AFCF to feed pellets.</td></tr>
<tr><td>Consumables</td><td>Concentrates with AFCF – these are not currently manufactured in the UK.</td></tr>
<tr><td>Skills</td><td>Farmer would have required skills.</td></tr>
</table>

1. Addition of AFCF to concentrate ration	
Work rates and operator time	No additional time unless farmer mixes the AFCF in the feed.
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: none. Members of the public: none.
Impact of protective action	
Environmental impact	None. Some soils may contain bacteria or fungi capable of degrading AFCF to its components, which include cyanide, however, toxic levels of this compound will not arise under field conditions. A beneficial side effect is that radiocaesium uptake in plants from soils fertilized with manure from treated animals is lower than that from soils fertilized with manure from untreated animals (7).
Agricultural impact	Change in production status for organic farms.
Practical experience	
	Used frequently after the Chornobyl accident in Norway with good results for cows, goats and reindeer (3). Used in the former Soviet Union but as a different locally produced hexacyanoferrate compound known as Ferrocyn (4). Not used in Japan after the Fukushima accident.
Key references	
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	1. Addition of AFCF to concentrate ration
	Science of the Total Environment: volume 137, pages 235 to 248 4. Howard BJ, Beresford NA and Voigt G (2001). 'Countermeasures for animal products: a review of effectiveness and potential usefulness after an accident' Journal of Environmental Radioactivity: volume 56, pages 115 to 137 5. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 6. Pearce J (1994). 'Studies on any toxicological effects of Prussian Blue compounds in mammals: a review' Food and Chemical Toxicology: volume 32, pages 577 to 582 7. Vandenhove H, Van Hees M, De Brouwer S, Vandecasteele C. (1997). 'Effects of ammonium-ferric (III)-hexacyano-ferrate (II) and faeces addition on yield and soil-plant transfer of radiocaesium to ryegrass' Journal of Environmental Radioactivity: volume 37, pages 235 to 246
Comments	
	Can be used in conjunction with: • live monitoring (reassurance that adding AFCF to concentrate ration is effective at reducing activity concentrations of Cs to below MPLs) • sheltering of livestock (pre-deposition and early phase) • clean feeding

[Return to index of protective actions in section 4]
[Return to decision-aiding look-up tables for food production systems in section 6.1]
[Return to index of protective actions for food production systems in Annexe A1]

2. Addition of calcium to concentrate ration	
General	
Objective	To reduce activity concentrations of radiostrontium in milk and meat to below maximum permitted levels (MPLs).
Other benefits	Reduces quantities of animal products requiring disposal. Normal animal management and/or grazing regimes can be maintained.
Protective action description	The absorption of radiostrontium from an animal's diet is controlled by the level of dietary calcium intake and the animals' requirement for calcium. Enhancing the intake of calcium relative to the calcium status of the animal will reduce the transfer of radiostrontium to milk. Additional calcium (as calcium carbonate) may be added to the daily ration of lactating animals to reduce radiostrontium transfer to milk. This is most easily achieved by adding Ca as a powder to the concentrate ration fed to (most) milk producing animals at milking time. Alternatively, pelleted concentrates with enriched levels of calcium can be fed. The latter option enables calcium intake to be more accurately quantified. Supplementation with calcium would be expected to be in the range 100 to 200 g/d for dairy cattle. No adverse effects provided Ca intake is 1 to 2% of dry matter intake and dietary Ca/P does not exceed 7:1 (impact on absorption of other nutrients). Calcium can also be added to the diet of meat and egg producing animals to reduce radiostrontium adsorption in animal tissues. Meat producing animals would only need to be fed calcium for a suitable period prior to slaughter.
Target	Primarily milk producing animals.
Targeted radionuclides	Known applicability: ^{89}Sr, ^{90}Sr. Probable applicability: other radionuclides in Group 2 of the periodic table. Not applicable: radionuclides not in Group 2 of the periodic table.
Scale of application	Large.
Timing of application to optimise effectiveness	Early application is best. Sources of calcium would be readily available and cheap. It could take longer to source supplies of pelleted feed enriched in calcium.
Constraints	
Legal	The sale of meat (and milk) intended for human consumption is subject to maximum permitted levels (MPLs). MPLs become legally

2. Addition of calcium to concentrate ration	
	binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). Standards of animal husbandry and welfare regulations would need to be observed (Animal Welfare Act (2006)). The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals. Calcium carbonate is not listed as an authorised feed additive in the database of Regulated Food and Feed Products for Great Britain.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Doubling of calcium intake results in reductions of approximately 50% (reduction factor of 2) in the transfer of radiostrontium to milk as the absorption of radiostrontium (and hence transfer to milk) is inversely proportional to calcium intake (1). The relationship between dietary calcium and the transfer of radiostrontium to milk of cattle, sheep and goats under UK conditions has been validated experimentally (2). Larger reductions are achievable in animals with low dietary calcium status prior to supplementation.
Technical factors influencing effectiveness of protective action	Animal's dietary calcium intake prior to calcium supplementation and its calcium requirements. While, in theory, every doubling of Ca intake would reduce Sr concentration in milk by 50% there are maximum advised Ca intakes over long term. Quantity of calcium ingested daily by each animal. Initial activity concentration and the biological half-life of radiostrontium in the animal.
Resourcing	
Specific equipment	None.
Ancillary equipment	None.
Utilities and infrastructure	A factory to incorporate calcium supplements into feed pellets.
Consumables	Calcium supplements or pelleted concentrates with enriched levels of Ca. These may not be readily available.

2. Addition of calcium to concentrate ration	
Skills	Farmer would have required skills and could, if necessary, add calcium supplements to the concentrate ration, if instructions were provided.
Work rates and operator time	No additional time unless farmer mixes the calcium supplements in the feed
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: none. Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	Possible change in production status for organic farms.
Practical experience	
	Increasing the calcium intake of animals was carried out extensively after the Kyshtym accident in 1957 (3).
Key references	
	1. Beresford NA, Mayes RW, Hansen HS, Crout NMJ, Hove K and Howard BJ (1998). 'Generic relationship between calcium intake and radiostrontium transfer to milk of dairy ruminants' Radiation and Environmental Biophysics: volume 37, pages 129 to 131 2. Beresford NA, Mayes RW, Colgrove PM, Barnett CL, Bryce L, Dodd BA and Lamb CS (2000). 'A comparative assessment of the potential use of alginates and dietary calcium manipulation as countermeasures to reduce the transfer of radiostrontium to the milk of dairy animals' Journal of Environmental Radioactivity: volume 51, pages 321 to 342 3. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475

2. Addition of calcium to concentrate ration	
Comments	
	In many countries, farmers will know the amounts of Ca in the feeds they use (both commercial and home grown). In the long-term these could be used to optimise the use of Ca as a protective action on a farm-by-farm basis. Can be used in conjunction with: • clean feeding • sheltering of livestock (pre-deposition and early phase)

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3. Addition of clay minerals to concentrate ration	
General	
Objective	To reduce activity concentrations of radiocaesium in milk and meat to below maximum permitted levels (MPLs).
Other benefits	Reduces quantities of animal products requiring disposal. Normal animal management and/or grazing regimes can be maintained.
Protective action description	Clay minerals such as bentonites, vermiculites and zeolites can be added to the concentrate ration (5 to 10%) to reduce gut uptake of radiocaesium by farmed livestock. Clay minerals can also be added into pelleted feeds at feed manufacturing plants, which avoids loss of the clay binder in feeding troughs. Clay minerals reduce activity concentrations of radiocaesium in milk, meat offal and other animal products. It may be necessary to provide additional water when clay minerals are added to the feed (1).
Target	Milk and meat producing animals, especially those handled daily as part of normal farming practice, that is, dairy livestock. Useful for meat producing livestock for a period prior to slaughter. Inappropriate for free grazing livestock unless they can be confined in enclosures.
Targeted radionuclides	Known applicability: specific to ^{134}Cs, ^{137}Cs.
Scale of application	Large.
Timing of application to optimise effectiveness	Early application is best. However, the requirement to secure suitable sources of clay minerals and incorporate into feed, makes it more likely be applied in the intermediate to long-term. Also, a period of adaptation to the clay mineral supplemented diet may be required.
Constraints	
Legal	Bentonite, Vermiculite and Clinoptilolite are all authorised feed additives in the UK. The sale of meat (and milk) intended for human consumption is subject to maximum permitted levels (MPLs). MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). Standards of animal husbandry and welfare regulations would need to be observed (Animal Welfare Act (2006)). The Animal Welfare Act

3. Addition of clay minerals to concentrate ration	
	2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Effectiveness data below comes from controlled experiments with lactating dairy cattle (3).

Bentonite (g/d)	Reduction factor	% reduction
300	2.6	62
600 [note 1]	3.7	73
Clinoptilolite (g/d) (natural zeolite)		
300	1.5	35

Notes

[note 1] No further reductions with increasing amounts of bentonite.

Experiments monitoring adsorption from the alimentary tract of reindeer, noted reduction factors of around 2.9 (65%) when bentonite was added to the diet at a rate of 25 g/d (1).

Technical factors influencing effectiveness of protective action	Source of clay minerals. Different types of clay minerals have different binding capacities for radiocaesium and therefore, vary in their ability to reduce uptake of radiocaesium. Quantity of clay minerals ingested. As the administration rate increases the greater the reduction of radionuclides in milk or meat. However, loss of appetite and weight has been observed if too much clay is given (1, 2). Initial activity concentration and the biological half-life of radiocaesium in the animal. A period of adaptation to pelleted feed may be required.
Resourcing	
Specific equipment	None.
Ancillary equipment	None.
Utilities and infrastructure	Natural sorbents, such as bentonite and zeolites, are extensively quarried and used on an industrial scale for many different applications, including incorporation into animal feed, for instance, to reduce scouring (diarrhoea). Transportation of clay minerals is required from extraction site.

3. Addition of clay minerals to concentrate ration	
	Storage facilities. A factory to incorporate clay minerals into to feed pellets.
Consumables	Concentrates with clay minerals.
Skills	Farmer would have required skills and could, if necessary, add clay minerals to concentrate ration, if instructions were provided.
Work rates and operator time	No additional time unless farmer mixes the clay mineral in the feed.
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: none. Members of the public: none.
Impact of protective action	
Environmental impact	Possible trace element deficiency in pasture if large quantities of clay minerals in slurry or manure are spread on the land.
Agricultural impact	Animal welfare issues associated with feeding atypically high quantities of clay minerals. There may be a change in production status for organic farms.
Practical experience	
	Bentonite was used in Norway and Sweden after Chornobyl, for reindeer in conjunction with clean feed. However, the cost was considered to be high relative to the additional 'effect' over clean feeding, so the practice was discontinued.
Key references	
	1. Åhman B (1996). ‘Effect of bentonite and ammonium-ferric(III)-hexacyanoferreate(II) on uptake and elimination of radiocaesium in reindeer’ Journal of Environmental Radioactivity: volume 31, pages 29 to 50 2. Beresford NA, Lamb CS, Mayes RW, Howard BJ, Colgrove PM (1989). ‘The effect of treating pastures with bentonite on the transfer of ^{137}Cs from grazed herbage to sheep’ Journal of Environmental Radioactivity: volume 9, pages 251 to 264

3. Addition of clay minerals to concentrate ration	
	3. Unsworth EF, Pearce J, McMurray CH, Moss BW, Gordon FJ and Rice D (1989). 'Investigations of the use of clay minerals and Prussian Blue in reducing the transfer of dietary radiocaesium to milk' Science of the Total Environment: volume 85, pages 339 to 347
Comments	
	Can be used in conjunction with: • live monitoring (reassurance) • sheltering of livestock (pre-deposition and early phase) • clean feeding The effect of treating upland pastures in the UK with bentonite on the transfer of ^{137}Cs to sheep tissues has been investigated (2). Repeated applications of 80 g/m^2 reduced activity concentrations in sheep tissue, but this also led to loss in body weight due to a reduction in herbage intake. A range of clay minerals have been tested in goats for reducing radiostrontium uptake to milk (Hansen and others, 1995). Only sodium aluminosilicate was effective (approximately 40% at a rate of 0.5 g/kg live weight). However, the implications for absorption of essential trace elements still needs further investigation. See: Hansen HS, Saether M, Asper NP and Hove K (1995). 'In vivo testing of compounds with possible strontium binding effects in ruminants' In: 'Proceedings of a symposium on environmental impact of radioactive releases' IAEA-SM-339/198P (pages 719 to 721)

Return to index of protective actions in section 4
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4. Administer AFCF boli to ruminants	
General	
Objective	To reduce activity concentrations of radiocaesium in meat and milk to below maximum permitted levels (MPLs).
Other benefits	Reduces quantities of animal products requiring disposal. Normal animal management and/or grazing regimes can be maintained in extensively farmed areas.
Protective action description	Slow release boli containing ammonium-ferric hexacyanoferrate (AFCF, Giese-salt, Prussian Blue), an effective radiocaesium binder, have been developed to reduce the gut uptake of radiocaesium by ruminants in agricultural and semi-natural environments (3). Toxicological studies have shown that AFCF has no adverse effects on animal or human health (8). Boli are produced by compression of a mixture of AFCF, barite and wax. The presence of a wax coating delays the release of AFCF and enhances the long-term effectiveness. To ease swallowing, the boli are immersed in liquid paraffin prior to administration. The boli (normally 2 to 3) are inserted into the rumen and gradually release AFCF. The release rate of AFCF follows first order kinetics. Boli are particularly suitable for free-grazing ruminants and can be administered when they are gathered for routine handling operations. Boli are administered to meat producing animals 2 to 3 months prior to slaughter, and to dairy animals every 6 to 8 months. Boli are made in different sizes to suit different animals. Live monitoring prior to slaughtering provides reassurance to consumers that the boli are an effective option.
Target	Primarily meat producing ruminants. Potential for milk producing animals, although more likely that addition of AFCF to concentrate ration would be used. AFCF boli cannot be used for monogastric animals such as pigs.
Targeted radionuclides	Known applicability: specific to ^{134}Cs, ^{137}Cs.
Scale of application	Large.
Timing of application to optimise effectiveness	Early application is best. However, AFCF is not manufactured in the UK. The lack of established production facilities or stockpiles means that the option will most likely be applied in the intermediate to long-term. In Norway, AFCF boli were given to ruminants 2 to 3 months prior to slaughter for meat producing animals. For milk producing animals, boli are given at varying intervals depending on the

<table>
<tr><th colspan="2">4. Administer AFCF boli to ruminants</th></tr>
<tr><td></td><td>species. In the former USSR, dairy cows were given 2 to 3 boli every 6 to 8 months (6).</td></tr>
<tr><td colspan="2">Constraints</td></tr>
<tr><td>Legal</td><td>The sale of meat (and milk) intended for human consumption is subject to maximum permitted levels (MPLs). MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019).

On 14 October 2001 permanent authorisation was given by the European Communities for AFCF to be used as a feed additive for the purposes of binding radiocaesium. AFCF is an authorised feed additive in the UK.

AFCF boli may not be permitted under some organic production regimes.

Standards of animal husbandry and welfare regulations would need to be observed (Animal Welfare Act (2006). The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals.</td></tr>
<tr><td>Physical environment</td><td>Adverse weather conditions may delay gathering of livestock and administration of boli.</td></tr>
<tr><td colspan="2">Effectiveness</td></tr>
<tr><td>Protective action effectiveness</td><td>
<table>
<tr><th>Livestock</th><th>AFCF boli application rate per animal</th><th>Reduction factor</th><th>% reduction</th></tr>
<tr><td>Sheep (Norway) [note 1]</td><td>3 (9 to 11 weeks)</td><td>2 to 3</td><td>48 to 65</td></tr>
<tr><td>Upland lambs (UK) [note 2]
Goat (milk) [note 3]</td><td>3 (3 to 8 weeks)
2 (4 to 6 weeks)</td><td>2
5</td><td>50
80</td></tr>
<tr><td>Goat (meat) [note 3]</td><td>2 (4 to 6 weeks)</td><td>2.5</td><td>60</td></tr>
</table>
</td></tr>
</table>

4. Administer AFCF boli to ruminants	
	Notes [note 1] Bolus 16 to 20 mm x 50 to 65 mm (15% AFCF) (4). [note 2] Small lambs (10 kg). Bolus 14 mm x 50 mm (20% AFCF) (1). [note 3] Bolus 16 to 20 mm x 50 to 65 mm (15% AFCF) (5).
Technical factors influencing effectiveness of protective action	Concentration of AFCF in each bolus and the number of boli used. The presence of a wax coating on the boli increases the release period from 2 to 3 months. Initial activity concentration and the biological half-life of radiocaesium in the animal. Time between boli administration and live monitoring (or slaughter). It is possible that some animals may not be gathered and would not receive boli. Marking treated animals (for example, with lanolin-based marker fluids) may provide reassurance that animals have been treated. However, treated animals can still regurgitate boli.
Resourcing	
Specific equipment	For sheep, cows, and goats the farmer can administer by hand or adapt dosing guns used for other intra-ruminal devices.
Ancillary equipment	If being administered remote from farmstead in areas where animals would not normally be gathered and handled, corrals and fences will be needed.
Utilities and infrastructure	Factory to manufacture AFCF boli. Currently there are no commercial facilities making boli within western Europe.
Consumables	Boli with AFCF. Liquid paraffin. Lanolin-based marker fluids.
Skills	Farmer would have required skills for sheep, cows, and goats with little additional training. Skills would need to be developed within manufacturing industry to make AFCF-boli on large-scale.
Work rates and operator time	Farmer time to: • gather the animals and return them to pasture. Ideally this would be fitted into normal management practices. However, this will not always be possible • administer boli. It takes a trained farmer 30 seconds per sheep to administer 2 boli

4. Administer AFCF boli to ruminants	
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: • external exposure while collecting livestock from pasture Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	Animal welfare when administering boli. Change in production status for organic farms.
Practical experience	
	Used in Norway for sheep and reindeer following the Chornobyl accident. Despite the high relative cost of AFCF, costs of boli production and animal handling costs, it has been estimated that the use of boli as a countermeasure for sheep was 2.5 times as cost effective as clean feeding (2). Tested on several upland farms in UK. Standard Norwegian sheep boli were too large for hill lambs in these areas. Smaller boli were developed and tested, these required a higher AFCF content which caused problems with the integrity of the bolus (1). A survey of hill farmers in Wales suggested that the use of AFCF could adversely affect the image of Welsh lamb as an 'organic' product (7).
Key references	
	1. Beresford NA, Hove K, Barnett CL, Dodd BA, Fawcett RH and Mayes RW (1999). 'The development and testing of an intraruminal slow-release bolus designed to limit radiocaesium absorption by small lambs grazing contaminated pastures' Small Ruminant Research: volume 33, pages 109 to 115 2. Brynildsen LI, Selnaes TD, Strand P and Hove K (1996). 'Countermeasures for radiocesium in animal products in Norway after the Chernobyl accident: techniques, effectiveness, and costs' Health Physics: volume 70, 665 to 672

4. Administer AFCF boli to ruminants	
	3. Giese WW (1988). 'Ammonium-ferric-cyano-ferrate (II) (AFCF) as an effective antidote against radiocaesium burdens in domestic animals and animal derived foods' British Veterinary Journal: volume 144, page 363 to 369 4. Hansen HS, Hove K and Barvik K (1996). 'The effect of sustained release boli with ammoniumiron(III)-hexacyanoferrate)II) on radiocesium accumulation in sheep grazing contaminated pasture' Health Physics: volume 71, pages 705 to 712 5. Hove K and Hansen HS (1993). 'Reduction of radiocaesium transfer to animal products using sustained release boli with ammoniumiron(III)-hexacyanoferrate(II)' Acta vetinaria Scandinavia: volume 34, pages 287 to 297 6. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 7. Nisbet AF and Woodman RFM (2000). 'Options for the Management of Chernobyl-restricted areas in England and Wales' Journal of Environmental Radioactivity: volume 51, pages 239 to 254 8. Pearce J (1994). 'Studies on any toxicological effects of Prussian Blue compounds in mammals: a review' Food and Chemical Toxicology: volume 32, pages 577 to 582
Comments	
	Can be used in conjunction with: • live monitoring (reassurance that administering AFCF boli is effective at reducing activity concentrations of Cs to below MPLs)

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5. Application of NPK fertilisers and/or lime to soils	
General	
Objective	To reduce radionuclide uptake by plant roots, including crops and pasture, by addition of potassium fertilisers or lime to the soil.
Other benefits	Improvement in soil fertility in some soils. Potential increase in crop yields. Does not produce any waste.
Protective action description	Combined use of mineral fertilisers and lime can reduce uptake of some radionuclides in crops and pasture. **Potassium fertilisers** May be applied (singly or in conjunction with nitrate and phosphate fertilisers) to soils of low potassium status to reduce plant uptake of radiocaesium. Potassium is used because of its analogous chemical behaviour to caesium which can result in it successfully competing with radiocaesium for uptake by plant roots. **Lime** May be applied to soils of low pH or low Ca status to reduce plant uptake (especially of radiostrontium). Lime (CaCO3) can be applied in various forms and the amount required will depend on the pH and other soil properties. In both cases, the action is most effective if land is ploughed or harrowed after application. Treatments can also be applied as a top dressing to grassland.
Target	Pasture or arable land.
Targeted radionuclides	**Potassium fertilisers** Known applicability: ^{134}Cs, ^{137}Cs. **Lime** Known applicability: ^{89}Sr, ^{90}Sr. Probable applicability: ^{60}Co, ^{106}Ru, ^{192}Ir, ^{235}U, ^{238}Pu, ^{239}Pu, ^{241}Am. Not applicable: short half-lives of the following radionuclides negate use of this protective action: ^{131}I. Application of lime increases the mobility of: ^{75}Se,^{134}Cs, ^{137}Cs.
Scale of application	Small to large. Areas can be identified using Geographical Information Systems (GIS) from readily available soil characteristic information.
Timing of application to optimise effectiveness	Short- to long-term. However, if crops are present at the time of deposition, application of ameliorants may have to be delayed until the following season.

5. Application of NPK fertilisers and/or lime to soils	
	A single application of lime is usually effective for a period of 4 to 5 years. The actions are most effective if land is ploughed or harrowed after application.
Constraints	
Legal	The Codes of Good Agricultural Practice should be followed. Parts of this Code of Good Agricultural Practice form a Statutory Code under Section 97 of the Water Resources Act 1991. Fertiliser and lime addition and subsequent ploughing may be restricted at farms participating in environmental stewardship schemes or in areas designated within nitrate vulnerable zones (NVZs). A consent from the relevant organisations may be required if fertilising and ploughing or liming and ploughing are to be carried out in an area with certain designations a (for example, sites of special scientific, conservation or archaeological interest). A consent from, for example, Natural England, will be required if a change in land use is to be carried out in an area designated a site of special scientific interest (SSSIs) in England, Scotland and Wales or an area of special scientific interest (ASSIs) in Northern Ireland. The notification of SSSIs is made under the Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way Act 2000 in England and Wales). Special areas of conservation (SACs) and special protection areas (SPAs) are European sites covered by The Conservation of Habitats and Species Regulations 2017 and would require a habitations regulations assessment.
Physical environment	Potassium fertilisers and lime are normally ploughed into the soil before the planting or sowing of arable crops. It may not be possible to plough or harrow soils that are excessively wet, dry or frozen without damaging soil structure. Slope or stoniness of some grassland may make it unsuitable for a tractor and spreader. Application may need to be restricted near watercourses and on flood plains - GIS could be used to identify such areas. It can be difficult to apply lime in windy conditions. Liming may not be allowed where crops such as flax are cultivated on acid soils.
Effectiveness	
Protective action effectiveness	**Potassium fertiliser**

5. Application of NPK fertilisers and/or lime to soils	
	Potassium is most effective when exchangeable potassium status is less than 0.5 meq/100g soil. Under these conditions, reduction factors for radiocaesium of up to 5 (approximately 80%) have been reported in the literature based on field experiments (3). Studies following use in former Soviet Union countries after the Chornobyl accident report a reduction factor of 1.5 to 3.0 for radiocaesium (approximately 30% to 60% reduction) and 1.5 to 2.0 for radiostrontium (approximately 30% to 50% reduction) (1). Recent studies in Japan suggest that potassium would be effective when the soil solution potassium concentration is below about 1 mmol per litre (5). Repeated applications of potassium may be necessary to maintain low transfer of radiocaesium. Specific effectiveness factors for soils of different potassium status are available (6). If soils are acidic, potassium should be applied with lime. **Lime** Liming from pH 5 to pH 7 may decrease plant uptake of ^{90}Sr by 50% (reduction factor of 2) on sandy soils, 67% (factor of 3) on loamy soils and 75% (factor of 4) on clay soils, from pH 4 to pH 6 by 83% (factor of 6) on organic soils (1). These data are from studies at Kyshtym. Liming of organic soils may lead to desorption of radiostrontium and increased uptake by plants Depending on soil type, liming when pH is higher than 7 has no effect in mineral soils, and no effect in organic soils when pH is in excess of 6. Corrective liming lasts for at least 5 years. Maintenance liming every 5 years, to pH 7 on mineral soils and to pH 6 on organic soils, is recommended (0.5 to 2 tonnes $CaCO_3$/ha) (6). The combined use of lime and organic matter may reduce radiostrontium uptake by plants by factors of 3 to 5 (66% to 80% reduction) with the effects persisting for 2 to 3 years. Lime effect on other radionuclides There are no data for the effectiveness of this protective action with regard to radionuclides other than Sr. However, a reduction in soil plant transfer could be expected for the other listed target radionuclides on the basis of their known chemical and environmental behaviours.

5. Application of NPK fertilisers and/or lime to soils	
	Note: Application of lime increases the mobility of ^{75}Se, ^{134}Cs, ^{137}Cs due to change in soil pH.
Technical factors influencing effectiveness of protective action	Acceptability of the implementation of the protective action to farmers. **Potassium fertiliser** Soil type and potassium status of the soil or soil solution. Crop type. **Lime** Soil type and pH, cation exchange capacity, calcium status of soil. Crop type. Type of lime applied (for example, $CaCO_3$ can be more effective at changing soil pH). Whether rainfall follows lime application.
Resourcing	
Specific equipment	Tractor (ideally 55 to 67 kW) with spreading device.
Ancillary equipment	Plough or harrow.
Utilities and infrastructure	Fertiliser or lime production facilities with access to suitable materials and a distribution network.
Consumables	Fuel. Fertiliser (K_2O or KCl; 100 to 200 kg/ha) or lime (CaO or $CaCO_3$; 1 to 4 tonnes/ha) as applicable. Repeated application may be required.
Skills	Farmers would possess the necessary skills, as this is an existing practice.
Work rates and operator time	On average approximately 0.25 h/ha for a single operator, but twice as fast with premium equipment on large farms (120 to 150 kW tractors on more than 200 acres). This estimate includes loading but not transport and other logistics (4).
Waste	
Type	None – assuming applied when no standing crop. Grassland receives a top-dressing.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a

5. Application of NPK fertilisers and/or lime to soils	
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer while spreading or ploughing: • external exposure • inadvertent ingestion and inhalation (to a lesser extent) Members of the public: none.
Impact of protective action	
Environmental impact	Application can change nutrient status and thus plant and animal diversity – possible changes in landscape. Grasslands are often the habitat of endangered species and a change in nutrient status may be harmful to these species. Changes in bioavailability and mobility of nutrients and pollutants may lead to effects on water quality.
Agricultural impact	Application of potassium fertilisers or lime may restrict subsequent use of the land (for example, organic farming). Crop yield and quality may be increased by bringing K level closer to optimum for the crop (potassium fertiliser) or by solving acidity problems (lime). General improvement in soil fertility. Liming prevents some diseases that attack crops. Liming may induce micronutrient deficiencies in crops (Mn and Zn in particular) and additional application of micro element fertilisers may be necessary.
Practical experience	
	Standard agricultural practice. Routinely applied in agriculture to optimise crop yields. Potassium fertilisers and lime used in conjunction with other fertilisers on contaminated arable soils in former Soviet Union following Kyshtym and Chornobyl accidents (1). Application of potassium fertilisers to paddy fields was used successfully in Japan following the Fukushima accident, with the result that in 2012 only 71 out of 10 million rice bags exceeded activity reference levels (from the combined effects of potassium fertiliser application and natural processes, such as radioactive decay of ^{134}Cs) (2).
Key references	
	1. Alexakhin RM (2009). ‘Chapter 4. Remediation of areas contaminated after radiation accidents’ Voigt G, Fesenko S

5. Application of NPK fertilisers and/or lime to soils	
	(editors) Radioactivity in the Environment: volume 14, pages 177 to 222 2. IAEA (2014). 'The follow-up IAEA International Mission on remediation of large, contaminated areas off-site the Fukushima Daiichi Nuclear Power Plant, Tokyo and Fukushima Prefecture, Japan, 14 to 21 October 2013' IAEA NE/NEFW/2013 23 January 2014 3. Nisbet AF, Konoplev AV, Shaw G, Lembrechts JF, Merckx R, Smoulders E, Vandecasteele CM, Lonjo H, Caarini F and Burton O (1993). 'Application of fertilisers and ameliorants to reduce soil to plant transfer of radiocaesium and radiostrontium in the medium to long term: a summary' Science of the Total Environment: volume 137, pages 173 to 182 4. Nix J (2007). 'Farm Management Pocketbook, 37th edition. Imperial College London 5. Smolders and Tsukada (2011). 'The transfer of radiocaesium from soil to plants: mechanisms, data, and perspectives for potential countermeasures in Japan' Integrated Environmental Assessment and Management: volume 7, number 3, pages 379 to 338 6. Woodman RFM and Nisbet AF (1999). 'Deep ploughing, potassium and lime applications to arable land' National Radiological Protection Board, Chilton (UK), NRPB-M1072
Comments	
	Both treatments are standard agricultural practices that should be acceptable to farmers, provided the incremental doses to tractor drivers from the deposited activity are trivial. **Potassium fertiliser** K and Mg fertilisation may be required to maintain optimal ionic equilibrium in soil and plant. Potassium would normally be applied in conjunction with nitrogen (not ammonium as this may enhance radiocaesium uptake) and phosphorus-based fertilisers to optimise crop yield. **Lime** Mg fertilisation and liming may be required to maintain optimal ionic equilibrium in soil and plant.

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6. Clean feeding	
General	
Objective	To reduce activity concentrations of radionuclides in milk, meat and other animal products to below maximum permitted levels (MPLs).
Other benefits	Reduces quantities of animal products requiring disposal.
Protective action description	Provide animals with less contaminated or uncontaminated feedstuffs. Livestock may be fenced in enclosures or housed to prevent grazing of contaminated pasture. The animals are then given nutritionally balanced diets comprising uncontaminated and/or less contaminated feed so that the final animal product has activity concentrations less than the MPLs. For milk or egg producing animals clean feeding will need to be continuous while pasture or food activity concentrations would result in milk or eggs exceeding MPLs. For meat producing animals clean feeding is only required for a suitable period prior to slaughter (depending upon initial activity concentrations and biological half-lives). This could be achieved by moving animals onto uncontaminated pasture prior to slaughter. A programme of grassland management must be implemented while livestock are fenced or housed to ensure that MPLs are not exceeded when the animals are reintroduced to pasture, and that the quality of pasture is maintained. Grassland management involves the cutting and subsequent disposal of contaminated grass before animals are returned to pasture.
Target	Meat, milk, and egg producing animals, especially those handled daily as part of normal farming practice. Particularly useful for lactating dairy animals to ensure continuous production of milk below MPLs. Inappropriate for free grazing livestock unless they can be confined in enclosures.
Targeted radionuclides	Known applicability: ^{134}Cs, ^{137}Cs, ^{90}Sr, ^{131}I. Probable applicability: ^{60}Co, ^{75}Se, ^{106}Ru, ^{192}Ir. Not applicable: the low feed to meat or milk transfer of the following radionuclides makes implementation of this management option unlikely to be required for: ^{238}U, ^{239}Pu, ^{241}Am.
Scale of application	Large scale – commercial production. Small scale – domestic production (for example, hens, chickens, goats).

6. Clean feeding	
Timing of application to optimise effectiveness	As soon as possible for milk and egg producing livestock to reduce accumulation of radionuclides. For meat producing animals, the period leading up to their slaughter is optimal. Effective over all timescales. Depends on availability of suitable housing with water, power supply, straw for bedding and ventilation; and availability of alternative clean feed.
Constraints	
Legal	The sale of milk, meat and other animal products intended for human consumption is subject to maximum permitted levels (MPLs). MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). Standards of animal husbandry, welfare and regulations governing feed storage would need to be observed (Animal Welfare Act (2006)). The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals. Some certification schemes may be contravened. For example, in the case of organic milk production, there is a limit on the proportion of concentrate in the diet of dairy cattle. Free range schemes may also be restricted following an accident if animals have to be housed. Local regulations on the use and siting of buildings and erection of fences must be consulted and followed, for example, in national parks, environmentally sensitive areas. Sites of special scientific interest (SSSIs), areas of outstanding natural beauty (AONBs) and archaeological areas. A consent from the relevant organisations may be required if carried out in an area with such designations. The notification of SSSIs is made under the Wildlife and Countryside Act 1981. Any disposal of collected radioactive waste would be sought under The Environmental Permitting (England and Wales) Regulations 2016; the Environmental Authorisations (Scotland) Regulations 2018; and The Radioactive Substances Act 1993, in Northern Ireland.
Physical environment	None
Effectiveness	
Protective action effectiveness	Is highly effective for most radionuclides as it removes or reduces the primary source of contamination.

6. Clean feeding	
	Reduction factors of 2 to 5 (50% to 80% reduction) for milk and meat were noted for ^{137}Cs following the Chornobyl accident (2). Activity concentrations of radiocaesium in milk respond rapidly to changes in diet as the biological half-life is a few days, whereas for meat the response time is longer due to the longer biological half-life in muscle. Similar reduction factors of 2 to 5 (50% to 80% reduction) for milk and meat were noted for ^{90}Sr following the Chornobyl accident (2). However, the impact of ^{90}Sr was only significant in part of the 30 km exclusion zone and some adjoining areas in Belarus. A combination of long biological and physical half-lives will limit the effectiveness of this management option for ^{239}Pu and ^{241}Am if used when animals are already contaminated.
Technical factors influencing effectiveness of protective action	Availability of conserved feed, which is dependent on the time of year that an accident occurs. For example, in winter there would be little impact for housed livestock being fed covered stored feeds. However, finishing lambs and other livestock which are still outdoors grazing pasture or forage crops would have to be housed and given conserved clean feed. Just before the growing season (that is, mid to late spring) would be the worst time for a radiation emergency, since cattle and lambs would be grazing outside, and stocks of previously harvested, uncontaminated fodder would be low, and no new season hay or silage would have been harvested. It is possible to buy uncontaminated feed from a wide variety of suppliers worldwide. If the radiation emergency occurred in the summer, animals could be fed hay or silage that had been cut earlier in the year. Level of contamination of alternative feeds. Biological half-life of specific radionuclide-livestock species combination. Physical half-life of radionuclide. Existing levels of radionuclide in animal tissues when clean feeding starts. Rate at which alternative diet is introduced and duration of feeding regime. If grazing stopped and the new (less contaminated) diet comprises root crops and cereals a period of adaptation of 2 weeks is desirable. This is less important if the uncontaminated diet contains silage and hay. For some of the alternative diets, reduction in grazing is only worth considering for restrictions lasting more than a few weeks because of time required to introduce alternative diets.

<table>
<tr><th colspan="2">6. Clean feeding</th></tr>
<tr><td></td><td>The effectiveness of clean feeding for some gamma emitters (notably radiocaesium) can be monitored rapidly using live monitoring techniques.</td></tr>
<tr><td colspan="2">Resourcing</td></tr>
<tr><td>Specific equipment</td><td>Existing fenced areas or farm buildings could be used to contain or house livestock prior to sale, although some would require modification to penning and feeding arrangements or ventilation in summer months due to high humidity, temperatures, and high concentrations of ammonia.
New fencing where enclosures do not exist.
New, purpose-built sheds could also be considered if the period of clean feeding warranted this (for example, years).</td></tr>
<tr><td>Ancillary equipment</td><td>Storage facilities for clean feed, slurry, and manure, and cut grass (grassland management).
Feeding and drinking troughs.
Slurry spreading equipment.
Forage harvester to cut grass for pasture management.</td></tr>
<tr><td>Utilities and infrastructure</td><td>Water.
Power supply.
Ventilation.</td></tr>
<tr><td>Consumables</td><td>Alternative feeds.
Additional concentrates may be required to nutritionally balance the alternative diets.
Organic feed may be required to maintain organic status of some farms.
Additional straw for bedding.</td></tr>
<tr><td>Skills</td><td>Farmers would possess the necessary skills as housing animals and providing feed is an existing practice. However, some expert guidance may be required when introducing new diets or housing livestock at unusual times of the year.</td></tr>
<tr><td>Work rates and operator time</td><td>Farmer time to:
• obtain uncontaminated feed
• look after animals not normally housed or fenced
• implement alternative feeding regime
• collect, store, and dispose of slurry or manure
• cut and dispose (for example, composting, silage making) of contaminated grass
• construct additional enclosures, adapt existing</td></tr>
</table>

6. Clean feeding	
Waste	
Type	Slurry or manure produced while livestock are fenced in or housed. Cut grass following the programme of grassland management.
Transport	It is foreseen that any waste would remain on the farm and not need transporting.
Treatment	The cut grass may be composted in situ. Alternatively, silage may be made from the harvested biomass. Such silage could later be fed to non-critical stock or stored for an extended period to allow for radioactive decay. If the critical radionuclide was ^{131}I (or other radionuclides with short physical half-lives), then the normal feed storage period of 6 to 12 months would more than suffice. For less contaminated pastures, an alternative to composting or ensilage of harvested pasture biomass, is to cut the pasture repeatedly and leave the cut material in situ.
Storage	On farm slurry tanks could be used (seek relevant environment agency advice as this could be considered a radioactive substances activity requiring a permit). If harvested biomass is stored for composting or silage making, care must be taken to control any liquid effluent produced because it is likely to be contaminated. The storage capacity on farms needs to be sufficient to handle the extra quantities of slurry or manure.
Disposal	Slurry or manure should be stored and disposed of by land spreading at appropriate times. When land is frozen or waterlogged, slurry or manure cannot be spread and must be stored to avoid water pollution. The disposal of compost back on farmland by spreading is only reasonable if the storage period is sufficient for the most important radionuclides to decay, or if the land was used for non-food production. Radiological impact assessments should be used to inform decision making. Seek relevant environment agency advice as these options could be considered a radioactive substances activity requiring a permit).
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: • external exposure from gamma emitting radionuclides while collecting livestock from pasture

6. Clean feeding	
	• external dose from gamma emitting radionuclides while looking after housed or enclosed animals • external exposure from gamma emitting radionuclides while mowing, composting or ensiling grass Members of the public: none.
Impact of protective action	
Environmental impact	Inappropriate disposal of additional slurry or manure could lead to pollution of water courses. Possible changes in landscape due to siting of new fences and buildings.
Agricultural impact	Animal welfare issues if animals are housed in the summer when temperature and ventilation could be a problem (for example, humidity, high levels of ammonia in buildings). Housing of animals will increase the risk of diseases such as foot rot and Pasteurella. Reduced grazing on fields. Greater volumes of manure, slurry, composted biomass to spread on the farm.
Practical experience	
	Clean feeding was used in Belarus, Russia, Ukraine, Norway and Sweden after the Chornobyl accident (1, 2). Clean feeding was also used in Japan following the Fukushima accident (3). Moving animals prior to slaughter is an existing practice in some areas of the UK (for example, fattening of hill-bred sheep on lowland pasture prior to slaughter).
Key references	
	1. Howard B, Beresford N and Hove K (1991). ‘Transfer of radiocaesium to ruminants in natural and seminatural ecosystems and appropriate countermeasures’ Health Physics: volume 61, issue 6, pages 715 to 725 2. Fesenko SV, Alexakhin RM, Balonov MI, Bogdevitch IM, Howard BJ, Kashparov, VA, Sanzharova NI,Panov AV, Voigt G, Zhuchenka YM (2007). ‘An extended critical review of 20 years of countermeasures used in agriculture after the Chernobyl accident’ Science of the Total Environment: volume 38, pages 1 to 24

6. Clean feeding	
	3. Manabe N, Takahashi T, Endo M, Piao C, Li J, Kokado H, Ohta M, Tanoi K and Nakanishi TM (2016). 'Chapter 7: Effects of "clean feeding" management on livestock products contaminated with radioactive caesium due to the Fukushima Daiichi nuclear power plant accident' In: 'Agricultural Implications of the Fukushima Nuclear Accident' TM Nakanishi, K Tanoi (editors) ISBN 978-4-431-55828-6
Comments	
	Can be used in conjunction with: • sheltering of livestock (pre-deposition and early phase) • addition of AFCF, clay minerals and/or lime to animal feed (intermediate to long term) • live monitoring (reassurance) Cost: may be high, considering; number of affected animals; consumables (that is, clean feed).

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7. Close air intake in greenhouses and food processing plants	
General	
Objective	To reduce contamination of indoor crops, processed foodstuffs, equipment, and growing media from intakes of contaminated air via ventilation systems.
Other benefits	Potentially reduce exposure of plant workers (from inhalation of contaminated air and external irradiation from indoor contaminants).
Protective action description	Switch off ventilation systems and close all windows, doors, and vents, before passage of the contaminated air mass. In food processing plants, relatively large volumes of air are used for drying, roasting and pneumatic transport of food products. Outdoor air may be used directly or after purification with filters (for example, EU filter categories 3 to 10). However, due to large air volumes, adequate filtering is not always possible. Contamination of foodstuffs can be prevented by cutting off the supply of contaminated air and halting those processes at risk before passage of the contaminated air mass. For protection of facilities in general, intake rates of air into buildings can be reduced to a minimum or stopped. Instructions for shutdown of a process or ventilation system must be followed.
Target	Greenhouse and/or polytunnel crops. All food processing facilities: milling, roasting, drying, dairy or meat plants, bakery, and catering industries.
Targeted radionuclides	All radionuclides.
Scale of application	Small to large.
Timing of application to optimise effectiveness	Short-term (pre-release). The measures are precautionary and are most effective if implemented before the contaminated air mass has arrived and should therefore be implemented as soon as the risk becomes apparent. In the event of an intermittent release, or prolonged duration release it may still be worth considering these actions to prevent additional contamination. Time available for stopping industrial processes and closing air intake systems will vary according to weather conditions, the distance from the source of release and any advance warning of a release. The duration of closure would depend upon the duration of the release and how long contaminated air mass remains in the area.
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of operators being exposed to contaminated air-masses (that is, if

7. Close air intake in greenhouses and food processing plants	
	time was short and operators had to drive to site), The Ionising Radiations Regulations 2017, Part 1, Regulation 2.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Up to 100% effective but most likely to be less than this particularly as greenhouses and polytunnels are not airtight structures.
Technical factors influencing effectiveness of protective action	Timing of closure with respect to passage of the contaminated air mass (that is, requires adequate notification and time to travel to site, if not already there). Also, adequate time is needed to stop a process prior to passage of the contaminated air. Furthermore, delays may occur if the protective action needs to be implemented out of hours. The removal efficiency of filters gradually decreases during operation so filtering may not always be adequate. Leakage of radioactive aerosols is also a possibility depending on the type of filter. Airtightness of buildings used for processing, greenhouses and polytunnels. Form of radionuclide: gaseous versus particulate versus aerosol.
Resourcing	
Specific equipment	None.
Ancillary equipment	None.
Utilities and infrastructure	None.
Consumables	After passage of the contaminated air any air filters would need to be changed and disposed of (precautionary action).
Skills	Capabilities exist but may be called upon out of hours.
Work rates and operator time	Implementers will need time to: • close down ventilation systems • shut down other processes • travel to site (if out of hours) • replace air filters Members of the public: none.
Waste	
Type	None, provided air intake system is shut down prior to arrival of the contaminated air.
Transport	n/a
Treatment	n/a

7. Close air intake in greenhouses and food processing plants	
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers, when closing air intake or ventilation system, potential for: • external exposure from the plume • external exposure to deposited contamination • inhalation of contaminated air No exposure if completed before arrival of the contaminated air mass, and implementers do not remain at the facility when plume passes. Members of the public: none
Impact of protective action	
Environmental impact	None.
Agricultural impact	There may be potential implications of a sudden and unscheduled shutdown on some industrial operations and processes. For growing facilities, there is potential for spoilage of crop to occur due to lack of ventilation but only in the unlikely event of a long duration release.
Practical experience	
	None.
Key references	
	None.
Comments	
	This protective action may also be relevant for food storage facilities, although non-radiological food safety issues may preclude use. In the case of greenhouses or polytunnels, operators may be reluctant to be outside while there is a risk of contamination. This is likely to be exacerbated if the action coincides with public sheltering advice or evacuation. Plants in greenhouses or polytunnels should be watered with clean water not contaminated by the incident.

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8. Consumer access to monitoring equipment	
General	
Objective	To provide the public with personal access to equipment or facilities giving information on radiation levels in foodstuffs or surroundings. The screening of home grown or self-gathered foodstuffs for radioactivity content is likely to reduce ingestion doses from consumption of contaminated food.
Other benefits	Consumers can make an informed choice about whether or not to eat a particular foodstuff. Useful for reassurance purposes. Enhances technical knowledge and skills among affected populations. Identifying areas of significant contamination in and around homes and places of work.
Protective action description	With Government support, local authorities and others, including those that are citizen-led, could set up an independent accredited monitoring service so that the general public can check foodstuffs for radionuclide content (particularly home grown or self-gathered). In highly populated areas this might be based at local health centres. For sparsely populated rural areas a mobile facility could be deployed. Members of the public would be given the opportunity to provide samples of home produced or self-gathered foodstuffs to trained personnel who would be responsible for determining their radionuclide content. Other services may include whole body monitoring or general advice on radiation risks.
Target	Home grown and/or self-gathered foodstuffs such as milk, meat, eggs, vegetables, fruit, berries, nuts, honey, fish and mushrooms.
Targeted radionuclides	Known applicability: ^{131}I,^{134}Cs, ^{137}Cs (that is, gamma emitting radionuclides that can be analysed at the monitoring station without being sent off for radiochemical analysis). Probable applicability: any radionuclide of concern if samples are taken back to a laboratory for radiochemical analysis.
Scale of application	Small or medium scale. Areas where food is home produced or self-gathered.
Timing of application to optimise effectiveness	Early to long-term. However, in the early phase capacity for provision of appropriate monitoring equipment is likely to be limited as time will be required to manufacture and calibrate monitoring kits and train personnel.
Constraints	
Legal	Ionising Radiations Regulations (Basic Safety Standards) 2018, enables the establishment of an infrastructure to support continuing

8. Consumer access to monitoring equipment	
	self-help protective measures, such as information provision, advice and monitoring. Some form of accreditation may be required for the analytical methods used as well as logging of samples, recording of results and data analysis. Personnel must be appropriately trained.
Physical environment	None.
Effectiveness	
Protective action effectiveness	This management option does not directly remove contamination from the food chain but has the potential to be effective in reducing ingestion doses by identifying contaminated foodstuffs, which can be discarded.
Technical factors influencing effectiveness of protective action	Quality of, and access to, monitoring equipment. Provision of information about the results and implications in terms of ingestion doses, enabling people to choose whether to eat or discard food products according to radionuclide content.
Resourcing	
Specific equipment	Depends on radionuclides and type of foodstuff to be measured: Most likely to require NaI and HPGe spectrometry systems for the determination of gamma-ray emitting radionuclides in foodstuffs. Provision of SAMs (small articles monitors) for gamma-ray emitters could be considered as a simple alternative or in addition to spectrometry systems. Alpha and beta spectrometry systems if the radionuclides of concern justify radiochemical analysis.
Ancillary equipment	Data recording equipment.
Utilities and infrastructure	Transport, distribution and co-ordination of monitoring equipment or service. Trained personnel to interpret and explain results to members of public. Radiochemical laboratories for sample preparation and analysis.
Consumables	Sample containers and chemicals, depending on monitoring type. Fuel for transport. Materials used to provide training and information.
Skills	Knowledge of radioanalytical and radiochemical methods. Provision of information about results and their interpretation.
Work rates and operator time	Analyst time which varies according to the number of samples to be processed and radionuclides to be determined: • preparation of samples

8. Consumer access to monitoring equipment	
	• determination of radionuclides in foodstuffs brought in for analysis • recording and reporting of results • other staff at monitoring centres • communication of results • provision of information about radioactivity in food products • maintenance and calibration of monitoring equipment
Waste	
Type	Depending on the results from monitoring and sample analysis, members of the public may not want to eat their homegrown foodstuffs or foods gathered from the wild. These will require disposal through council-run refuse or garden waste collection.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Monitoring personnel (if not local): • external exposure from working in a more contaminated area Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	None.
Practical experience	
	Monitoring equipment was made available to householders in the contaminated villages of Belarus, for the determination of radiocaesium in locally produced foodstuffs such as milk, mushrooms, and berries (1). The Fukushima accident created an unprecedented upsurge of citizen science initiatives within the affected area and far beyond, giving rise to international organizations such as Safecast and dozens of local citizen radiation measuring organizations in Japan. These initiatives measure a wide range of items in addition to food products (2).

8. Consumer access to monitoring equipment	
	In 2012 there were more than 100 citizen radioactivity monitoring stations (CRMS) in Japan, which reduced to about 70 in 2015. The CRMS have produced a large body of open access data on radioactive contamination in food post Fukushima (3).
Key references	
	1. Hériard Dubreuil GF, Lochard J, Girard P, Guyonnet JF, Le Cardinal G, Lepicard S, Livolsi P, Monroy M, Ollagon H, Pena-Vega A, Pupin V, Rigby J, Rolevitch I and Schneider T (1999). 'Chernobyl post-accident management: the ETHOS project' Health Physics: volume 77, pages 361 to 372 2. Kenens J (2020). 'Changing perspectives: tracing the evolution of citizen radiation measuring organizations after Fukushima' Radioprotection: volume 55 (HS2), pages S249 to S253 3. Reiher C (2016). 'Lay People and experts in citizen science: monitoring radioactively contaminated food in post-Fukushima Japan' The German Journal on Contemporary Asia ASIEN: volume 140 (July 2016), pages 56 to 73
Comments	
	This protective action should be carried out in conjunction with provision of dietary advice. Monitoring stations and mobile facilities can also be used to monitor external doses in affected areas.

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9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
General	
Objective	To permanently release contaminated areas (terrestrial or aquatic) from the restrictions imposed by Food and Environment Protection Act orders (FEPA, 1985).
Other benefits	Farmers and commercial fishermen can market their produce without any restrictions, delays or requirements for monitoring.
Protective action description	**Derestriction surveys: sheep or beef cattle, grazing extensive pastures** Derestriction surveys can be carried out where routine monitoring indicates that activity concentrations of gamma emitting radionuclides in grazing livestock have decreased and are no longer exceeding the maximum permitted levels (MPLs). Depending on scale of survey required and resources available, full flock (or herd) surveys are carried out, otherwise a representative sample needs to be considered (at least 10% of stock). The surveys are targeted when radiocaesium levels peak in late spring or early summer, and within 24 to 48 hours of animals being gathered from contaminated pasture (usually uplands). The surveys can be time consuming. **Derestriction surveys: fish, shellfish (marine and inland water bodies)** Derestriction surveys can be carried out where routine monitoring indicates that activity concentrations of radionuclides in aquatic foods have decreased and are no longer exceeding the maximum permitted levels (MPLs). Depending on scale of survey required and resources available, representative sampling of aquatic fish and shellfish should be carried out. The surveys should be targeted at the point of catch. These can be time consuming. **Dose assessment for terrestrial or aquatic foods** If possible, given available information on the range of contamination within food and the habits of those consuming that food product, a probabilistic assessment [note 1] of doses to consumers of the food should be undertaken. Decisions to lift restrictions should be based on the level of confidence that individuals are unlikely to receive doses above the reference levels (for example, a decision to lift restrictions could be made if the dose to more than 95% of consumers of the food is estimated to not exceed the reference level). If a probabilistic assessment is not possible, then an assessment to calculate the dose to a

9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
	representative person [note 2] should be performed, with that dose being compared directly to the reference level. Notes [note 1] A probabilistic assessment defines parameter values as ranges rather than discrete values. The output of such an assessment is a range of dose that members of a population may receive rather than the dose to a specific individual. From that range, different percentiles of dose received by members of that population can be determined including the mean (50th percentile) and a high-rate food consumer (typically taken to be the 95th percentile). [note 2] The representative person is a hypothetical individual who is assumed to be an above average consumer of meat or fish or shellfish sourced from the restricted area. In addition, the representative person is also assumed to consume food containing above average levels of radioactivity. The dose to the representative person will therefore be towards the upper end of the range likely to be received by members of the population although it may be below the dose received by an individual with extreme food consumption rates.
Target	Meat-producing livestock extensive grazing (cattle, sheep) Fish and shellfish
Targeted radionuclides	Known applicability: Live monitoring of animals – gamma emitting radionuclides such as ^{134}Cs and ^{137}Cs, would be the primary targets. Samples taken back for laboratory analysis – any radionuclide. Probable applicability: Live monitoring of animals: ^{60}Co, ^{75}Se, ^{131}I,^{192}Ir. While in theory live monitoring may be possible for all gamma-emitting radionuclides with an energy sufficiently high to detect there is little field experience of trying to determine levels in meat for radionuclides other than Cs. For radionuclides with no effective photon emissions (that is, beta and alpha emitters) and radionuclides with low photon energies (for example,^{235}U, ^{238}Pu, ^{239}Pu and ^{241}Am), laboratory analysis would be necessary.
Scale of application	Small to medium (can be resource intensive).
Timing of application to optimise effectiveness	Intermediate to long term (takes time to understand environmental fate of radionuclide and behaviour).

9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of operators being exposed to contaminated surfaces, that is, The Ionising Radiations Regulations 2017, Part 1, Regulation 2. The sale of foods intended for human consumption is subject to maximum permitted levels (MPLs) of radioactivity in food and feed. MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). Food and Environment Protection Act (FEPA, 1985), also known as FEPA orders, can be used to restrict the gathering of food within defined geographical areas in the UK. These areas are also known as ‘restricted areas’. The Food and Environment Protection Act 1985 may be used to protect the public from exposure to potentially contaminated food, using the MPLs as outlined above. The Act gives the Secretary of State and devolved ministers (on advice from the Food Standards Agency or Food Standards Scotland) the powers to make emergency orders (FEPA orders). These FEPA orders will define a designated area and specify activities which may be prohibited in respect to this area. For example, the order can make it an offence to supply (for example, sell) food, or anything from which food can be produced (for example, animals) that has originated in the designated area. It can also make it an offence to prepare or process food from the designated area. Once a FEPA order is in place, FSA and FSS may issue ‘consents’ to permit otherwise prohibited activities where FSA or FSS are satisfied that food or animal feed is safe. The Welfare of Farmed Animals (England) Regulations 2000 cover all farmed animals and contain specific requirements regarding activities such as inspections and feeding and watering of animals. Equivalent legislation in other parts of the UK is Welfare of Farmed Animals (Scotland) Regulations 2000, Welfare of Farmed Animals (Wales) Regulations 2001 and Welfare of Farmed Animals (Northern Ireland) Regulations 2000. The Animal Welfare Act 2006 has brought together and modernised

9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
	welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals.
Physical environment	Weather conditions: equipment needs to be weatherproof (that is, resistant to low temperatures (potentially to -20°C), water including salt water, snow and so on under field conditions); rapid temperature shocks to the detector should be avoided.
Effectiveness	
Protective action effectiveness	Can be highly effective at releasing large numbers of farms and other areas from restrictions.
Technical factors influencing effectiveness of protective action	Accuracy of the monitoring result will be influenced by the equipment and techniques being used. **Sheep or beef cattle, grazing extensive pastures** Effectiveness of derestriction surveys comprising live monitoring can be maintained by taking a probabilistic approach across a flock or herd to the estimated radionuclide concentration at which animals are rejected for entry into the food chain. Duration of counting time. Variation in size of animals being monitored. **Fish, shellfish (marine and inland water bodies)** Effectiveness of derestriction surveys comprising sampling and laboratory analysis of fish and shellfish can be maintained by appropriate sampling design and quality control procedures in the laboratory.
Resourcing	
Specific equipment	Portable, preferably lead-shielded, NaI detector linked to multi-channel analyser with battery supply - calibrated for animals being monitored. Detector and analyser should be weatherproof. Sampling apparatus for fish and shellfish. Laboratory based NaI and HpGe detectors, liquid scintillation counters, alpha spectrometers.
Ancillary equipment	Restraints for livestock (for example, cattle crush) will be required while monitoring some animals. Fishing nets.
Utilities and infrastructure	Suitable penned area to keep livestock before monitoring. Motorised boat (if commercial fishing was banned). Standard sample preparation facilities in accredited laboratory. Access to a probabilistic dose assessment model.

9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
	Administrative support for data handling, recording and interpretation.
Consumables	Paint and ear tags to mark failed animals, or alternative identification method. Containers for storing samples. Containers for sample analysis.
Skills	Monitoring, sampling, and radiochemical analysis would be carried out by trained personnel. Probabilistic modelling and dose assessment expertise.
Work rates and operator time	Monitoring or sampling implementers, time [note 1] required to: • travel to or from an area (including travel to an accredited laboratory if required) • set up equipment • monitor livestock • collect fish and shellfish samples • prepare and analyse samples Notes [note 1] There may be a requirement to depurate seafood so it is equivalent to what is sold (may take 24 to 48 hours). Farmer: • time required to gather animals for monitoring • time required to construct enclosure for monitoring Scientific staff or advisers: • development of dose or risk assessment models • calculation of doses to representative person
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Monitoring implementers: • external exposure while working in a contaminated area (terrestrial) • external irradiation from radionuclides in sediment (aquatic)

9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
	Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	Disruption caused by having to gather animals for monitoring (this can be minimised by co-ordinating with the routine gathering of animals, for example, gathering sheep for shearing). Once, released from restrictions normal marketing practices can be resumed.
Practical experience	
	Sheep or beef cattle, grazing extensive pastures Carried out in Cumbria and North Wales to progressively release contaminated areas from restrictions. Initially derestriction surveys, involved full flock surveys, conducted during the summer months when contamination levels were at their highest and when lambs had just been brought down from upland pastures. Farms would only be derestricted if no sheep had levels above the MPL (in this case 1,000 Bq/kg) for 2 consecutive years. This was a very cautious and labour-intensive approach (1, 2). For the probabilistic dose assessment carried out for derestriction of Chornobyl restricted areas, 3 exposure populations were defined according to buying habit: 1. Farmer – annual consumption sourced from one animal 2. Bulk buyer – purchases ‘freezer packs’ 4 times a year (4 animals) 3. Frequent buyer – purchases fortnightly (26 animals) **Fish, shellfish (marine and inland water bodies)** Sampling of coastal foods routinely done as part of permit compliance conditions (3, 4).
Key references	
	1. Nisbet AF and Woodman RFM (1999). ‘Options for the management of Chernobyl-restricted Areas in England and Wales’ National Radiological Protection Board, Chilton (UK), NRPB-R305 2. Nisbet AF and Woodman RFM (2000). ‘Options for the management of Chernobyl-restricted areas in England and Wales’ Journal of Environmental Radioactivity: volume 51, pages 239 to 254

9. Derestriction surveys and dose assessment (Removal of FEPA orders)	
	3. 'Radioactivity in Food and the Environment (RIFE) report' (2019) 4. Sellafield Ltd (2018). 'Monitoring our environment: discharges and environmental monitoring annual report 2017'

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10. Dietary advice, including culinary preparation techniques	
General	
Objective	To reduce ingestion doses to consumers of domestic produce and free foods by providing food safety advice on contamination levels in the produce and options for simple culinary practices that can be used in the home to reduce radionuclide content.
Other benefits	Improves personal control and ability to make informed dietary choices. Helps maintain a way of life (that is, allotments, kitchen gardens, fishing, hunting and gathering of wild foods such as mushrooms and berries). Reduces the need for disposal of produce.
Protective action description	**Provision of advice and information** Information on activity concentrations in a range of domestically grown products and free foods will be provided by various food standards agencies (for example, FSA and FSS) in conjunction with advice on the risks from consuming contaminated produce and options for reducing intakes. Information and advice on which foodstuffs can be eaten without restrictions, those which should only be consumed occasionally, and those which should be avoided completely will be communicated nationally as well as via local networks, (for example, National Society of Allotment and Leisure Gardeners, (NSALG)), social media, the internet, association magazines, and leaflets. The provision of advice on how individuals can restrict their own radionuclide intake represents a cost-effective method by which their radiation dose can be considerably reduced. Local monitoring stations may be established for radiation emergencies extending over several months or years, to provide allotment holders, kitchen gardeners and gatherers of wild food, including fish and game, with the opportunity of measuring activity concentrations in their produce. The provision of monitoring equipment locally helps the population to better control their own radiological situation and to act dynamically in response to temporal fluctuations in activity concentrations. **Culinary preparation** Standard preparation techniques such as washing, blanching, removing outer leaves, and peeling or shelling are suitable for fruits, berries, vegetables, herbs and nuts following contamination via direct deposition (5). The peel and foliage must be discarded and not re-used in another part of the cooking process. In the longer term, when contamination has been incorporated into the tissues of vegetables via root uptake and translocation, blanching, boiling and

10. Dietary advice, including culinary preparation techniques	
	soaking in brine can help reduce their radionuclide content. Meat and fish can be deboned, and/or soaked in brine. Freezing and storage of produce is also appropriate for short-lived radionuclides, as activity concentrations will diminish quickly over the first few months. Freezing may increase storage times up to one year, particularly for meat, fish, fruit and vegetables.
Target	Generally applicable to all consumers of domestic produce and those gathering foods from the wild. Special focus on vulnerable groups such as children and pregnant women and all those with a high rate of wild food or home-grown vegetable consumption.
Targeted radionuclides	Potentially all radionuclides. Processing: ^{134}Cs, ^{137}Cs, ^{90}Sr (extensive data support applicability). Storage: ^{75}Se, ^{131}I, ^{192}Ir (short-lived radionuclides).
Scale of application	Small to large.
Timing of application to optimise effectiveness	During the early phase, directly deposited radionuclides can be removed very effectively from vegetables and fruit by culinary preparation techniques. However, where contamination levels are predicted to be very high, initial advice may be to avoid harvesting domestic produce altogether. Dietary advice and culinary preparation continue to be effective throughout the early, intermediate and long-term phases, and will aid in reducing ingestion doses from domestic and free foods, which are not subject to legislative controls.
Constraints	
Legal	The Food and Environment Protection Act, 1985 is not applicable to domestic produce for home consumption but can be used to restrict the gathering of foods from the wild. Ionising Radiations Regulations (Basic Safety Standards) 2018, enables the establishment of an infrastructure to support continuing self-help protective measures, such as information provision, advice and monitoring. Any disposal of collected radioactive waste and would be sought under The Environmental Permitting (England and Wales) Regulations 2016; the Environmental Authorisations (Scotland) Regulations 2018; and The Radioactive Substances Act 1993, in Northern Ireland.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Stopping consumption of highly contaminated foodstuffs from the diet in the immediate aftermath of a radiation emergency, is 100%

10. Dietary advice, including culinary preparation techniques	
	effective at reducing ingestion doses from those foodstuffs. However, by carrying out various culinary practices, that significantly reduce radionuclide content, home produced foods and foods gathered from the wild can still be enjoyed. Typical reduction factors for the various techniques are summarised below: **Washing** is most effective when carried out soon after deposition before absorption and translocation occur. It is radionuclide independent. Reductions in activity concentrations of up to 90% (reduction factor up to 10) have been recorded, especially when carried out vigorously and repeatedly (2). Radionuclides are more easily removed from smooth surfaces. **Removing inedible outer leaves, peeling or shelling** are most effective when carried out soon after deposition and are radionuclide independent. The degree of division between edible and inedible parts, influences effectiveness of removing inedible portion. For vegetables such as spinach, which is normally consumed whole, the effectiveness of the procedure is minimal (less than 10% reduction, reduction factor less than 1.1). Peeling is very effective at removing insoluble radionuclides such as plutonium and americium as root uptake and translocation are minimal. Over time the more soluble radionuclides become incorporated into the plant, so that removal of inedible parts and peeling become much less effective at removing the contamination (2). **Blanching or boiling** of fruit and vegetables (in salted water following peeling) removes an additional fraction of the contamination (approximately 50%, reduction factor approximately 2) depending on the solubility of the radionuclide. **De-boning of meat**: very effective for ^{89}Sr and ^{90}Sr when the meat is subsequently roasted. **Boiling meat** is very effective in removing radiocaesium (approximately 70%, reduction factor approximately 3.3) into the cooking liquid (which must then be discarded); it is recommended that small pieces of meat are boiled in large quantities of water (salted water further increases the efficiency (by about 10%, reduction factor approximately 1.1)). Slightly less effectiveness is seen for ^{106}Ru and ^{131}I and radiostrontium. **Soaking in brine solution** is one of the most effective ways (up to 90%, reduction factor up to 10) of removing radiocaesium from meat and fish, without causing significant deterioration in nutritional value or taste, appearance, and texture (2). **Preservation and storage:**

10. Dietary advice, including culinary preparation techniques	
	Preservation by jam making or freezing is highly effective for short-lived radionuclides such as ^{131}I.
Technical factors influencing effectiveness of protective action	Type of foodstuff, for example, texture of surface. Methods of processing. Radionuclides and their physicochemical forms (determines solubility). Perishability of the foodstuff and amenability to preservation and storage. Storage period. Availability of appropriate lines of communication.
Resourcing	
Specific equipment	Normal cooking equipment and utensils, freezer.
Ancillary equipment	None.
Utilities and infrastructure	Appropriate lines of communication. Monitoring data. Local network of monitoring stations.
Consumables	Brine solution for soaking. Dependent on communication method selected, for example, leaflets.
Skills	Communication.
Work rates and operator time	The time used for providing information, advice and guidance will depend on the communication method (press releases, television interviews, public meetings, magazine articles, letters, leaflets, internet and social media, telephone).
Waste	
Type	Discarded food products from gardens and allotments. Peelings, bones and liquids from boiling, soaking, and blanching of foodstuffs.
Transport	Suitable for transport via road. All wastes should be covered or contained during transport using leak-proof vehicles and containers. Specialist noxious waste transport contractors should be used. Medical waste containers may be suitable.
Treatment	None identified.
Storage	In containers which prevent escape of liquids or odour. Consider refrigerated storage if delays in disposal.

10. Dietary advice, including culinary preparation techniques	
	In both cases seek relevant environment agency advice as these options could be considered a radioactive substances activity requiring a permit.
Disposal	Preferred solution (subject to suitability of material present) is a permitted incinerator. Alternative routes to consider include disposal to LLW permitted landfill. Nuclear Waste Services can provide advice on the viability of these waste routes if information on waste volume and characteristics are provided. Anaerobic digestion may also be considered subject to guidelines provided by the relevant environment agencies. If anaerobic digestion is selected, then the digestate by-product may need further management depending on contamination levels. If contamination levels are sufficiently low, the digestate can be made into bedding for livestock, soil amendments, and certain types of fertilizers.
Pathways of exposure to implementers and the public	
Exposure pathways	None.
Impact of protective action	
Environmental impact	None.
Agricultural impact	n/a
Practical experience	
	Dietary advice Provision of clearly explained dietary advice has been very effective in other countries, such as Norway. Following the Chornobyl accident, the Norwegian Directorate of Health published a brochure aimed at groups, such as hunters, fishermen and reindeer breeders, who were most likely to consume large quantities of comparatively highly contaminated foods such as reindeer meat and freshwater fish. The brochure gave examples of the best ways to prepare food to limit radiocaesium intake and presented the advised intake rates in easily understandable units (for example, ‘meals per week’). Follow-up surveys estimated that up to 80% of the individuals within the target groups changed their diet as a consequence of the advice (1, 4). **Culinary preparation** Used in western Europe (especially Scandinavia) (3, 4) and in the former Soviet Union after the Chornobyl accident (1).

10. Dietary advice, including culinary preparation techniques	
Key references	
	1. Beresford NA, Voigt G, Wright SM, Howard BJ, Barnett CL, Prister B, Balonov M, Ratnikov A, Travnikova I, Gillett AG, Mehli H, Skuterud L, Lepicard S, Semiochkina N, Perepeliantnikova L, Goncharova N and Arkhipov AN (2000). 'Self-help countermeasure strategies for populations living within contaminated areas of Belarus, Russia and the Ukraine' Journal of Environmental Radioactivity: volume 56, pages 215 to 239 2. Long S, Pollard D, Cunningham JD, Astasheva NP, Donskaya GA, Labetsky EV (1995). 'The effects of food processing and direct decontamination techniques on the radionuclide content of foodstuffs: a literature review. Part 2: Meat, fruit, vegetables, cereals and drinks' Journal of Radioecology: volume 3, issue 2, pages 15 to 38 3. Petäjä E, Rantavaara A, Paakkola O, Puolanne E (1992). 'Reduction of radioactive caesium in meat and fish by soaking' Journal of Environmental Radioactivity: volume 16, pages 273 to 285 4. Strand P, Selnaes TD, Boe E, Harbitz O and Andersson-Sorlie A (1992). 'Chernobyl fallout: internal doses to the Norwegian population and the effect of dietary advice' Health Physics: volume 63, issue 4, pages 385 to 392 5. Wilkins BT, Bradley EJ and Dodd NJ (1987). 'The effects of culinary preparation on radionuclide levels in vegetable foodstuffs' Radiation Protection Dosimetry: volume 20, pages 187 to 190
Comments	
	Can be used in conjunction with: • consumer access to monitoring equipment (domestic produce) • restrictions on hunting and fishing

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11. Live monitoring (Mark and Release)	
General	
Objective	To determine whether activity concentrations in live animals are below the maximum permitted levels (MPLs).
Other benefits	Use in the optimisation of other protective actions. Reduces amount of meat in excess of MPLs requiring disposal. Provides reassurance to consumers and other stakeholders that contaminated foodstuffs are not entering the food chain.
Protective action description	Live monitoring can establish activity concentrations of gamma-emitting radionuclides in livestock before slaughtering. It may be carried out on the farm and at slaughterhouses. A quick and effective method of monitoring contamination for gamma-emitting radionuclides in live animals is to use a portable, preferably lead-shielded, NaI detector. Adequate shielding of monitors is crucial in highly contaminated areas or areas with high natural background. The activity detected by live monitoring is correlated to radiocaesium activity concentrations in sheep meat by calibration against laboratory-based high-resolution gamma ray spectrometry measurements of samples from slaughtered animals. A background count rate measurement should be taken with the probe held against the monitoring team member's body, at approximately the same height as the livestock animal to be monitored. This accounts for the naturally occurring radioisotope ^{40}K present in all animals. The counting time chosen has to be a compromise between a long time giving better accuracy and a short time determined by how long an animal could be kept still. The most effective counting procedure is to make 3 10-second counts by holding the detector firmly against the animal's rump (3). The background reading is subtracted from the mean of the 3 measurements taken and compared to a pre-determined action level. Due to the variation between individual animals, this action level should be calculated to give a statistical probability (for example 1 in 40) of the reading corresponding to an exceedance of the MPL. If the activity concentration is above the MPL for animals held on the farm, the animals are marked (for example, with indelible paint or ear tags) and must not be sold or slaughtered for a specified minimum period of time (for example, a period of 3 months has previously been found appropriate for upland grazed lambs). During this time other protective actions can be used to lower the activity concentration in animal tissues before they are monitored again prior to going for slaughter.

11. Live monitoring (Mark and Release)	
Target	Meat-producing livestock (for example, cattle, sheep, goats).
Targeted radionuclides	Known applicability: ^{134}Cs, ^{137}Cs (primary targets). Probable applicability: ^{60}Co, ^{75}Se, ^{131}I,^{192}Ir. While in theory live monitoring may be possible for all gamma-emitting radionuclides with an energy sufficiently high to detect, there is little field experience of trying to determine levels in meat for radionuclides other than Cs. Not applicable: radionuclides with no effective photon emissions (that is, beta and alpha emitters) and radionuclides with low photon energies (for example, ^{90}Sr,^{235}U, ^{238}Pu, ^{239}Pu and ^{241}Am).
Scale of application	Large scale, according to availability of monitoring kit and trained staff. Resource intensive.
Timing of application to optimise effectiveness	Short to long-term. However, in the early phase, the availability of monitoring equipment is likely to be limited and there may be a shortage of trained personnel. it will take time to manufacture and calibrate new equipment and train staff. These limitations mean that live monitoring is largely an intermediate to long-term measure. Live monitoring is most useful in the few months prior to slaughter to determine whether other protective actions are required to reduce activity concentrations in animal tissues to below the MPL.
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of operators being exposed to contaminated surfaces, that is, The Ionising Radiations Regulations 2017, Part 1, Regulation 2. The sale of meat intended for human consumption is subject to maximum permitted levels (MPLs) of radioactivity in food and feed. MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). The Welfare of Farmed Animals (England) Regulations 2000 cover all farmed animals and contain specific requirements regarding activities such as inspections and feeding and watering of animals. Equivalent UK legislation is Welfare of Farmed Animals (Scotland) Regulations 2000, Welfare of Farmed Animals (Wales) Regulations 2001 and Welfare of Farmed Animals (Northern Ireland) Regulations 2000. The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals.

11. Live monitoring (Mark and Release)	
Physical environment	Weather conditions: equipment needs to be weatherproof (that is, resistant to low temperatures (potentially to -20°C), snow and so on under field conditions); rapid temperature shocks to the detector should be avoided.
Effectiveness	
Protective action effectiveness	Can be highly effective (nearly 100%) at excluding meat above MPLs from the food chain.
Technical factors influencing effectiveness of protective action	Accuracy of the monitoring result and hence effectiveness of excluding animals exceeding the MPL from the food chain, will be influenced by variations between individual animals and the equipment and techniques being used. Effectiveness can be maintained by including a safety margin, so that the MPL in Bq/kg value corresponds to the upper bound of the 97.5% confidence interval. In practice this leads to animals with measured activity concentrations below the MPL being classed as failures (4). Duration of counting time. Variation in size of animals being monitored.
Resourcing	
Specific equipment	Portable, preferably lead-shielded, sodium iodide detector linked to multi-channel analyser with battery supply. The detector must be calibrated for the animals being monitored. There may be a shortage of detectors and trained personnel in the early phase. Detector and analyser should be weatherproof.
Ancillary equipment	Restraints for livestock (for example, cattle crush) will be required while monitoring some animals.
Utilities and infrastructure	Suitable penned area to contain livestock before monitoring. Administrative support for data handling, recording and interpretation.
Consumables	Paint and ear tags to mark failed animals, or alternative identification method.
Skills	Monitoring would be carried out by trained personnel. Animal handling experience or training would also be preferred. Ideally, team would consist of 2 people with farmer providing assistance (catching animals and so on). More people may be required for large animals (for example, cattle, horses).
Work rates and operator time	Monitoring implementers: • time required to travel to or from an area and between farms • time required setting up equipment, including taking background readings

11. Live monitoring (Mark and Release)	
	• time required to monitor livestock (one animal per minute). One team of 2 staff with one instrument can monitor 1,500 to 2,000 animals in a 5-day week (6 to 7 hour day) • time required to mark 'failing' livestock with paint or to secure ear tags • number of staff per team (minimum of 2) Farmer: • time required to gather animals for monitoring • time required to construct enclosure for monitoring
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Monitoring implementers: • external exposure from land and livestock while working in a contaminated area Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	No direct impact other than the disruption caused by having to gather animals and have them monitored before leaving the farm (this can be minimised by co-ordinating with the routine gathering of animals, for example, gathering sheep for shearing). A monitoring result in excess of the MPL (with any associated uncertainty) may result in slaughter or sale times being delayed until activity concentrations fall below MPLs. This represents a loss of flexibility in marketing practice and may also result in the production of overfat animals.
Practical experience	
	Combined with clean feeding, live monitoring was the main method of managing the entry of meat into the food chain in the former Soviet Union (2). Used in the UK (from 1986 until 2012) for monitoring sheep from Chornobyl in restricted areas (the 'Mark and Release' scheme) (3). This programme required considerable human and financial resources, the costs of which were borne by government.

11. Live monitoring (Mark and Release)	
	Used in Norway for sheep, cattle, and goats after the Chornobyl accident (1).
Key references	
	1. Brynilsen L and Strand P (1994). 'A rapid method for the determination of radioactive caesium in live animals and carcasses and its practical application in Norway after the Chernobyl accident' Acta Veterinaria Scandinavica: volume 35, pages 401 to 408 2. Fesenko SV, Alexakhin RM, Balonov MI, Bogdevitch IM, Howard BJ, Kashparov, VA, Sanzharova NI,Panov AV, Voigt G, Zhuchenka YM (2007). 'An extended critical review of 20 years of countermeasures used in agriculture after the Chernobyl accident' Science of the Total Environment: volume 38, pages 1 to 24 3. Meredith RCK, Mondon KJ, Sherlock JC (1988). 'A rapid method for the in vivo monitoring of radiocaesium activity in sheep' Journal of Environmental Radioactvity: volume 7, pages 209 to 214 4. Nisbet AF, Woodman RFM (1999). 'Options for the management of Chernobyl-restricted areas in England and Wales' National Radiological Protection Board, Chilton (UK), NRPB-R305
Comments	
	Can be used in conjunction with: • clean feeding • selective grazing • addition of AFCF and clay minerals to animal feed (intermediate to long term)

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12. Manipulate slaughter times	
General	
Objective	To reduce activity concentrations of radionuclides in meat to below maximum permitted levels (MPLs).
Other benefits	Reduces quantities of contaminated meat requiring disposal.
Protective action description	The option is intended to reduce radionuclide activity concentrations in meat, by changing the slaughter time to a season of the year when the contamination level is at its lowest. The option applies to animals with large seasonal differences in diet and radionuclide intake, including animals released onto pastures for part of the year. Free ranging animals may graze areas where highly contaminated fungi or lichen can be abundant, leading to greatly enhanced radiocaesium activity concentrations in meat. Slaughter can be early (that is, advanced) or postponed, to avoid the seasonal peak in radionuclide levels in meat. In the early to intermediate phase, manipulation of slaughter times may be used to either: 1. Minimise the entry of radionuclides into animal derived food products by slaughtering soon after deposition before the livestock have eaten sufficient contaminated feed that meat concentrations exceed the MPLs. 2. Reduce activity concentrations in meat as a consequence of physical decay of short-lived radionuclides, or losses from the tissues (biological half-life) by adopting a longer finishing period than normal which may need to be combined with the provision of uncontaminated feeds. In the longer-term, seasonal variation in the radionuclide content of animal’s diets, and hence meat, may be exploited (that is, slaughtering occurring at a time of year when the contamination levels are low).
Target	Meat producing livestock including farmed animals, free grazing sheep.
Targeted radionuclides	Known applicability: ^{131}I, ^{134}Cs, ^{137}Cs. Probable applicability: ^{75}Se, ^{90}Sr, ^{192}Ir. Not applicable: the low feed to meat or milk transfer of the following radionuclides makes implementation of this management option unlikely: ^{60}Co, ^{106}Ru, ^{235}U, ^{238}Pu, ^{239}Pu, ^{241}Am.
Scale of application	Small to large scale depending on timing (that is, capacity to slaughter soon after deposition may be limited but delaying slaughter may be possible on a larger scale).

12. Manipulate slaughter times	
Timing of application to optimise effectiveness	Early for immediate slaughter. Medium to late for livestock undergoing prolonged fattening.
Constraints	
Legal	The sale of milk, meat and other animal products intended for human consumption is subject to maximum permitted levels (MPLs). MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). Standards of animal husbandry and welfare would need to be observed (Animal Welfare Act (2006)). The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals.
Physical environment	None.
Effectiveness	
Protective action effectiveness	The effectiveness of the option is highly variable. Early phase slaughter: up to 100% if slaughter time brought forward to prevent uptake of radionuclides to meat. Delayed slaughter: Up to 100% if clean feed is provided during the period when slaughtering has been delayed. If animals graze pastures where fungi are abundant in certain years, their slaughter can be brought forward to avoid mushroom consumption in August and September. This can give 75% to 80% reduction (reduction factor of 4 to 5) in radiocaesium concentrations in sheep meat. Even where fungi consumption is not important, Cs levels in free-ranging sheep are generally higher in summer, so an earlier slaughter time can be effective (2, 3). After the Chornobyl accident, a 3- to 4-fold reduction (67% to 75%) in reindeer meat contamination was obtained in Norway by slaughtering in autumn instead of in winter (5). Similarly, in extensive farming conditions in the former USSR, a 1.5- to 4-fold (33% to 75%) reduction was obtained by postponing slaughter of cattle grazing low productivity pastures within forested areas (with abundant fungi) (4).

12. Manipulate slaughter times	
Technical factors influencing effectiveness of protective action	Speed of gathering free-ranging animals soon after deposition (early phase). Availability or capacity at slaughterhouses, particularly for immediate slaughter (early phase). Rate of change of activity concentrations in pasture over the extended fattening period. Biological half-life, which is animal, organ and radionuclide specific. Physical half-life of radionuclide. The availability of live monitoring data on which to base decisions on slaughter.
Resourcing	
Specific equipment	Abattoir or slaughtering equipment on farm for immediate slaughter (early phase). Monitoring equipment to assess contamination status of land. Monitoring equipment to carry out live monitoring.
Ancillary equipment	Additional cold storage facilities if many animals are slaughtered in a short time period
Utilities and infrastructure	Slaughterhouses. Transportation to take animals to abattoirs or slaughterhouses.
Consumables	Additional supplies of feed for periods when slaughter is delayed.
Skills	Slaughtering would be carried out by licensed slaughtermen with necessary skills. Herders or farmers would possess other skills required.
Work rates and operator time	Farmer time to: • gather animals (including free range animals) for immediate slaughter • care for animals during periods of prolonged slaughter Monitoring staff time to: • carry out monitoring of pasture • carry out live monitoring Slaughterhouse staff: • additional time to slaughter animals in larger numbers in early phase
Waste	
Type	None.
Transport	n/a
Treatment	n/a

12. Manipulate slaughter times	
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: • external exposure from gamma emitting radionuclides gathering animals soon after deposition Slaughterhouse staff: • external exposure from gamma emitting radionuclides if slaughter carried out on farm in early phase Members of the public: none.
Impact of protective action	
Environmental impact	Changes in vegetation or landscape may occur if there are prolonged changes in grazing pressure.
Agricultural impact	Changes in animal numbers on farms, which could cause pressure on accommodation and have implications for animal welfare. Changes in the annual cycles of farming activity which may affect the need for manpower and the provision of feed over longer periods. Change in quality of animal products (for example, meat, pelt). Markets may be prone to seasonal gluts and shortages.
Practical experience	
	Used in Norway after the Chornobyl accident for sheep, but other management options including the use of saltlicks or boli with AFCF and clean feeding became more important. Used in Norway for reindeer (1).
Key references	
	1. Åhman B and Åhman G (1990). 'Levels of ^{137}Cs in reindeer bulls in July to August and September and the effect of early slaughter' Rangifer, special issue number 5, pages 34 to 38 2. Brynildsen LI, Selnaes TD, Strand P, Hove K (1996). 'Countermeasures for radiocaesium in animal products in Norway after the Chernobyl accident: techniques, effectiveness, and costs' Health Physics: volume 70, issue 5, pages 665 to 672 3. Howard B, Beresford N and Hove K (1991). 'Transfer of radiocaesium to ruminants in natural and seminatural

12. Manipulate slaughter times	
	ecosystems and appropriate countermeasures' Health Physics: volume 61, issue 6, pages 715 to 725 4. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 5. Skuterud L and Hansen H (2008). 'Managing radiocaesium contamination in Norwegian reindeer 22 years after the Chernobyl accident: the need for a new regulation' Radioecology and Environmental Radioactivity (Proceedings of the International Conference, Bergen: Strand P, Brown J, Jolle T, editors). Norwegian Radiation Protection Authority, pages 121 to 124
Comments	
	If radionuclides accumulating within offal are the cause for concern it may be possible to dispose of these organs at slaughter. This would remove the need for delaying slaughter time. Reassurance, via monitoring programmes, would be necessary to show that livestock have radionuclide concentrations less than MPLs. Can be used in conjunction with: • sheltering of livestock (pre-deposition and early phase) • clean feeding (intermediate to long term) • selective grazing (intermediate to long term) • addition of AFCF, clay minerals and/or lime to animal feed (intermediate to long term) • live monitoring

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13. Natural attenuation (with monitoring)	
General	
Objective	To allow contamination in the environment to decrease, such that activity concentrations in aquatic and terrestrial foods are below maximum permitted levels (MPLs).
Other benefits	No active implementation of protective actions, other than monitoring.
Protective action description	Natural decay of radionuclides will occur with time. When the contamination involves a radionuclide that has short half-life, then it may be sufficient to allow activity concentrations of the radionuclide to decrease with time without active implementation of any other protective actions. For some situations, no other protective actions are applicable, so that natural attenuation becomes the default option, always to be accompanied by a monitoring programme and dose assessment, and a communication plan. This datasheet focusses on natural attenuation in food production systems to reduce doses from the ingestion pathway. There is a complementary datasheet for applying natural attenuation to reduce doses from external exposure and inhalation of resuspended material in places where people spend their time. **Terrestrial foodstuffs** Natural weathering via rain may lead to downward migration of mobile radionuclides in soil profile, leading to lower root uptake by crops and pasture. Some radionuclides bind to clay minerals which may also reduce availability for root uptake over time. However, in general, there will be pressure to maintain production and livelihoods, necessitating the implementation of other protective actions to reduce activity concentrations more quickly in terrestrial foods (milk, meat and crops). **Aquatic foodstuffs** **a) Marine and estuarine environments** The movement of radionuclides in marine and estuarine environments is dynamic and therefore it is difficult to reduce activity concentrations in foodstuffs from these environments by implementation of other types of protective action. Natural attenuation and a targeted monitoring programme will identify when activity concentrations in fish, shellfish and seaweed have decreased to below MPLs. **b) Inland waters** Lakes may concentrate activity as there is little mechanism for radionuclides to be naturally removed from the water besides

	13. Natural attenuation (with monitoring)
	absorption onto sediment and radioactive decay. Lakes are often vulnerable to run-off from surrounding land which may add significant levels of activity over time to the water. However, there are few viable options to reduce radionuclide concentrations in freshwater fish (4), so natural attenuation and a targeted monitoring programme will identify when activity concentrations in fish have decreased to below MPLs.
Target	Mainly marine and aquatic foodstuffs (fish, shellfish). Crops and meat producing livestock when radionuclide has a short half-life. Not applicable to dairy livestock due to rapid transfer of radionuclides to milk.
Targeted radionuclides	**Terrestrial foodstuffs** Probable applicability: Short-lived radionuclides such as ^{131}I, relatively short-lived radionuclides ^{134}Cs, ^{192}Ir. Not applicable: Long-lived radionuclides. **Aquatic foodstuffs** All radionuclides, particularly those with short half-life.
Scale of application	Potentially large scale according to availability of monitoring equipment and personnel.
Timing of application to optimise effectiveness	Early to intermediate phase.
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of operators being exposed to contaminated surfaces – The Ionising Radiations Regulations 2017, Part 1, Regulation 2. The sale of marine, aquatic and terrestrial foods for human consumption is subject to maximum permitted levels (MPLs) of radioactivity in food and feed. MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019).
Physical environment	Affected areas need to be accessible to monitoring teams. Physical environment may limit opportunity for taking representative samples of environment media for example, soils, mussels, fish for laboratory analysis.

13. Natural attenuation (with monitoring)	
Effectiveness	
Protective action effectiveness	Does not remove the radionuclide from the food chain but instead relies on radioactive decay, and physical and chemical processes that lead to reduced availability of the radionuclide for uptake to marine, aquatic, and terrestrial foods. It is only effective if used in conjunction with monitoring of the environment, sampling of terrestrial, aquatic, and marine foodstuffs and the live monitoring of animals for gamma emitting radionuclides.
Technical factors influencing effectiveness of protective action	Physical half-life of the radionuclide. Biological half-life of the radionuclide. Weathering rates (terrestrial) and fluxes (aquatic) of the radionuclide in the environment. It may take a prolonged period of time for the radionuclides to undergo radioactive decay and weathering from land surfaces. Accessibility for monitoring.
Resourcing	
Specific equipment	Although not essential, vehicle mounted large area monitors can prove very useful. If collecting food from offshore, a motorised fishing boat may be required to collect samples (particularly if a FEPA order is in place and there are no commercial fishing boats landing a catch from which to take samples).
Ancillary equipment	Sampling and monitoring equipment as appropriate for the radionuclides of concern.
Utilities and infrastructure	Laboratory to undertake analysis of samples. Administrative support for data handling, recording and interpretation.
Consumables	None.
Skills	Monitoring and sampling would be carried out by trained personnel. Dose assessment. Communication.
Work rates and operator time	Monitoring implementers, time required to: • travel to or from an area • set up sampling and monitoring equipment • take samples of terrestrial or aquatic foodstuffs and to carry out environmental monitoring (if appropriate) • maintain equipment and vehicles

13. Natural attenuation (with monitoring)	
	Laboratory staff: • time required to carry out sample preparation and analysis
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Monitoring implementers: • external exposure while working in a contaminated area (beta-gamma emitting radionuclides) • inhalation of material resuspended by the wind (alpha emitting radionuclides) Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	None.
Practical experience	
	Samples of marine foods and environmental media are regularly taken to support routine monitoring programmes by both operators and the regulators (2, 3). Vehicle mounted GroundHog systems for large area monitoring have been used on several beaches around the Dounreay and Sellafield sites for more than 20 years (1).
Key references	
	1. Etherington G, Youngman MJ, Brown J and Oatway WB (2012). 'Evaluation of the Groundhog Synergy Beach Monitoring System for detection of alpha-rich objects and implications for the health risks to beach users' HPA, Chilton (UK), HPA-CRCE-038 2. 'Radioactivity in Food and the Environment (RIFE) report' (2019) 3. Sellafield Ltd (2018). 'Monitoring our environment: discharges and environmental monitoring annual report 2017'

13. Natural attenuation (with monitoring)	
	4. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). 'A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs' Journal of Environmental Radioactivity: volume 56, issues 1 and 2, pages 11 to 32
Comments	
	Can be used in conjunction with: • restrictions on entry of terrestrial and aquatic foodstuffs into food chain (FEPA orders) • live monitoring or mark and release (sheep) • derestriction surveys and dose assessment (removal of FEPA orders)

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14. Ploughing options	
General	
Objective	To reduce radionuclide uptake by plant roots, including crops and pasture, by moving surface contamination deeper in the soil. Contamination is diluted in the soil profile.
Other benefits	Reduction in external doses from contaminated land. Reduction in resuspension doses from contaminated land. Less adhesion of contaminated soil to plant surfaces. Does not produce any waste.
Protective action description	This protective action considers shallow ploughing and 2 options for deep ploughing, one of which makes use of readily available equipment. **Shallow ploughing** A single-furrow mouldboard plough can be used to mix the top 20 to 30 cm of the soil profile. This can be done with the crop still present (incorporation) – although pre-treatment or other equipment may be required – or following crop removal. Much of the contamination at the surface will be buried more deeply in the vertical profile, which (a) may reduce radionuclide uptake by plant roots depending on their specific rooting behaviour; and (b) will reduce external exposure to agricultural workers from the contaminants. **Deep ploughing** If no crop is present, an ordinary single-furrow mouldboard plough can be used to invert the top 45 cm of the soil profile (the soil could be inverted to a different depth if required by the distribution of radioactivity within the soil or the presence of pebbles or other items in the soil). **Skim and burial** If no crop is present, a specialist plough with 2 ploughshares (6) can be used to skim off a thin layer of contaminated topsoil (about 5 cm; adjustable) and bury it at a depth of about 45 cm. The deeper soil layer (about 5 to 50 cm) is lifted by the other ploughshare and placed at the top without inverting the 5 to 45 cm horizon. The effect on soil fertility should be minimised in this approach. In both cases, much of the contamination at the surface will be buried deep in the vertical profile, which (a) may reduce radionuclide uptake by plant roots depending on their specific rooting behaviour; and (b) will reduce external exposure to agricultural workers from the contaminants.
Target	Pasture or fallow arable land.

14. Ploughing options	
Targeted radionuclides	Known applicability: ^{90}Sr, ^{134}Cs, ^{137}Cs. Probable applicability : ^{60}Co, ^{75}Se, ^{106}Ru,^{192}Ir, ^{238}Pu, ^{239}Pu, ^{241}Am. Not applicable: This protective action may increase the mobility of ^{235}U and ^{238}U. The relatively short physical half-lives (1 to 2 months) of the following radionuclides may preclude this radical protective action: ^{131}I.
Scale of application	Small to large, where ploughing is possible. Areas suitable for ploughing could be identified using geographical information systems (GIS) and information on soil type and slope. For shallow and standard deep ploughing, ploughs are often readily available. For skim and burial, ploughs are not available and special arrangements would have to be made for their manufacture.
Timing of application to optimise effectiveness	Should be carried out as soon as possible, but significant reductions are still possible in the longer term for relatively immobile radionuclides such as ^{134}Cs, ^{137}Cs. There is a tendency for the more mobile radionuclides such as ^{90}Sr to move down the soil profile with time. Shallow ploughing is only effective the first time it is carried out. Deep ploughing options should only be applied once, otherwise contamination may be brought back to the rooting zone. Skim and burial ploughing is more likely to only be practical in the medium to long term because none of these specialist ploughs are available in the UK.
Constraints	
Legal	The Codes of Good Agricultural Practice should be followed. Parts of this Code of Good Agricultural Practice form a Statutory Code under Section 97 of the Water Resources Act 1991. Ploughing may be restricted at farms participating in environmental stewardship schemes or in areas designated within nitrate vulnerable zones (NVZs). A consent from the relevant organisations may be required if ploughing is to be carried out in an area with certain designations (for example, sites of special scientific, conservation or archaeological interest). A consent from for example, Natural England or its devolved equivalents, will be required if ploughing is to be carried out in an area designated a site of special scientific interest (SSSIs) in England, Scotland and Wales or an area of special scientific interest (ASSIs) in Northern Ireland. The notification of SSSIs is made under the Wildlife and Countryside Act 1981 (as amended by the

14. Ploughing options	
	Countryside and Rights of Way Act 2000 in England and Wales). Special areas of conservation (SACs) and special protection areas (SPAs) are European sites covered by The Conservation of Habitats and Species Regulations 2017 and would require a habitats regulations assessment.
Physical environment	**All ploughing methods** Excessively stony soils cannot be ploughed. Soils which are excessively wet, dry or frozen cannot be ploughed without damaging the soil structure. Use of machinery difficult on land with greater than 15° slope. **Deep ploughing options** Soil profiles must be more than 0.5 m deep. The depth of the water table must be taken into account as deep ploughing may bring contamination closer to ground water sources which could lead to the transfer of radionuclides to other areas.
Effectiveness	
Protective action effectiveness	While observed data on the effectiveness of these measures are limited to Sr and Cs it is reasonable to expect similar reduction factors for the other targeted radionuclides as the protective action results in mechanical redistribution of radionuclides within the soil profile. **Shallow ploughing** An average reduction in plant uptake by a factor of 1.5 (approximately 33% reduction) was recorded in the former Soviet Union (8). IAEA TRS 475 (3) cites an average reduction factor of 2 (50% reduction). External dose reduced by factors of 2 to 5 (50% to 80% reduction), depending on depth of ploughing (3). **Deep ploughing** Plant uptake reduced by factors of 2 to 4 (50% to 75% reduction) (3). External dose reduced by 50% to 95% (factors of 2 to 20), the highest reduction factors are for complete inversion of soil (3). Remediation in Japan following the Fukushima accident reduced dose rates by up to 57% (factor of 2.3) (2). **Skim and burial** Reduction in soil-to-plant transfer by 90% (factor of 10) (3). Reduction in external dose of around 94% (factor of 16.7) (6). Note: These protective actions may result in increased mobility of U.

14. Ploughing options	
Technical factors influencing effectiveness of protective action	Soil type and conditions. Sandy soils are friable and may crumble during ploughing meaning that inversion may be incomplete. Vertical radionuclide distribution prior to action. Ploughing depth. Fertility of new topsoil. Rooting depths of crops to be grown. Efficiency of inversion of upper layer (deep ploughing only). Chemical form as this determines the rate of vertical migration. a large variety of different Cs species have been identified in the Fukushima and Chornobyl fallout, each with a distinctive chemistry. For example, it has been suggested that ploughing in the Chornobyl exclusion zone increased radionuclide availability, possibly due to disintegration of fuel particles and so the type of contamination should be considered before implementation.
Resourcing	
Specific equipment	**Shallow ploughing** Plough and tractor. **Deep ploughing including skim and burial** Plough with minimum furrow width of 0.75 m (only depths of up to 45cm can be ploughed by normal agricultural machinery). Skim and burial plough (limited availability). Tractor (powerful tractors, for example, 76 to 90 kW, are required for deep ploughing but are not necessarily readily available).
Ancillary equipment	None.
Utilities and infrastructure	Skim and burial plough manufacturer. Transport network to transport skim and burial plough or deep plough.
Consumables	Fuel.
Skills	Farmers or agricultural workers are likely to possess the necessary skills but must be instructed carefully about the objectives.
Work rates and operator time	**Shallow ploughing** On average, approximately 1.5 h/ha for a single operator, but 1 h/ha with premium equipment on large farms (120 to 150 kW tractors on more than 200 acres) (5). **Deep ploughing** On average approximately 2.5 h/ha for a single operator, but almost twice as fast with premium equipment on large farms (120 to 150 kW tractors on more than 200 acres) (5).

14. Ploughing options	
	Skim and burial Work rates for skim and burial ploughs likely to be similar to those for deep ploughing, approximately 3 h/ha (6).
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Operative ploughing land: • external exposure • inadvertent ingestion and inhalation (to a lesser extent) Members of the public: none.
Impact of protective action	
Environmental impact	Minimal additional environmental impact on land routinely ploughed. Severely complicates subsequent removal of the contamination (particularly deep ploughing options), as radionuclides are dispersed in a much greater volume of soil. If not routinely ploughed, long term changes in physical characteristics and structure of the surface horizon, for example, enhanced mineralisation of organic matter which may enhance availability and mobility of some radionuclides, change of nutrient loading and soil erosion (7). Biodiversity could be affected, particularly for soil dwelling organisms. Potential for ecosystem change or damage. Changes in landscape.
Agricultural impact	**Shallow ploughing** Additional fertilisation may be required on land not normally ploughed. Pastureland will require reseeding. **Deep ploughing options** Field drainage systems may be destroyed. Soil fertility is markedly reduced (in case of deep ploughing) or potentially reduced (in case of skim and burial) – fertilisation may be required. Deep ploughing would not be acceptable in regions with

14. Ploughing options	
	thin topsoils as soil fertility and structure would be detrimentally affected. Pastureland will require reseeding. Future restriction on land use: must not be deep tilled although, for skim and burial, subsequent normal ploughing (to approximately 25 cm) will not bring much contamination back to the surface.
Practical experience	
	Shallow ploughing Widely used in former Soviet Union following the Chornobyl accident (1, 8). Used in Japan following the Fukushima accident, where ploughing twice to about 30 cm was carried out (4). **Deep ploughing** Used in former Soviet Union following the Chornobyl accident, but thin topsoils limited more widescale application (1). Used in Japan following the Fukushima accident, where ploughing depths between 30 cm and 60 cm were tested (2). **Skim and burial ploughing** Used in former Soviet Union following the Chornobyl accident, but thin topsoils limited more widescale application (1). Also tested in Denmark on a small scale (6).
Key references	
	1. Fesenko SV, Alexakhin RM, Balonov MI, Bogdevitch IM, Howard BJ, Kashparov VA, Sanzharova NI, Panov AV, Yury VG and Zhuchenka M (2007). 'An extended critical review of 20 years of countermeasures used in agriculture after the Chernobyl accident' Science of the Total Environment: volume 338, issues 1 to 3, pages 1 to 24 2. IAEA (2011). 'Final report of the international mission on remediation of large, contaminated areas off-site the Fukushima Dai-ichi NPP 7-15 October 2011, Japan' IAEA NE/NEFW/2011, 15 November 2011 3. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 4. MOE (2013). 'Decontamination Guidelines (second edition)' Ministry of the Environment, Japan (accessed 20 July 2023) 5. Nix J (2007). 'Farm Management Pocketbook, 37th edition' Imperial College London, UK

14. Ploughing options	
	6. Roed J, Andersson KG and Prip H (1996). 'The skim and burial plough: a new implement for reclamation of radioactively contaminated land' Journal of Environmental Radioactivity: volume 33, issue 2, 117 to 128 7. Salt CA and Rafferty B (2001). 'Assessing potential secondary effects of countermeasures in agricultural systems: a review' Journal of Environmental Radioactivity: volume 56, pages 99 to 114 8. Vovk IF, Blagoyev VV, Lyashenko AN and Kovalev I S (1993). 'Technical approaches to decontamination of terrestrial environments in the CIS (former USSR)' Science of the Total Environment: volume 137, pages 49 to 63
Comments	
	Ploughing options may be used in conjunction with application of fertilisers and lime. Ploughing is a standard agricultural practice that should be acceptable to farmers, provided the incremental doses to tractor drivers from the deposited activity are trivial. It should be carried out on land that is normally ploughed to minimise environmental impact both in terms of run-off and loss of biodiversity. Long term control over land that has been deep ploughed (including skim and burial) is necessary for radionuclides with long physical half-lives as future management of the land may return 'buried' contamination to the surface.

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15. Processing and storage (commercial)	
General	
Objective	To process and/or store foodstuffs until the activity concentrations are less than the maximum permitted levels (MPLs)
Other benefits	Reduces the amount of waste food requiring disposal.
Protective action description	Commercial food processing can lead to a significant reduction in the radionuclide contamination of foodstuffs. This reduction can be achieved by many of the normal practices used in the preparation, cooking and processing of food. Delay times from harvest to point of sale, processing times as well as storage are also useful for reducing the concentrations of short-lived radionuclides (2, 3, 7). **Processing** Commercial processing of crops, vegetables and other plant products includes washing, peeling, milling, fermentation, distillation, blanching and canning. Processing of raw milk involves conversion to a wide range of products including skimmed milk, milk powder, cream, butter and cheese. Processing of meat and fish includes boiling, pickling, salting, marinating and deboning. **Delay times, processing times and storage times** Normal delays between harvest and consumption are important in reducing activity concentrations of short-lived radionuclides, such as ^{131}I. Long-storage and processing times also significantly decrease levels of short-lived radionuclides.
Target	Potentially applicable to all contaminated food products that can be processed and/or stored, such as cereals, milk, meat, eggs, fruit, berries, vegetables, nuts, fish and honey.
Targeted radionuclides	Potentially all radionuclides, but not proven for ^{60}Co, ^{106}Ru, ^{235}U, ^{239}Pu and ^{241}Am. **Processing**: ^{134}Cs, ^{137}Cs, ^{90}Sr (extensive data). **Harvesting and processing delays and storage**: ^{75}Se, ^{131}I, ^{192}Ir (that is, short-lived radionuclides).
Scale of application	Small to medium scale. Can be carried out on a large scale if processing and storage facilities are available.
Timing of application to optimise effectiveness	Any time after deposition, or for as long as selected foodstuffs have enhanced activity concentrations.
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of operators being exposed to contaminated food and waste by-

15. Processing and storage (commercial)	
	products. The Ionising Radiations Regulations 2017, Part 1, Regulation 2. MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). The Food and Environment Protection Act, 1985 may be used to protect the public from exposure to potentially contaminated food, using the maximum permitted levels (MPLs) of radioactivity on food and feed. Waste disposal of contaminated by-products would be covered by The Environmental Permitting (England and Wales) Regulations 2016. Scotland – the Environmental Authorisations (Scotland) Regulations 2018. Northern Ireland – The Radioactive Substances Act 1993.
Physical environment	None.
Effectiveness	
Protective action effectiveness	In reporting the effectiveness of food processing, the following food processing transfer parameters are used: the food processing retention factor, Fr, is the fraction of radionuclide activity that is retained in the food after processing; the processing efficiency, Pe, is the ratio of the fresh weight of the processed food to the weight of the original raw material; the processing factor, Pf, for a foodstuff is the ratio of the radionuclide activity concentrations. **Processing of crops, vegetables, and other plant products** Data on effectiveness of various types of processing of vegetables, fruit and grain are given in the table below. More extensive information on these and other products (for example, shellfish, mushrooms) and processes (for example, production of fruit juice and wine) can be found in IAEA TRS 472 and 475 (5, 6). In the following table: washing and boiling apply to vegetables, berries and other fruit; peeling applies to vegetables only; milling applies to wheat, barley, rye and oats. The numbers in brackets represent retention factor for external contamination only.

Process	Food processing retention factor, Fr				Pe
	^{131}I	^{134}Cs, ^{137}Cs	^{89}Sr, ^{90}Sr	^{238}Pu [note1], ^{241}Am	
Washing	0.8 (0.1-0.9)	0.6-1.0 (0.1-0.9)	0.4-1.0 (0.1-0.5)	No data	1.0

15. Processing and storage (commercial)						
	Peeling	No data	0.4-0.9	0.5-0.9	0.1-1.0	0.7-0.9
	Boiling	- (0.1-0.5)	0.4-0.9 (0.1-0.5)	0.6-1.0	0.3-1.0	0.8-1.0
	Canning, blanching, pickling	No data	0.1-1.0	No data	No data	0.5-0.9
	Milling cereal grain to white flour	No data	0.2-0.6	0.1-0.6	0.1-0.2	0.6-0.8
	Fr Rapeseed to oil: Pf for ^{134}Cs,^{137}Cs = 0.004; Pf for ^{89}Sr, ^{90}Sr = 0.002					

Notes

[note 1] Data likely to be applicable to all Pu isotopes.

Processing of fruits and vegetables includes surface cleansing or washing and other more vigorous or deeply penetrating measures. The efficiency of radionuclide removal through processing of plant products varies widely and can remove up to 99% of the initial activity in raw material. However, the efficiency of surface cleansing or washing of fruit and vegetables is rather low and gives a reduction in the ^{137}Cs content of up to 10% to 30% (reduction factor of 1.1 to 1.4) of the initial activity. Some more vigorous processing can be more effective. Thus, the ^{137}Cs content is reduced by 30% to 80% after boiling, salting, pickling, and juice and wine production. Most of the initial radionuclide content remains in water wastes and filter-pressed precipitate. The technological processing of grain to flour, sugar-beet to sugar and potatoes to starch provides products with lower ^{137}Cs and ^{90}Sr concentrations.

Processing of forest plant products

The most effective processing techniques for berries and mushrooms are soaking, boiling, and salting. Use of these measures gives decreases of factors of 2 to 10 (50% to 90% reduction) in the ^{137}Cs content of forest products. Washing of mushrooms alone gives a reduction in the radiocaesium content of the product by a factor of 2. Significant reductions in ^{137}Cs activity concentrations can be achieved by soaking of dried mushrooms and berries for several hours and salting of mushrooms (7).

Processing of milk

Data on effectiveness of various types of milk processing are given in the table below (5, 6).

15. Processing and storage (commercial)

Product	Food processing retention factor, Fr			Pe
	^{131}I	^{134}Cs, ^{137}Cs	^{89}Sr, ^{90}Sr	
Milk powder	1.0	1.0	1.0	0.12
Cream	0.06	0.05	0.04	0.08
Sour cream	-	0.1	0.1	0.1
Skim milk	~0.9	0.95	0.93	0.92
Butter	0.02	0.01	0.006	0.04
Butter milk	~0.1	0.05	0.06	0.04
Condensed milk	1.0	1.0	1.0	0.4
Goat cheese	~0.1	~0.1	0.6	0.12
Cow cheese (rennet)	0.2	0.07	0.7	0.12
Cow cheese (acid)	~0.2	0.06	0.08	0.10
Ion exchange	0.1	0.05	0.1	1

Milk products prepared by isolating the fat and/or protein components from the aqueous fraction tend to be depleted in radiocaesium compared with raw milk. Radiocaesium is concentrated in the water phase of milk, whereas radiostrontium is bound by casein and milk protein. Neither radionuclide preferentially associates with the fat content of milk, so they do not accumulate in high fat products (7). Radiocaesium activity concentrations after processing of cream, sour cream, butter, natural hard cheese, Greek 'feta' cheese, cottage cheese and casein are 1% to 30% of that in raw milk. Radiostrontium closely follows the behaviour of calcium. Hence, products, such as cottage cheese, cream and butter, with high fat content, which are relatively low in calcium, tend to have low levels of radiostrontium (1% to 30% of those in raw milk), while high calcium products, such as skimmed milk and cheese, have higher levels of radiostrontium (7). For radioiodine, processing of contaminated milk into storable food products (cheese, butter, and long-life milk or skimmed milk powder, chocolate and so on) is very effective in reducing activity concentrations before consumption.

Processing of meat and fish

Data on effectiveness of various types of meat processing are given in the table below (5, 6).

15. Processing and storage (commercial)

Process	Food processing retention factor Fr			Pe
	^{131}I	^{134}Cs, ^{137}Cs	^{89}Sr, ^{90}Sr	
Boiling meat (beef, pork, lamb, venison)	~0.6	0.4	0.5	0.5-0.7
Frying meat (beef, pork, lamb, venison)	0.2-0.6	0.7	0.8	0.4-0.7
Salting or marinating meat and fish	No data	0.5	No data	0.9-1.0

Radiocaesium activity concentrations can be reduced by 20% to 50% (reduction factor of 1.25 to 2) after boiling meat from mammals (cow, pig, sheep, deer, rabbit), birds and fish. After soaking in salt solution, radiocaesium and radiostrontium contamination of meat may both be reduced by more than 80% (reduction factor of 5), although the effectiveness may be as low as 10% for radiocaesium (7).

Delay times, processing times and storage times

The table below shows the average length of time that elapses between the harvesting or collection of a foodstuff and its consumption by a typical individual (3).

Products	Average delay, days
Dairy	
Condensed milk	270
Skimmed milk powder	180
Pasteurised cream	5
Yoghurt	6
Butter	14
Hard cheese (cheddar)	195
Ice cream	30
Wheat	
Bread, flour or cakes	210
Breakfast cereals	240
Cereals other than wheat	
Barley and beer	270
Oats	210

15. Processing and storage (commercial)

	Potatoes	
	Fresh new potatoes	3
	Fresh main crop potatoes	165
	Frozen potato products	365
	Crisps and potato snacks	270
	Canned potatoes	540
	Other root vegetables	
	Fresh carrots	7
	Fresh onions	40
	Fresh leeks	4
	Fresh turnips, swedes, parsnips	5
	Frozen vegetables	60
	Canned vegetables	180
	Leafy green vegetables	
	Fresh cauliflower, cabbage, Brussel sprouts	5
	Fresh leafy salads	3
	Legumes	
	Fresh peas and beans	3
	Canned peas and beans	180
	Frozen peas and beans	90
	Dried peas and beans	365
	Fruit	
	Fresh apples and pears	90
	Fresh strawberries, raspberries, blackberries	4
	Fresh gooseberries and currents	6
	Fresh rhubarb	4
	Frozen soft fruit	180
	Sugar	270
	Honey	180
	Eggs	6
	Meat	

<table>
<tr><th colspan="2">15. Processing and storage (commercial)</th></tr>
<tr><td></td><td>
<table>
<tr><td>Fresh chicken</td><td>4</td></tr>
<tr><td>Fresh beef</td><td>16</td></tr>
<tr><td>Fresh pork</td><td>7</td></tr>
<tr><td>Fresh lamb</td><td>9</td></tr>
<tr><td>Bacon</td><td>21</td></tr>
<tr><td>Frozen chicken, beef and pork</td><td>90</td></tr>
<tr><td>Fish</td><td></td></tr>
<tr><td>Fresh or smoked marine fish</td><td>8</td></tr>
<tr><td>Frozen fish</td><td>90</td></tr>
<tr><td>Fresh shellfish</td><td>7</td></tr>
</table>
</td></tr>
<tr><td>Technical factors influencing effectiveness of protective action</td><td>Mode of contamination (direct deposition, root uptake, ingestion and so on).
Interval between deposition and time of collection for processing.
Half-life of radionuclides involved.
Whether boiling and blanching, or marinating fluids have been discarded or re-used in another part of the cooking process.
The length of time that elapses between the harvesting of a foodstuff and its consumption is influenced by a number of factors including:
perishability of the foodstuff and availability of preservation techniques
storage between harvest and processing
duration of manufacturing process and packaging
storage after processing and before sale
storage at retail outlet
storage at home</td></tr>
<tr><td colspan="2">Resourcing</td></tr>
<tr><td>Specific equipment</td><td>Existing equipment – there may be limited availability as it may be in use all year. There may also be reluctance by the processor to accept contaminated produce.</td></tr>
<tr><td>Ancillary equipment</td><td>Equipment for monitoring products.</td></tr>
<tr><td>Utilities and infrastructure</td><td>Additional cleaning of production equipment.
Sampling and data analysis.
Certification of products.</td></tr>
<tr><td>Consumables</td><td>Existing products, for example, brine, marinades.
Consumables that may be used to decontaminate equipment.</td></tr>
</table>

15. Processing and storage (commercial)	
Skills	Processing foodstuffs is an existing practice, so the necessary skill should be available. Knowledge of appropriate storage times for different foods and half-life of radionuclides will be required.
Work rates and operator time	Standard processes with typical work rates, unless additional PPE is required which would reduce work rate. • time required for the monitoring of products • time required to decontaminate equipment
Waste	
Type	Boiling and blanching solutions, marinated fluids. Milk products, for example, milk powder Amount and type depend on foodstuffs being dealt with and preparation carried out prior to storage.
Transport	Marinated fluids and milks can be transported via tankers. Typical articulated tanker maximum volume 30,000 litres.
Treatment	None identified.
Storage	Liquids: tanks (temporary) or at point of generation stored in bunded areas. Consider decay storage of milk powder. The relevant environment agency must be consulted on any of these options as they may be considered radioactive substances activities which require permits.
Disposal	Options for marinated fluids include: 1. Anaerobic digestion with disposal to landfill 2. Solidify and send to landfill (hazardous waste) 3. Small volumes may be suitable for disposal to a sewage treatment works If anaerobic digestion is selected, then the digestate by-product may need further management depending on contamination levels. If contamination levels are sufficiently low, the digestate can be made into bedding for livestock, soil amendments, and certain types of fertilizers. Dried milk can be stored and disposed of to landfill or incinerator. The relevant environment agency must be consulted on any of these options as they may be considered radioactive substances activities which require permits.
Pathways of exposure to implementers and the public	
Exposure pathways	Doses to implementers

15. Processing and storage (commercial)	
	• external exposure at processing plants where radionuclides are concentrated in waste Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	None.
Practical experience	
	Processing of milk with a high concentration of ^{131}I during the acute phase of the Chornobyl accident into foodstuffs stored for long periods (such as butter, cheese and dried milk) ensured significant decreases of ^{131}I concentrations in these foodstuffs due to radioactive decay before their eventual consumption (5). In general, the processing of foodstuffs was widely used in areas contaminated by the Chornobyl and other radiation accidents (1, 4, 7).
Key references	
	1. Fesenko SV, Alexakhin RM, Balonov MI, Bogdevitch IM, Howard BJ, Kashparov, VA, Sanzharova NI,Panov AV, Voigt G, Zhuchenka YM (2007). 'An extended critical review of 20 years of countermeasures used in agriculture after the Chernobyl accident' Science of the Total Environment: volume 383, issues 1 to 3, pages 1 to 24 2. Green N and Wilkins BT (1995). 'Effects of processing on the radionuclide content of foods: derivation of parameter values for use in radiological assessments' National Radiological Protection Board, Chilton (UK), NRPB-M587 3. HPA (2008). 'Delay times between harvesting or collection of food products and consumption for use in radiological assessments' HPA Chilton (UK) HPA-RPD-04 4. IAEA (2006) 'Environmental consequence of the Chernobyl accident and their remediation: 20 years of experience. Report of the Chernobyl Forum Expert Group "Environment"' 5. IAEA (2010). 'Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments' IAEA Technical Report Series number 472 6. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475

15. Processing and storage (commercial)	
	7. Kashparov V, Conney S, Uchida S, Fesenko S, Krasnov V (2009). 'Food processing' In: 'Quantification of radionuclide transfers in terrestrial and freshwater environments for radiological assessments' IAEA-TECDOC-1616

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16. Product withdrawal and recall	
General	
Objective	To prevent terrestrial and aquatic foodstuffs with activity concentrations in excess of the maximum permitted levels (MPLs), from being consumed once they have entered the food supply chain.
Other benefits	May help to maintain consumer confidence in food products.
Protective action description	A product withdrawal occurs when a risk assessment indicates a public health concern relating to that product such that it must be withdrawn from the food supply chain prior to the point of sale. A product recall applies to food products that have already been purchased and are in the customer's possession. Advice is issued to the public to not consume specific products and to take appropriate action, for example to return the items to the retail outlet where they were purchased, normally for a refund. Product withdrawal and recall would normally be carried out in conjunction with other restrictions on the food supply chain (for example, through the placing of FEPA orders). Consumers should be informed effectively and accurately of the reason for the recall of the product and consideration given to those who may already have consumed affected products (that is, to avoid unnecessary anxiety and whether or not they should seek medical advice).
Target	Food supply chain including retailers. People who have purchased affected products.
Targeted radionuclides	All radionuclides.
Scale of application	Any.
Timing of application to optimise effectiveness	Early phase as soon as a risk is recognised.
Constraints	
Legal	Under general food law Regulation (EC) 178/2002 Article 19.1 places the obligation on food businesses to recall products where necessary to protect public health. Article 18.3 obliges food business operators to maintain records of the businesses to whom they supply their products. The basis for enforcement under 178/2002 is risk to health. As risk assessments tend to be subjective by nature, it is possible that the need for a recall may be challenged by the food business operator.

16. Product withdrawal and recall	
	Food businesses must also notify the competent authorities (their local Authority and the Food Standards Agency or Food Standards Scotland) and collaborate with these authorities on the action that should be taken to avoid or reduce the risks posed by the food. MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). European Regulation (Euratom) 2016/52 sets maximum permitted levels (MPLs) in food and animal feed following a nuclear emergency and it is these levels we would apply when implementing emergency orders. This will become retained law in the UK after the end of the transition period and has been amended under the EU Withdrawal Act such that the Secretary of State and devolved ministers (on advice from FSA/FSS) must bring in "measures" that prevent food and feed exceeding the MPLs from being placed on the market. In practice, these "measures" are likely to be emergency orders under FEPA85 of FSA90 although could potentially be a bespoke Statutory Instrument. See Regulation 2016/52. See also The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019 Any disposal of withdrawn or recalled items would be sought under The Environmental Permitting (England and Wales) Regulations 2016; the Environmental Authorisations (Scotland) Regulations 2018; and The Radioactive Substances Act 1993, in Northern Ireland.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Withdrawal is highly effective (up to 100%) at preventing consumption of contaminated purchased foodstuffs. Recall can be less effective when it is difficult for the recall message to reach all purchasers of affected batches (for example, supermarkets versus farmers markets). Some affected food may have been consumed.
Technical factors influencing effectiveness of protective action	Efficiency of tracking mechanisms. There may be challenges associated with widespread distribution networks (for example, overseas). The European Rapid Alert System for Food and Feed (RASFF) and the International Food Safety Authorities Network (INFOSAN) are useful resources. Methods of communication and clarity of information.

16. Product withdrawal and recall	
Resourcing	
Specific equipment	Tracking equipment.
Ancillary equipment	Containers and temporary storage facilities may be needed for recalled food.
Utilities and infrastructure	Communication infrastructure. As food recalls are relatively common, appropriate communication plans should be available. Transport facilities for collecting and storing withdrawn and recalled food.
Consumables	Dependent on communication method.
Skills	Communication.
Work rates of operator time	Time associated with: • design and implementation of communication strategy • enforcement of restrictions
Waste	
Type	Withdrawn or recalled foodstuffs including, milk, meat, eggs, cereal crops, fruit, vegetables, fish, or derived products from the processing of any of these foodstuffs.
Transport	All wastes should be covered or contained during transport using leak-proof vehicles and containers and accompanied by a commercial document. Specialist noxious waste transport contractors should be used. Consider using medical waste containers. Biodegradable wastes should be covered and transported as soon as possible. Suitable for transport via road.
Treatment	None identified.
Storage	Waste should be stored in dedicated specialist containers which prevent escape of liquids or odour. Consider refrigerated storage where there are delays in disposal. If on farm storage is pursued, the environment agencies must be consulted as this may be considered a radioactive substances activity, and require a permit.
Disposal	Preferred solution is permitted incinerator. Alternative routes include disposal to LLW permitted landfill. If incineration is selected, the bottom ash may need further management and disposal to permitted LLW landfill. Nuclear Waste

16. Product withdrawal and recall	
	Services can provide advice on the viability of these waste routes if information on waste volume and characteristics are provided. Anaerobic digestion, rendering or on farm burial for livestock may also be considered subject to guidelines from Defra and environment agencies. If anaerobic digestion is selected, then the digestate by-product may need further management depending on contamination levels. If contamination levels are sufficiently low, the digestate can be made into bedding for livestock, soil amendments, and certain types of fertilizers. The environment agencies must be consulted as these actions may be considered as radioactive substances activities and require a permit.
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure during handling and disposal of waste foodstuffs Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	Food supply chain may be impacted.
Practical experience	
	Product withdrawals and recalls are very common for non-radiological contaminants (1, 2).
Key references	
	1. FSA and FSS (2019). Guidance on food traceability, withdrawals and recalls within the UK food industry 2. FSA (2024). Food incidents, product withdrawals and recalls

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17. Protect harvested crops from deposition	
General	
Objective	To prevent or reduce contamination of crops which have been harvested prior to passage of the contaminated air mass and to protect those stored outside awaiting processing (for example, sugar beet).
Other benefits	n/a
Protective action description	Cover hay, silage (stored in clamps), fodder crops (for example, beets) and other harvested produce stored on farms with plastic sheets or waterproof tarpaulin, before arrival of the contaminated air mass.
Target	All harvested crops (cereals, fruit and vegetables) including those used for animal feed. Cost may be high and only be appropriate for high value crops.
Targeted radionuclides	All radionuclides.
Scale of application	Small to medium. Depends on the time available between notification and arrival of the plume and availability of necessary resources and materials.
Timing of application to optimise effectiveness	Short-term (pre-release). The measures are precautionary and are most effective if implemented before the contaminated air mass has arrived and should therefore be implemented as soon as the risk becomes apparent. In the event of an intermittent release, or prolonged duration release, it may still be worth considering the protection of harvested crops from additional sources of contamination. Time available for carrying out the action will vary according to weather conditions, the distance from the source of release and any advance warning of a release.
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of operators being exposed to contaminated air-masses (that is, if time was short and operators had to drive to site), The Ionising Radiations Regulations 2017, Part 1, Regulation 2. Any disposal of contaminated covering materials would be sought under The Environmental Permitting (England and Wales) Regulations 2016; the Environmental Authorisations (Scotland) Regulations 2018; and The Radioactive Substances Act 1993, in Northern Ireland.
Physical environment	Would be difficult to implement in high winds.

17. Protect harvested crops from deposition	
	Some crops may spoil if covered for prolonged periods in hot weather.
Effectiveness	
Protective action effectiveness	Depending on timing and effectiveness of the covering implemented, the action could be up to 100% effective (1).
Technical factors influencing effectiveness of protective action	Timing of covering with respect to passage of the contaminated air mass. Completeness of coverage. Availability of covering materials and means to secure them.
Resourcing	
Specific equipment	None.
Ancillary equipment	None.
Utilities and infrastructure	None.
Consumables	Plastic sheeting or waterproof tarpaulin and method of securing (for example, pegs, ropes, rocks).
Skills	Farmers would have the necessary skills.
Work rates and operator time	Depends on area to be covered and location of covering materials that may need to be fetched.
Waste	
Type	Contaminated covering materials.
Transport	Place in Isofreight container or suitable bag or drum. Suitable for transport via road.
Treatment	If going to LLWR, the material will have to be super-compacted and grouted into an Isofreight container. No specific treatment required for LLW incinerator or landfill. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Suitable propriety bin or Isofreight container stored and managed near point of generation. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Either sent to permitted LLW incinerator or landfill or LLWR.

17. Protect harvested crops from deposition	
	Existing organised routes of disposal of agricultural plastic wastes, such as silage bale wrapping, will be inappropriate where recycling is the aim of the existing schemes. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Doses to implementers (farmers): • when applying covering materials, no exposure if completed before the arrival of the contaminated air mass. Otherwise, potential for 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, suspension of dusts may occur so inhalation or ingestion can be important Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	Risk of spoilage of some crops if covered for prolonged periods.
Practical experience	
	Farmers will have experience of covering crops after harvest (for example, silage clamps) or to protect them from bad weather. No experience of implementation in accidental situations has been found.
Key reference	
	1. IAEA (1994). ‘Guidelines for agricultural countermeasures following an accidental release of radionuclides’ IAEA Technical Report Series number 363 (section 15.2)
Comments	
	Farmers may be reluctant to be outside while there is a risk of contamination. This is likely to be exacerbated if the measure coincides with advice for public sheltering or evacuation.

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18. Removal of topsoil	
General	
Objective	To reduce radionuclide uptake by plant roots, including crops, pasture, and allotment or kitchen garden produce.
Other benefits	Reduction in external dose from contaminated land. Reduction in resuspension doses.
Protective action description	**On agricultural scale** Removal of topsoil generally applies to the top 5 cm, where most of the contamination is located. On pastureland, turf is removed with the soil. On arable land any crops or plants that are present need to be removed first. A soil hardener may be used before removal of soil. The removal may be carried out using road construction equipment such as a bobcat, mini-bulldozer, hammer-knife equipment, backhoe, or mechanical digger. The type of equipment used will depend on the size of the area to be treated. Dust suppression can be achieved by water sprays. Uneven surfaces may result in some patches not being stripped - these will need to be stripped manually. Additionally, manual collection of soil and roots may be required, depending on the equipment used (for example, hammer knife mower). **On allotment or kitchen garden scale** In allotments and kitchen gardens, topsoil can be manually removed by spade and either relocated to an area of the garden not used for food production, for example, flower bed, or disposed of.
Target	Pasture or fallow arable land; areas used for domestic production such as gardens and allotments.
Targeted radionuclides	Known applicability: ^{60}Co, ^{75}Se, ^{90}Sr, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{192}Ir, ^{235}U, ^{238}Pu, ^{239}Pu, ^{241}Am. Not applicable: the relatively short physical half-lives (1 to 2 months) of the following radionuclides may preclude this protective action on an agricultural scale: ^{131}I.
Scale of application	Small to large, but the high volumes of waste produced per unit area may limit large scale application.
Timing of application to optimise effectiveness	Should be carried out as soon as possible, but significant reductions are still possible in the longer term for relatively immobile radionuclides such as ^{134}Cs, ^{137}Cs. There is a tendency for the more mobile radionuclides such as ^{90}Sr to move down the soil profile with time.

18. Removal of topsoil	
Constraints	
Legal	The Codes of Good Agricultural Practice should be followed. Parts of this Code of Good Agricultural Practice form a Statutory Code under Section 97 of the Water Resources Act 1991. Topsoil removal may be restricted at farms participating in environmental stewardship schemes or in areas designated within nitrate vulnerable zones (NVZs). A consent from the relevant organisations may be required if topsoil removal is to be carried out in an area with certain designations a (for example, sites of special scientific, conservation or archaeological interest). A consent from, for example, Natural England, will be required if a change in land use is to be carried out in an area designated a site of special scientific interest (SSSIs) in England, Scotland and Wales or an area of special scientific interest (ASSIs) in Northern Ireland. The notification of SSSIs is made under the Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way Act 2000 in England and Wales). Special areas of conservation (SACs) and special protection areas (SPAs) are European sites covered by The Conservation of Habitats and Species Regulations 2017 and would require a habitats regulations assessment. Waste disposal of collected radioactive waste, especially relevant as there is a risk of generating very large volumes of waste materials, would be covered by The Environmental Permitting (England and Wales) Regulations 2016. Scotland – the Environmental Authorisations (Scotland) Regulations 2018. Northern Ireland – The Radioactive Substances Act 1993.
Physical environment	Topsoil removal may be difficult on soils that are shallow, stony and unstructured. Not applicable if crop is present. Heavy equipment may break furrows. Fields need to have compact soil with sufficient weight bearing capacity for the equipment used. It can be difficult to use large machinery on wet, peaty soils. Heavy clay soils also present a challenge. On uneven surfaces, manual stripping may be required in addition to mechanical removal. It may not be possible to remove frozen topsoil.

18. Removal of topsoil	
Effectiveness	
Protective action effectiveness	The DF (decontamination factor) for soil can range 10 to 100 (90% to 99% reduction), if optimised according to the contaminant distribution in the soil profile. Furthermore, the reduction factors (RF) for soil-to-plant transfer can be in the range 10 to 20 (90% to 95% reduction) (3). Topsoil removal on agricultural land affected by Fukushima accident reduced caesium in soil with reported DFs of 4 to 33 (75 to 97% reduction) (2). Topsoil removal in Japan reduced Cs concentrations in the remaining soil with a DF of 5 (80% reduction) (6). Reduction factors of 5 to 15 (80% to 93% reduction) for ^{90}Sr transfer to crops were noted after topsoil removal from land affected by the Kyshtym accident (3).
Technical factors influencing effectiveness of protective action	Depth of topsoil removed. Application in the field may result in greater or shallower depths being removed. For example, in Japanese trials, typically 5 to 7 cm was removed rather than the planned 3 to 5 cm (5). This has implications for the volumes of waste generated. Identification of hotspots where removal of greater soil depths may be required. Vertical radionuclide distribution. Soil texture and moisture content. Soil unevenness and the presence of vertical cracks in the soil. Vegetation cover Operator skill. Time between deposition and implementation (for downward migration).
Resourcing	
Specific equipment	**On agricultural scale** Bobcat mini bulldozer or bulldozer, hammer-knife mower, backhoe, or mechanical digger. **On allotment or kitchen garden scale** Typical garden equipment (for example, spade).
Ancillary equipment	**On agricultural scale** Vehicle to transport contaminated topsoil. **On allotment or kitchen garden scale** Wheelbarrow.

18. Removal of topsoil	
Utilities and infrastructure	Suitable disposal site. Roads to transport waste.
Consumables	Fuel for bobcat or other equipment. Respiratory protection if soil is dry.
Skills	**On agricultural scale** Can be carried out by already skilled operators such as municipal workers and additional operators could be instructed within a day. **On allotment or kitchen garden scale** None: can be implemented as 'self-help' measure. Possible need for radiation protection training of workers.
Work rates and operator time	When applied on an agricultural scale, typically, up to 50 to 100 h/ha, including loading to waste transport truck, but excluding waste transport and work at repository.
Waste	
Type	Removal of 5 cm of topsoil from 1 ha of farmland generates 60 to 70 kg/m of waste. The volume of waste is approximately 500 m^3 and the mass is approximately 700 to 1,000 tonnes.
Transport	Suitable for transport via road or for large volumes it may be most efficient to consider transport via rail (ONR and Nuclear Transport Solutions can advise). Can be transported in dumpy bags or conventional skips, for large volumes consider roll on roll off skips. Use sealed 'hook and drop' style truck mounted containers for moving soils to a treatment site
Treatment	Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. Not suitable for compaction. May also consider backwashing prior to disposal to landfill if liquid wastes can be managed appropriately. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Where possible waste should be stored in bags or containers on hardstanding which allows the separation and collection of run off. Tarpaulins should be used to minimise rainfall infiltration. If disposal to LLWR is needed, dumpy bags should be loaded into an Isofreight container.

18. Removal of topsoil	
	Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Permitted LLW landfill (mainly non-hazardous waste), or LLWR can be considered dependent on waste properties. Nuclear Waste Services (and radioactive waste advisers) can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Operative removing soil on an agricultural scale: • external exposure from contamination in topsoil • inadvertent ingestion of contaminated soil • inhalation of resuspended soil Members of the public, as a self-help action: • external exposure from contamination in topsoil • inadvertent ingestion of contaminated soil • inhalation of resuspended soil
Impact of protective action	
Environmental impact	Risk of soil erosion due to disruption of soil structure. Impact on soil biota and associated decomposition processes. Possible loss of biodiversity and changes in landscape. Potential for large volumes of waste to be generated.
Agricultural impact	Disruption to farming. Soil fertility may be affected by the loss of top 5 cm of soil. Topsoil may need to be replaced and additional fertilisation may be required. The underlying soil may be compacted with implications for subsequent cultivation. Vegetation needs to be re-established.
Practical experience	
	Used on agricultural land in: USSR following Mayak accident in 1957 (small scale). USSR following the Chornobyl accident in 1986 (small scale).

18. Removal of topsoil	
	Brazil following the Goiânia incident in 1987 (1). Spain following Palomares incident in 1966 (small scale). Japan following the Fukushima accident in 2011 (wide scale) (4).
Key references	
	1. IAEA (1988). 'The radiological accident in Goiânia' STI/PUB/815 ISBN 92-0-129088-8 2. IAEA (2011). 'Final report of the international mission on remediation of large, contaminated areas off-site the Fukushima Dai-ichi NPP 7-15 October 2011, Japan' IAEA NE/NEFW/2011 15 November 2011 3. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 4. Ministry of the Environment, Japan (2013). Decontamination guidelines, second edition 5. Nakano M. and Yong RN (2013). 'Overview of rehabilitation schemes for farmlands contaminated with radioactive cesium released from Fukushima power plant' Engineering Geology: volume 155, pages 87 to 93 6. Yamaguchi N, Taniyama I, Kimura T, Yoshioka K and Saito M (2016) 'Contamination of agricultural products and soils with radiocesium derived from the accident at TEPCO Fukushima Daiichi Nuclear Power Station: monitoring, case studies and countermeasures' Soil Science and Plant Nutrition: volume 62, issue 3, pages 303 to 314
Comments	
	Topsoil removal would not be justified for short-lived nuclides. Cost may be high, considering; equipment; personnel; size of the affected area and volume of topsoil requiring disposal.

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19. Restrict hunting and fishing	
General	
Objective	To reduce ingestion doses from consumption of contaminated meat and fish by restricting hunting or fishing to certain times within the usual seasons when activity concentrations in these animals are low.
Other benefits	By restricting hunting and fishing to certain times, rather than prohibiting entirely, traditional hunting for game can be preserved and the amount of condemned meat will be reduced.
Protective action description	Hunting and fishing (coarse or salmon species) are typically restricted to certain periods of the year. At other times during the so-called 'closed season' it is illegal to shoot game or go fishing. The closed season for hunting and fishing varies with species and location. By altering the dates of the closed season, the protective action further restricts hunting or fishing to the times of year when contamination levels in the game meat and fish are at their lowest. This reduces the doses to people from consuming contaminated game meat and fish. Activity concentrations of some radionuclides in game and fish can vary significantly by season and so a targeted monitoring programme is required to optimise the protective action. For example, activity concentrations of radiocaesium in the muscle of game from areas where fungi can be abundant in certain years can be much higher than the average annual values (3, 7). In the short term, a ban on or a delay in hunting may be appropriate while animals ingest plants with high levels of surface deposition on and to allow decay of short-lived radionuclides. It is possible that the length of the hunting or fishing season may be significantly reduced or cancelled completely for one or more years.
Target	Hunting of waterfowl or wildfowl (for example, ducks, geese), game fowl (strains of domestic fowl), ground game (for example, rabbits, hares), or deer by farmers, landowners, gamekeepers, hunters and poachers. Hunting as sport could continue as long as the prey is kept out of the food chain. Fishing of salmon family (for example, salmon, trout, char) and other freshwater fish (coarse fish) (for example, pike, perch, tench). Competition angling, complying with 'catch and release', does not pose a risk.
Targeted radionuclides	All radionuclides, especially radiocaesium in long term.
Scale of application	Small to large scale.
Timing of application to optimise effectiveness	Short-long term. Restrictions may consist of shortening or changing of the time of the hunting or fishing season for a number of years.

19. Restrict hunting and fishing	
	In some cases, it may be necessary to cancel the seasons altogether for one or more years.
Constraints	
Legal	The Food and Environment Protection Act 1985 (2) may be used to protect the public from exposure to potentially contaminated food. A FEPA order issued under this act typically applies to all forms of agricultural production, but there are also provisions for wild foods, including the hunting of wild game and fish. Similar powers are available in other legislation, such as emergency control orders under the Food Safety Act 1990 and may be more appropriate in certain situations. **Fishing** Salmon and Freshwater Fisheries Act 1975. Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003 sets out coarse fish close season and makes provision for this to be altered or dispensed with through fisheries byelaws. Byelaws are the statutory rules and regulations that are put in place to prevent damage to fish stocks from insensitive fishing methods and to make sure that fisheries are sustainable for the enjoyment of current and future generations of anglers. The byelaws apply to all types of fisheries, be they owned by angling clubs, local authorities or private individuals. The coarse fish close season applies to all rivers and streams in England and Wales and all waters in the Specified Sites of Special Scientific Interest. It does not apply to most still waters and/or canals. Fishery owners and angling clubs are free to introduce a close season through club or fishery rules if they wish to. There is no legal close season for marine species caught in UK waters. **Hunting** The Wildlife and Countryside Act 1981, Wildlife and Countryside (Amendment) Act 1991, The Wildlife (Amendment) (Northern Ireland) Order 1995 and Wildlife and Countryside Act 1981 (Amendment) (Wales) Regulations 2004: protection of wildlife in the UK, including specific Wildfowl and Waterfowl species during closed season. The Game Act 1831 and Game Act 1970: protection of specific game birds during closed season in England and Wales. The Game (Scotland) Act 1832: protection of specific game birds during closed season in Scotland. Game Preservation (Amendment) Act (Northern Ireland) 2002: protection of specific game species during closed season. Ground Game Act 1880 and Ground Game (Amendment) Act 1906: rights of landowners to take

19. Restrict hunting and fishing	
	game. Firearm and Game hunting licences are legal requirements for hunting.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Will effectively reduce consumption of contaminated meat of hunted species and freshwater fish. The effects of restrictions on fishing for freshwater fish following Mayak PA plant discharges have been assessed (1). Varying hunting times can achieve a 50% to 70% reduction (reduction factor of 2 to 3) in radiocaesium activity concentrations in moose meat, with even higher reductions of up to 80% (reduction factor up to a factor of 5) in meat from roe deer and wild boar (6).
Technical factors influencing effectiveness of protective action	Success of communicating information regarding the restrictions to hunters or anglers. Individual willingness to submit to restrictions. Availability of more highly contaminated foodstuffs (for example, mushrooms) to game before and during hunting (varies by year, time of hunting and location). Ability to predict times during the season when the contamination levels in the meat or fish would be below intervention levels. The hunting of rabbits, hares and pigeons is not restricted to seasonal hunting and may be hunted at any time of the year. Furthermore, there is no legal closed season for marine species caught in UK waters. Thus, control over the hunting or fishing of these species may be more difficult. Availability of monitoring capability if restrictions are prolonged and/or extensive.
Resourcing	
Specific equipment	Signage and information boards. Monitoring equipment for authorities.
Ancillary equipment	Monitoring equipment for authorities to check levels of contamination in game and fish species. Typical hunting or fishing equipment if separate population management programme is required. Surveying equipment (for example, electrofishing techniques) to establish fish populations.
Utilities and infrastructure	Communication infrastructure (for example, internet and telephone) to inform affected communities about restrictions.
Consumables	Dependent on communication method (for example, leaflets and signage).

19. Restrict hunting and fishing	
Skills	Communication skills.
Work rates and operator time	Time associated with: • design and implementation of communications • erection of signs in relevant areas • targeted monitoring programme
Waste	
Type	Waste in the form of contaminated carcasses would arise if separate population management programmes were required
Transport	Carcasses should be covered and contained during transport using leak-proof vehicles and containers. Specialist noxious waste transport contractors should be used. Can be transported via road.
Treatment	None identified.
Storage	Carcasses should be stored in dedicated specialist containers which prevent escape of liquids or odour. Refrigerated storage should be considered where there are delays in disposal. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Preferred solution is a permitted incinerator. Alternative routes include disposal to LLW permitted landfill. If incineration is selected the bottom ash may need further management and disposal to permitted LLW landfill. Nuclear Waste Services (and radiation waste advisers) can provide advice on the viability of these waste routes if information on waste volume and characteristics are provided. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure while erecting signs and information boards in affected areas (likely to be minimal) • external exposure while carrying out monitoring in the affected area • external exposure while implementing separate population management programmes, if applicable Members of the public: none.

19. Restrict hunting and fishing	
Impact of protective action	
Environmental impact	Hunting or fishing seasons help manage populations and the environment. If contamination levels in the species were such that the overall length of the hunting or fishing season was significantly reduced or completely cancelled in a year, then a separate management programme may have to be introduced to preserve the stability of the ecosystem. For example, culling species normally hunted if overpopulated or removing fish from waters if overstocked (where the resulting meat or fish would require appropriate disposal). The Environment Agency carries out regular surveys on principal rivers to determine fish populations in England (SEPA does not routinely do this in Scotland but District Salmon Boards and/or charitable Fisheries Trusts may undertake such surveys on a more regular basis). If the fishing season had to be reduced significantly or stopped completely then data from these surveys could play an important part in establishing whether a management programme is required.
Agricultural impact	May cause an increase in the numbers of herbivores which may have impact on grassland, forestry and other environments, including agricultural lands potentially. Increase in predator numbers may impact farm animal husbandry.
Practical experience	
	Hunting and fishing restrictions (or changes to normal practices) were applied in several countries of the former Soviet Union (4, 8) and further afield in game animals, for example, Norway and Sweden following the Chornobyl accident (3, 7). Hunting practices were altered, and fishing restricted in parts of Japan following the Fukushima accident (5).
Key references	
	1. Cabianca T, Bexon AP, Pozolotina V, Trapeznikov A, and Simmonds J (2000). ‘Preliminary assessment of current radiation doses to the population of Brodokalmak from contamination of the Techa River’ Journal of Environmental Radioactivity: volume 50, pages 193 to 206 2. Food and Environment Protection Act 1985 3. Hove K, Pedersen O, Garmo TH, Hansen HS, Staaland H (1990). ‘Fungi: a major source of radiocaesium contamination of

19. Restrict hunting and fishing	
	grazing ruminants in Norway' Health Physics: volume 59, pages 189 to 192 4. IAEA (2006). 'Environmental consequence of the Chernobyl accident and their remediation: 20 years of experience' Report of the Chernobyl Forum Expert Group 'Environment' 5. IAEA (2011). 'Final Report of the International mission on remediation of large, contaminated areas off-site the Fukushima Dai-ichi NPP 7 to 15 October 2011, Japan' IAEA NE/NEFW/2011, 15 November 2011 6. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' Technical Report Series number 475 7. Johanson KJ (1994). 'Radiocaesium in game animals in the Nordic countries' (Dahlgaard H (editor)) In: 'Nordic radioecology: the transfer of radionuclides through Nordic ecosystems to man' Studies in Environmental Science: volume 62, pages 287 to 301 8. Nesterenko AV and Nesterenko VB (2009) 'Protective measures for activities in Chernobyl's radioactively contaminated territories' Annals of the New York Academy of Sciences: volume 1,181, 'Chapter IV. Radiation protection after the Chernobyl catastrophe', pages 311 to 317
Comments	
	If hunting occurs earlier in the year than usual, this may result in lower slaughter weights. If hunting takes place in summer, hygiene problems in handling of meat are more likely. If restricted to winter, hunting less attractive. Closed seasons exist to allow time for breeding and for populations to recover from previous hunting or fishing seasons. Restrictions under the Food and Environment Protection Act 1985 that fall entirely within a closed season should not be required as hunting and fishing is already prohibited. The British Association for Shooting and Conservation provides details of the timings of closed seasons. The Environment Agency provides details of closed seasons for coarse fishing in England.

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20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
General	
Objective	To prevent terrestrial and aquatic foodstuffs with activity concentrations in excess of the maximum permitted levels (MPLs), from entering the food supply chain.
Other benefits	May help to maintain consumer confidence in food products from affected areas and sustain economic value of produce.
Protective action description	The Food and Environment Protection Act 1985 (FEPA) authorises the making of emergency orders to prohibit agricultural or fishing activities such as harvesting, movement, sale, preparation, and processing of food required to protect consumers from risks associated with contaminated foodstuffs. Maximum permitted levels of radionuclides in food and animal feed as specified by UK legislation in retained European Union regulations are used to guide the placing of FEPA orders. These orders are imposed by the Food Standards Agency in as little as 24 to 48 hours of a radiation emergency and can make use of modelling and measurement data. These restrictions can be in place for many years. A FEPA order may impose an outright ban on certain activities such as the movement and sale of affected products and livestock from the designated area. However, particularly if controls are applied for a longer period, FEPA gives powers to the Food Standards Agency (FSA) and Food Standards Scotland (FSS) to issue ‘consents’ that permit otherwise prohibited activities provided any conditions as specified by FSA or FSS are met, for example to permit the placing of food on the market where monitoring shows the levels in the product are below the MPLs. Similar powers are available in other legislation, such as emergency control orders under the Food Safety Act 1990 and may be more appropriate in certain situations.
Target	All commercially produced foodstuffs. Predominantly milk, meat, marine and aquatic fish, and other seafood, as well as crops (cereals, fruit and vegetables). Also applicable to derived products from the processing of foodstuffs. All foodstuffs gathered from the wild, including berries, herbs, edible flowers, aquatic plants, nuts, mushrooms, and honey.
Targeted radionuclides	All radionuclides.
Scale of application	Small to large. Food restrictions may extend hundreds of kilometres.

20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
Timing of application to optimise effectiveness	This option should be considered as soon as a risk is recognised. The placing of a FEPA order may be preceded by precautionary food advice while legislation is drafted and made. Restrictions can be applied where there is a reasonable assumption of a hazard to human health, for example based on modelling predictions of radionuclides in foodstuffs.
Constraints	
Legal	MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019) The Food and Environment Protection Act 1985 may be used to protect the public from exposure to potentially contaminated food, using the MPLs as outlined above. The Act gives the Secretary of State and devolved ministers (on advice from the Food Standards Agency or Food Standards Scotland) the powers to make emergency orders (FEPA orders). These FEPA orders will define a designated area and specify activities which may be prohibited in respect to this area. For example, the Order can make it an offence to supply (for example, sell) food, or anything from which food can be produced (for example, animals), that has originated in the designated area. It can also make it an offence to prepare or process food from the designated area. The full list of prohibitions which are available are listed in Schedule 1 of the Act. A FEPA order issued under this act typically applies to all forms of agricultural production, but there are also provisions for the gathering of wild foods (foraging). Such orders may prohibit the gathering or picking of wild plants or the movement, preparation and processing for supply of food or food products from within a designated area. This can also prevent people moving food from an allotment. The FSA believes that providing advice to the public would be the most effective route to achieve these aims. This would be at least as effective as legislation. Once a FEPA order is in place, FSA and FSS may issue ‘consents’ to permit otherwise prohibited activities where FSA or FSS are satisfied that food or animal feed is safe. Similar powers are available in other legislation, such as emergency control orders under the Food Safety Act 1990 and may be more appropriate in certain situations. The Food Safety Act 1990 gives the Secretary of State and devolved ministers (on advice from FSA/FSS) the powers to make emergency control orders. These orders can prohibit “commercial operations with respect to food, food sources or

20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
	contact materials of any class or description involves or may involve imminent risk of injury to health. See the Food Safety Act 1990. Any disposal of contaminated items would be sought under The Environmental Permitting (England and Wales) Regulations 2016; the Environmental Authorisations (Scotland) Regulations 2018; and The Radioactive Substances Act 1993, in Northern Ireland.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Highly effective (up to 100%) at preventing commercial foodstuffs containing radionuclides above MPLs from entering the food supply chain. The level of compliance relating to restrictions on the gathering of foods from the wild (foraging) may be difficult to monitor and full compliance may be difficult to achieve. Most effective if gatherers and locations of wild or free foods are known in community. Furthermore, the placing of FEPA orders does not prevent food products with activity concentrations below the MPLs from entering the food chain, and as a consequence, ingestion doses will not be zero.
Technical factors influencing effectiveness of protective action	Timing of the placing of FEPA orders. Extent of the FEPA order; it may be difficult to identify all sites which are used for foraging. Requirement to establish a monitoring and surveillance programme. Success of communicating the restrictions to gatherers. It is likely to be harder to 'police' occasional free food consumers than regular consumers who are known amongst the local community.
Resourcing	
Specific equipment	None for restrictions on commercial foodstuffs. Signage, information boards, leaflets for the gatherers of food from the wild.
Ancillary equipment	None.
Utilities and infrastructure	Sampling and monitoring programmes to confirm boundaries of restricted areas. Radiochemical laboratories with alpha, beta and gamma spectrometry. Enforcement personnel. Communication infrastructure (for example, internet, telephone, leaflet production) to inform affected communities about restrictions on foraging.
Consumables	Dependent on communication method (for example, leaflets and signage).

20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
Skills	Sampling, monitoring and analysis. Communication.
Work rates and operator time	Time associated with: • sourcing alternative sources of food • design and implementation of communications, including leaflets • erection of signs in areas known to be used by gatherers of wild foods • distribution of leaflets • enforcement of restrictions
Waste	
Type	Restricted foodstuffs. However, the implementation of additional protective actions in the restricted areas can significantly reduce the range and volume of foodstuffs requiring disposal.
Transport	All wastes should be covered or contained during transport using leak-proof vehicles and containers (consider using medical waste containers). Specialist noxious waste transport contractors should be used. Biodegradable wastes should be covered and transported as soon as possible. Suitable for transport via road.
Treatment	Consider lime stabilisation.
Storage	Waste should be stored in dedicated specialist containers which prevent escape of liquids or odour. Consider refrigerated storage where there are delays in disposal. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Preferred solution – permitted incinerator. Alternative routes - disposal to LLW permitted landfill. If incineration is selected the bottom ash may need further management and disposal to permitted LLW landfill. Nuclear Waste Services (and radiation waste advisers) can provide advice on the viability of these waste routes if information on waste volume and characteristics are provided. Anaerobic digestion, rendering or on farm burial for animals may also be considered within Defra and environment agencies guidelines. If anaerobic digestion is selected, then the digestate by-product may need further management depending on contamination levels. If contamination levels are sufficiently low, the digestate can be made

20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
	into bedding for livestock, soil amendments, and certain types of fertilizers. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure while carrying out monitoring in the affected area • external exposure while erecting signs and information boards in affected areas • external exposure during handling and disposal of waste foodstuffs Members of the public: none.
Impact of protective action	
Environmental impact	Potential positive ecological effects, for example, greater abundance or diversity due to cessation of large-scale fungi or berry collections, conservation of habitats and increased nutrient availability resulting from increased decomposition.
Agricultural impact	Food supply chain may be impacted.
Practical experience	
	Following the Windscale Fire (1957), restrictions on milk were imposed in an area of around 500 km^2 for 25 days after the accident. At that time the intervention level for milk was 3,700 Bq/l. All milk from the restricted area was collected and dumped (3 million litres) (5). Condemnation of meat occurred in the former Soviet Union and Norway following the Chornobyl accident. In Norway condemned meat was used as feed for fur animals (9). Bans on consumption and on the sale of freshwater fish were applied in many water bodies affected by the Chornobyl accident (8). Following the Fukushima accident, the Japanese government stopped the distribution and sale of contaminated food from Fukushima prefecture and surrounding areas. Food restrictions have been essential in ensuring low internal dose during the first 2 years after the accident (1, 4). Restrictions on access to forests and gathering forest foods were applied in several countries of the former Soviet Union following the Chornobyl accident (2). Studies show that in Belarus, activity concentrations in contaminated forest products (for example, wild

20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
	berries and mushrooms) exceeded those in domestic agricultural products and were more persistent over time (7). Harvesting of foods (mainly berries and mushrooms) by the public in some forest areas in Japan was restricted following the Fukushima accident (3). Efforts to monitor radiocaesium in locally produced foods (including wild foods) in one town are described in a paper by Kunii and others (6). The requirement for monitoring sheep in the UK under the Mark and Release Scheme following Chornobyl was underpinned by FEPA orders.
Key references	
	1. Hamada N, Ogino H (2012). 'Food safety regulations: what we learned from the Fukushima nuclear accident' Journal of Environmental Radioactivity: volume 111, pages 83 to 99 2. IAEA (2006). 'Environmental consequence of the Chernobyl accident and their remediation: twenty years of experience' Report of the Chernobyl Forum Expert Group 'Environment' 3. IAEA (2011). 'Final Report of the International mission on remediation of large, contaminated areas off-site the Fukushima Dai-ichi' NPP 7-15 October 2011, Japan' IAEA NE/NEFW/2011 15 November 2011 4. IAEA (2014). 'The follow-up IAEA International Mission on remediation of large, contaminated areas off-site the Fukushima Daiichi Nuclear Power Plant, Tokyo and Fukushima Prefecture, Japan, 14 to 21 October 2013' IAEA NE/NEFW/2013 23 January 2014 5. Jackson D and Jones SR (1991). 'Reappraisal of environmental countermeasures to protect members of the public following the Windscale nuclear reactor accident, 1957' (EUR-13574(V2)). Commission of the European Communities (CEC) 6. Kunii N, Fujimura M, Komasa Y, Kitamura A, Sato H, Takatsuji T, Jimba M and Kimura S (2018). 'The knowledge and awareness for radiocaesium food monitoring after the Fukushima Daiichi nuclear accident in Nihonmatsu City, Fukushima Prefecture' International Journal of Environmental Research and Public Health: volume 15, page 2,289 7. Nesterenko AV and Nesterenko VB (2009). 'Protective measures for activities in Chernobyl's radioactively contaminated territories' Annals of the New York Academy of Sciences: volume 1,181,

20. Restrictions on terrestrial and aquatic foods (FEPA orders)	
	‘Chapter IV. Radiation protection after the Chernobyl catastrophe’, pages 311 to 317 8. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). ‘A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs’ Journal of Environmental Radioactivity: volume 56, issues 1 and 2, page 11 to 32 9. Tveten U, Brynildsen LI, Amundsen I and Bergan T (1998). ‘Economic consequences of the Chernobyl accident in Norway in the decade 1986 to 1995’ Journal of Environmental Radioactivity: volume 41, issue 3, pages 233 to 255

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21. Select alternative land use (non-edible products)	
General	
Objective	To allow agricultural land to be used for other gainful activities, for example by selecting crops or animals for the production of non-edible products.
Other benefits	Keeps land in production and provides income to farmer.
Protective action description	Contaminated land may be used for non-food production, such as flax for fibre; rapeseed for biodiesel; sugar beet for bioethanol; perennial grasses or coppice for biofuel. Agricultural land may also be used for the production of leather and wool. In extreme situations land may be used for forestry or given over to recreational use (for example, golf courses). The ease of substitution of non-edible crops for farmers and associated industries needs to be considered when selecting this option.
Target	Pasture or arable land.
Targeted radionuclides	Known applicability: ^{134}Cs, ^{137}Cs. Probable applicability: ^{60}Co, ^{90}Sr. Not applicable: The relatively short physical half-lives of the following radionuclides may preclude this radical protective action: ^{75}Se, ^{131}I, ^{192}Ir. Low soil-to-plant or feed-to-meat or milk transfer may also mean that radical protective actions are inappropriate for: ^{106}Ru ^{235}U, $^{238,239}Pu$, ^{239}Pu, ^{241}Am.
Scale of application	Small to large.
Timing of application to optimise effectiveness	Long-term. Unlikely to be an option applicable to the short and intermediate phase after an accident. Nevertheless, it could be considered as a longer-term option for land that must be taken out of food production due to high levels of contamination over a prolonged period. It takes time to organise and is a radical option that is likely to need financial support or compensation. Change in land use may be expected to endure for number of years depending on the radioactive half-lives and mobility of the radionuclides present.
Constraints	
Legal	In England and Wales, The Codes of Good Agricultural Practice should also be followed. Parts of this Code of Good Agricultural Practice form a Statutory Code under Section 97 of the Water Resources Act 1991.

21. Select alternative land use (non-edible products)	
	Change in land use may be restricted at farms participating in environmental stewardship schemes or in areas designated within nitrate vulnerable zones (NVZs). However, grants may be available for the creation of new woodland on agricultural land and farms under some programmes. A consent from the relevant organisations may be required if a change in land use is to be carried out in an area with certain designations (for example, sites of special scientific, conservation or archaeological interest). A consent from, for example, Natural England, will be required if a change in land use is to be carried out in an area designated a site of special scientific interest (SSSIs) in England, Scotland and Wales or an area of special scientific interest (ASSIs) in Northern Ireland. The notification of SSSIs is made under the Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way Act 2000 in England and Wales). Special areas of conservation (SACs) and special protection areas (SPAs) are European sites covered by The Conservation of Habitats and Species Regulations 2017 and would require a habitats regulations assessment.
Physical environment	The agricultural limitations of the affected land - this will determine the non-food crops and practices that the land can support.
Effectiveness	
Protective action effectiveness	This action does not directly remove contamination from the soil but can be effective at reducing or removing the ingestion exposure pathway for consumers. Depending on the alternative land use chosen, other exposure pathways may be introduced for those producing or using the alternative crop or animal products.
Technical factors influencing effectiveness of protective action	Expertise in cultivation for alternative practices, for example, growing alternative crops or supporting different livestock. Suitability of soil type, drainage and so on, for growing or supporting alternative products Availability of seed stock of alternative crops; alternative animals. Wider access to other food-sources to replace lost supply.
Resourcing	
Specific equipment	Equipment required for alternative practice, for example sowing and harvesting equipment for alternative crop type. Investment may be required for specialist equipment.

21. Select alternative land use (non-edible products)	
Ancillary equipment	Ancillary equipment required for alternative practice.
Utilities and infrastructure	Processing facilities for chosen crop or animal product. Transportation of crop or livestock to processing plant.
Consumables	Seed stock of alternative crop (availability may be limited). Stock of alternative livestock.
Skills	Expertise in alternative practices, for example growing alternative crops or supporting different livestock.
Work rates and operator time	Variable, depending on pre-existing and new land uses. Additional work or labour is likely to be required for transition to new practice, for example preparation of land and associated facilities.
Waste	
Type	There may be contaminated by-products depending on type of alternative land use selected, for example from refining of rapeseed and sugar beet
Transport	Transport to appropriate facilities for processing by-products, if necessary.
Treatment	On-site treatment plants or sewage treatment works for processing by-products.
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Variable, depending on alternative practices. There may be a redistribution of dose from consumers to those involved in producing alternative crops or animal products. Pathways could include: Farmer: • external exposure from working on contaminated land Driver: • external exposure while transporting crops or livestock for processing Processing plant operative: • external exposure to non-food crop at processing plant (depending on degree of automation) Operative at wood burning power plants (from coppice): • external exposure to the fly-ash Members of the public: none.

21. Select alternative land use (non-edible products)	
Impact of protective action	
Environmental impact	Change in ecosystem, for example, possible loss of biodiversity depending on pre-existing and new land uses.
Agricultural impact	Change in crop type and associated fertiliser requirements, nutrient cycling. In communities affected by overproduction, the associated diversification may be advantageous. Availability of market and demand for selected alternative products. Alternative practices may not be as economically viable or profitable as those used previously.
Practical experience	
	Alternative practices can be selected from existing commercial processes (2, 3). Selection of alternative land use (and others, arable land into meadows; agricultural land to forestry; rapeseed production in Belarus) was used in the former USSR following both the Chornobyl and Kyshtym accidents (1).
Key references	
	1. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 2. Vandenhove H (1999). 'Relevancy of short rotation coppice vegetation for the remediation of contaminated areas. Project F14-CT95-0021c (PL 960 386)' Co-funded by the Nuclear Fission Safety Programme of the European Commission. RECOVER final report 99, BLG 826. SCK.CEN, Mol, Belgium 3. Vandenhove H, Goor F, O'Brien S, Grebenkov A and Timofeyev S (2002). 'Economic viability of short rotation coppice for energy production for reuse of caesium-contaminated land in Belarus' Biomass and Bioenergy: volume 22, pages 421 to 443
Comments	
	This protective action assumes that land has been cleared of previous land use where necessary. Adopting a change of land use depends on its acceptability and ease of transition both to the farmer and associated industries. It also depends on acceptability to processors, retailers, and members of the public.

21. Select alternative land use (non-edible products)	
	Demand for selected products and proof of profitability in advance of investments, will also influence whether change of land use can be adopted.

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22. Selective grazing	
General	
Objective	To reduce activity concentrations of radionuclides in milk, meat and other animal products to below maximum permitted levels (MPLs).
Other benefits	Reduces amount of animal products requiring disposal.
Protective action description	Selective grazing optimises the management of farm animals so that pastures with the least contaminated vegetation are used in the most appropriate way. For instance, for dairy (rather than meat animals) or for meat animals before slaughter to allow contamination levels to fall to below MPLs at slaughter. Selective grazing is most efficiently carried out within a farm. However, in some circumstances, animals may be transported from areas of high contamination to other farms where contamination levels are lower. Livestock can also be physically excluded from highly contaminated areas by erection of temporary fences, including electric fences.
Target	Grazing animals
Targeted radionuclides	Known applicability: ^{134}Cs, ^{137}Cs. Probable applicability: ^{75}Se, ^{90}Sr, ^{192}Ir. Not applicable: The relatively short physical half-life of ^{131}I may preclude this option for ^{131}I. The low feed to meat or milk transfer of the following radionuclides makes implementation of this management option unlikely: ^{60}Co, ^{106}Ru, ^{235}U, ^{238}Pu, ^{239}Pu, ^{241}Am.
Scale of application	Large scale application, depending on availability of alternative pastures.
Timing of application to optimise effectiveness	As soon as possible for milk and egg producing livestock to reduce accumulation of radionuclides, bearing in mind that it takes time to organise. For meat producing animals, the period leading up to their slaughter is optimal. Effective over all timescales, although because of the amount of administration and organisation required, it may only be applicable in the intermediate to long term.
Constraints	
Legal	The sale of milk, meat and other animal products intended for human consumption is subject maximum permitted levels (MPLs). MPLs become legally binding for marketed foodstuffs following the declaration of a nuclear emergency or other radiological incident. (Retained Council Regulation (Euratom) 2016/52 as amended by

22. Selective grazing	
	The Food and Feed (Maximum Permitted Levels of Radioactive Contamination) (Amendment) (EU Exit) Regulations 2019). Grazing may be restricted depending on the status of the land (that is, sites of special scientific interest, conservation areas, national parks, areas of outstanding natural beauty) and according to environmental stewardship schemes. A consent from the relevant organisations (for example, Natural England) may be required if selective grazing is to be carried out in an area with certain designations. The notification of SSSIs is made under the Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way Act 2000 in England and Wales. There may also be restrictions on where temporary fences can be erected, for example, in National Parks and Environmentally Sensitive Areas.
Physical environment	None.
Effectiveness	
Protective action effectiveness	Is highly effective for most radionuclides as it removes or reduces the principal source of contamination. Reduction factors of 2 to 5 (50% to 80% reduction) in milk and meat were achieved in the former USSR (2). Fesenko and others (1) refer to 'clean feeding' which in their paper, encompasses the provision of less contaminated pasture, that is, selective grazing. The reduction factors quoted are the same as those quoted for clean feeding. Activity concentrations of radiocaesium in milk respond rapidly to changes in diet as the biological half-life is a few days, whereas for meat the response time is longer due to the longer biological half-time in muscle. Sheep lose radiocaesium from tissues with a half-life of around 10 days (3). A combination of long biological and physical half-lives will limit the effectiveness of this management option for ^{239}Pu and ^{241}Am if used when animals are already contaminated.
Technical factors influencing effectiveness of protective action	Availability and level of contamination in alternative pasture. The area of cultivated grassland is limited, and usually commensurate with the normal stocking rate of livestock on each farm. Biological half-life of specific radionuclide-livestock combination. Physical half-life of radionuclide Existing levels of radionuclide in animal tissues when selective grazing starts.

22. Selective grazing	
	The availability of nuclide specific monitoring data on the farm (or other farms) on which to base decisions on where to carry out selective grazing.
Resourcing	
Specific equipment	Monitoring equipment to assess contamination status of existing and alternative land and pastures.
Ancillary equipment	Transport to move livestock to less contaminated areas. Construction machinery, if fences are to be erected to temporarily restrict access of animals to contaminated land. New fencing.
Utilities and infrastructure	None.
Consumables	Fuel for transportation of livestock.
Skills	Farmers would possess the necessary skills.
Work rates and operator time	Farmer time to: • herd animals and transport them • erect fencing Monitoring staff: • carry out monitoring of existing and alternative pastures
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Farmer: • external exposure from gamma emitting radionuclides while collecting or moving livestock to less contaminated pasture Members of the public: none.
Impact of protective action	
Environmental impact	Change in biodiversity of fenced areas or areas where grazing has stopped.
Agricultural impact	Possibility for over grazing where animals are moved to alternative less contaminated pastures.

22. Selective grazing	
Practical experience	
	Used widely in the former Soviet Union and in Norway after the Chornobyl accident (1). The principle of moving livestock from poorer quality upland pasture to improved pasture for a period of fattening is common practice for upland lambs in the UK (5). It was used effectively in the Chornobyl-restricted areas of UK, to produce lamb with activity concentrations below MPL (4).
Key references	
	1. Fesenko SV, Alexakhin RM, Balonov MI, Bogdevitch IM, Howard BJ, Kashparov, VA, Sanzharova NI, Panov AV, Voigt G, Zhuchenka YM (2007). 'An extended critical review of twenty years of countermeasures used in agriculture after the Chernobyl accident' Science of the Total Environment: volume 38, pages 1 to 24 2. IAEA (2012). 'Guidelines for remediation strategies to reduce the radiological consequences of environmental contamination' IAEA Technical Report Series number 475 3. Howard B, Beresford N and Hove K (1991). 'Transfer of radiocaesium to ruminants in natural and seminatural ecosystems and appropriate countermeasures' Health Physics: volume 61, issue 6, pages 715 to 725 4. Howard B, Beresford N, Burrow, L., Shaw, PV, Curtis, EJC (1987). 'A comparison of caesium 137 and 134 activity in sheep remaining on upland areas contaminated by Chernobyl fallout with those removed to less active lowland pasture' Journal of Radiological Protection: volume 7, pages 71 to 73 5. Nisbet AF and Woodman RFM (2000). 'Options for the management of Chernobyl-restricted areas in England and Wales' Journal of Environmental Radioactivity: volume 51, pages 239 to 254
Comments	
	Can be used in conjunction with: • sheltering of livestock (pre-deposition and early phase) • addition of AFCF, clay minerals and/or lime to animal feed (intermediate to long term) • live monitoring (reassurance)

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23. Shelter livestock	
General	
Objective	To prevent or reduce contamination of food products derived from grazing livestock (by reducing the ingestion of contaminated feed and inhalation of contaminated air during and soon after the passage of the contaminated air mass).
Other benefits	May reduce the need for other protective actions.
Protective action description	When a radiation emergency is foreseen, grazing livestock are brought into barns and provided with stored clean feed before arrival of the contaminated air mass. The livestock then remain indoors as the contaminated air passes over. Depending on the levels and extent of contamination on pasture, plans should be considered for extending the period of sheltering (see datasheet 6: 'Clean feeding'). Depending on the distance from the source of release and magnitude of release, it is possible that this protective action may coincide with the sheltering or evacuation of the human population. Under these circumstances, it is unlikely that the farmer would have time to shelter his livestock and to care for them.
Target	All milk, meat or egg producing animals outdoors at the time of the passage of the contaminated air mass. Unlikely to be applicable to extensive meat production, due to distances involved.
Targeted radionuclides	All radionuclides.
Scale of application	Small to medium.
Timing of application to optimise effectiveness	Short-term (pre-release). This is a precautionary measure and is most effective if implemented before the contaminated air mass has arrived and should therefore be done as soon as the risk becomes apparent. In the event of an intermittent release, or prolonged duration release, it may still be worth considering the sheltering of livestock to provide protection from additional sources of contamination. Time available for carrying out the action will vary according to weather conditions, the distance from the source of release and any advance warning of a release. The duration of sheltering would depend upon the duration of the release and how long the contaminated air mass remains in the area.
Constraints	
Legal	Requirement to consider radiation protection if there is a risk of farmers being exposed to contaminated air-masses (that is, if time

23. Shelter livestock	
	were short and operators had to drive to site), The Ionising Radiations Regulations 2017, Part 1, Regulation 2. The Welfare of Farmed Animals (England) Regulations 2000 cover all farmed animals and contain specific requirements regarding activities such as inspections and feeding and watering of animals. Equivalent UK legislation is Welfare of Farmed Animals (Scotland) Regulations 2000, Welfare of Farmed Animals (Wales) Regulations 2001 and Welfare of Farmed Animals (Northern Ireland) Regulations 2000. The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals. Regulations on the management of agricultural discharges, for example, the protective action will result in the production of manure and/or slurry on which there may be legal restrictions with regard to when it can be spread to land. This may be covered by The Environmental Permitting (England and Wales) Regulations 2016. Scotland – the Environmental Authorisations (Scotland) Regulations 2018; Northern Ireland – The Radioactive Substances Act 1993.
Physical environment	Distance between barns and location of grazing livestock.
Effectiveness	
Protective action effectiveness	Up to 100% effective in reducing ingestion of contaminated pasture by livestock (1). However, depending on the type of housing provided, livestock are still likely to inhale some contamination due to ingress of radionuclides in contaminated air.
Technical factors influencing effectiveness of protective action	Timing of notification of release with respect to time required to shelter livestock. Availability of suitable housing and distance between pastures and shelters. Type of housing will determine level of exposure to airborne radionuclides (for example, some housing is likely to be of a more open construction). Some degree of inhalation of radionuclides will still occur in most types of housing. This is potentially more important for radioiodine and other key volatile radionuclides.
Resourcing	
Specific equipment	None.
Ancillary equipment	None.

23. Shelter livestock	
Utilities and infrastructure	Suitable housing with water supply, and power if required.
Consumables	Stored feed must be available. Bedding (straw and so on) if used.
Skills	Farmers would possess the necessary skills as housing animals is general practice.
Work rates and operator time	Time taken dependent on local conditions (for example, distance from grazing to housing).
Waste	
Type	Minimal contaminated waste expected although manure and/or slurry may be slightly contaminated through the inhalation route and will need to be disposed of when emergency situation has passed.
Transport	n/a
Treatment	n/a
Storage	On farm slurry tanks.
Disposal	Use of normal slurry or manure disposal routes is unlikely to be a problem given short term nature of protective action.
Pathways of exposure to implementers and the public	
Exposure pathways	Doses to implementers (farmers): • when bringing livestock indoors, no exposure if completed before arrival of contaminated air mass. Otherwise, potential for external exposure from the plume, potential for external exposure to deposited contamination and inhalation of contaminated air • potential external exposure when returning to stable to milk and feed animals Members of the public: none.
Impact of protective action	
Environmental impact	None.
Agricultural impact	Normally, changes from grazing to conserved feeds would be progressive. In an emergency situation, diet would have to be changed rapidly and this could lead to reduced productivity and negative health effects. Animal welfare issues associated with housing animals in emergency facilities (that is, may not be as well prepared as when normally housed) and if housed in summer when ventilation or temperature may be a problem.

23. Shelter livestock	
Practical experience	
	Potential efficacy demonstrated in those countries where animals were still housed at time of Chornobyl accident (for example, Norway, Austria) (1).
Key references	
	1. IAEA (1994). 'Guidelines for agricultural countermeasures following an accidental release of radionuclides' Technical Reports Series number 363 (section 15.2)
Comments	
	This protective action can be most effective for dairy animals to reduce the volumes of contaminated milk (and subsequently waste milk requiring treatment). Contaminated meat is not such a short-term issue, so clean feeding and/or changing slaughter time are likely to be more appropriate in reducing contamination in meat products. Farmers may be reluctant to be outside while there is a risk of contamination. May need to take into account public messaging to avoid any conflict between sheltering advice to members of the public and advice to farmers on sheltering livestock.

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24. Slaughter and suppression of lactation	
General	
Objective	To remove the source of highly contaminated milk, eggs or meat from the production system.
Other benefits	Maintains consumer confidence in food products.
Protective action description	**Slaughtering** Slaughtering could be considered for those animals whose milk or meat would be so contaminated that it would be considered unfit for human consumption for a significant proportion of their productive life. This may be due to the lack of clean feed or access to other protective actions. Slaughtering could also be considered on animal welfare grounds in areas where farmers have been evacuated leaving animals un-milked and possibly unfed. It is possible that following a large-scale accident, killing by free bullet (that is by a marksman in the field using rifle, shotgun, or humane killer) or chemical euthanasia would be the primary method of culling considered initially (on farm or abattoir). Other options would include culling an animal on the farm or at a knacker's yard using a bullet and gun. Condemnation completely removes contaminated food from the market but can leave large quantities of animal waste needing disposal. The capacity for immediate slaughter should in most circumstances be sufficient to negate the need for suppressing lactation. **Suppression of lactation before slaughter** If a decision has been made to slaughter dairy livestock, methods for suppressing lactation should be used to reduce volumes of waste milk requiring disposal, where immediate slaughter is not possible. Synthetic oestrogens are effective at inhibiting milk production, although many forms are currently banned by the EU for food producing animals unless a decision has been made to slaughter the animals. Progestogens or prostaglandins could also be considered. The more natural method of drying off involve the abrupt cessation of milking, accompanied by provision of poor-quality feed, removal of concentrates from the diet and restricted access to water. For high yielding cows the drying off method would be to reduce the frequency of milking over a 2-week period.
Target	Dairy, egg or intensively produced meat
Targeted radionuclides	Known applicability: ^{60}Co, ^{75}Se, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{192}Ir.

24. Slaughter and suppression of lactation	
	Probable applicability: ^{106}Ru, ^{226}Ra. Not applicable: The relatively short physical half-lives and/or low transfers from feed to diet of the following radionuclides is likely to preclude use of this radical action: ^{131}I, ^{235}U, ^{238,239}Pu, ^{241}Am.
Scale of application	Small to medium scale depending on severity of accident.
Timing of application to optimise effectiveness	Short to intermediate phase. Slaughter of livestock may be considered in the early phase if farmers have been evacuated. Otherwise, livestock would be carefully selected on the basis of levels of contamination, age and availability of other protective actions, such as clean feeding. If slaughtering of dairy livestock cannot be carried out immediately, suppression of lactation should be considered as soon as possible to reduce the volumes of milk requiring disposal.
Constraints	
Legal	There are no legal powers in terms of food safety, to order destruction of livestock to prevent contamination of the food chain. The FSA's policy aim is to prevent contaminated food from entering the food chain which can be done using FEPA orders (described above). FSA with local authorities and Defra and so on would then work with farmers to agree the best protective actions, which might include destruction of animals. This would likely get better buy-in and compliance than a mandatory slaughter order. However, in extreme circumstances, the FSA could use FEPA orders to restrict the movement of animals and the sale of any food products from the animals to such an extent that destruction is the only economically viable option for the farmer. Hormone treatments using synthetic oestrogens are not permitted for food producing animals. However, if a decision has been made to slaughter dairy livestock, hormonal treatments may be used to reduce the volumes of waste milk arising before slaughter. The Animal Welfare Act 2006 has brought together and modernised welfare legislation, particularly the Protection of Animals Act 1911 and equivalent acts, for farmed and non-farmed animals. Livestock farmers and employers are required by law to ensure that all those attending to their livestock are familiar with, and have access to, the relevant welfare codes. Any disposal of carcasses or contaminated milk should be sought under The Environmental Permitting (England and Wales) Regulations 2016; the Environmental Authorisations (Scotland)

	24. Slaughter and suppression of lactation
	Regulations 2018; and The Radioactive Substances Act 1993, in Northern Ireland.
Physical environment	Slaughter sites outside of controlled premises may require an environmental impact assessment.
Effectiveness	
Protective action effectiveness	Slaughtering is highly effective (that is, 100%) at removing contaminated animal products from the food chain. In terms of suppression of lactation, hormone treatments can be considered 100% effective when lactation ceases. The time taken to achieve this depends on the method adopted but can take up to 2 weeks. The shorter the period that drying-off is achieved over, the greater the potential for animal welfare problems to evolve. Suppression of lactation can also be regarded as being highly effective if the rate of milk production is greatly reduced but not ceased.
Technical factors influencing effectiveness of protective action	**Slaughtering** Availability of licensed slaughtermen to visit farms in immediate aftermath of accident. Availability of transport to take livestock to abattoirs, although attention should be paid to the inadvertent spread of contamination. **Suppression of lactation before slaughter** The method used to suppress lactation. If hormonal, the type of treatment selected. The daily milk yield or stage of lactation of the dairy animal.
Resourcing	
Specific equipment	Abattoir or slaughtering equipment on farm.
Ancillary equipment	Vehicles for transport of livestock to abattoir.
Utilities and infrastructure	Disposal routes for carcasses, for example, incinerators, rendering plants, burning and burial sites.
Consumables	**Slaughtering** Cartridges for captive bolts and so on. Fuel for transport to abattoir if necessary. Disinfectants. PPE, waste disposal bags **Suppression of lactation before slaughter** Synthetic oestrogens, progestogens or prostaglandins. Long-acting antibiotic for udders (in case of mastitis) if more natural methods of drying off used.

24. Slaughter and suppression of lactation	
Skills	Slaughtering would be carried out by licensed slaughtermen with necessary skills. Farmers would possess necessary skills for drying off ‘naturally’ in preparation for calving, lambing or kidding. Some instruction may be required for administering hormonal treatments.
Work rates to operator time	Time to transport livestock to abattoir. Time to slaughter cattle at abattoir or on-farm. In terms of suppression of lactation, less time would be spent milking livestock, but an increased amount of time might be spent controlling animal welfare issues.
Waste	
Type	Condemned livestock carcasses. For dairy animals, contaminated milk will be produced until lactation is suppressed. This will require disposal. If synthetic oestrogens have been used, all milk will require disposal irrespective of radionuclide content. Disinfectants, if used. Animal bodily fluids and faeces. PPE.
Transport	Livestock: Wastes should be covered or contained during transport using leak-proof vehicles and containers (medical waste containers can be considered). Specialist noxious waste transport contractors should be used. Biodegradable wastes should be covered and transported as soon as possible. Suitable for transport via road. Milk: can be transported via tankers. Typical articulated tanker max volume 30,000 litres.
Treatment	None identified.
Storage	**Livestock** Waste should be stored in dedicated specialist containers which prevent escape of liquids or odour. Consider refrigerated storage where there are delays in disposal. **Milk** Tanks (temporary, on farm slurry tanks – capacity will depend on time of year, for example they are likely to be full at the end of winter, when livestock are kept indoors).

	24. Slaughter and suppression of lactation
	Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	**Livestock** Preferred solution – permitted incinerator. Alternative routes – disposal to LLW permitted landfill. If incineration is selected the bottom ash may need further management and disposal to permitted LLW landfill. Nuclear Waste Services can provide advice on the viability of these waste routes if information on waste volume and characteristics are provided. Anaerobic digestion, rendering or on farm burial for livestock may also be considered within Defra and environment agencies guidelines. If anaerobic digestion is selected, then the digestate by-product may need further management depending on contamination levels. If contamination levels are sufficiently low, the digestate can be made into bedding for livestock, soil amendments, and certain types of fertilizers. **Milk** Preferred option is land spreading; small volumes may be suitable for disposal to a sewage treatment works. Alternatively, can consider disposal via long sea sewage outfalls or making use of an existing milk processing plant to convert liquid milk into dried milk which can be stored and disposed of to landfill or incinerated. For land spreading, milk has a high biochemical oxygen demand (BOD) and high nitrogen content so may cause pollution if allowed to enter water bodies. Landspreading may be banned is which may preclude this option. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Driver: • external exposure while transporting livestock to abattoir Operative at abattoir • external exposure while slaughtering livestock Members of the public: none.
Impact of protective action	
Environmental impact	Potential for contamination of surface waters due to run off from carcasses.

	24. Slaughter and suppression of lactation
	Pollution issues related to hormone treatments, for example, if waste milk is allowed to contaminate waterways. Synthetic oestrogens are known to persist in waterways causing endocrine disruption to fish.
Agricultural impact	If the entire herd or flock is slaughtered, under-grazing of pasture will occur. In extreme cases, there might be disruption of milk production at dairy farms and to the supply of milk to food industry and potential market shortages.
Practical experience	
	Cattle (95,500) and pigs (23,000) were slaughtered between May and July 1986, following the Chornobyl accident. Many carcasses were buried, and some were stored in refrigerators, but this produced great hygiene, practical and economic difficulties (1). Slaughtering and disposal of highly contaminated reindeer and sheep took place during 1986 in Norway after the Chornobyl accident (3). Slaughtering of cattle has been carried out in the UK and other European countries following the condemnation of beef because of Bovine Spongiform Encephalopathy ('mad cow disease'). On a larger scale there has been slaughter and burning or burial of complete farm stocks (ruminants and pigs) as a consequence of the foot and mouth epidemic in the UK (2). Herds and flocks were also slaughtered and disposed of in many other Member States including France, Belgium, Germany, and the Netherlands.
Key references	
	1. IAEA (2006). 'Environmental consequence of the Chernobyl accident and their remediation: 20 years of experience' Report of the Chernobyl Forum Expert Group 'Environment' 2. Smith J, Nisbet AF, Mercer JA, Brown J and Wilkins BT (2002). 'Management options for food production systems affected by a nuclear accident: options for minimising the production of contaminated milk' National Radiological Protection Board, Chilton (UK), NRPB-W8 3. Tveten U, Brynildsen LI, Amundsen I and Bergan TDS (1998). 'Economic consequences of the Chernobyl accident in Norway in the decade 1986 to 1995' Journal of Environmental Radioactivity: volume 41, issue 3, pages 233 to 255

24. Slaughter and suppression of lactation	
Comments	
	This is a radical action and only to be used as a last resort. Farming industry recommends that breeding stock are moved to uncontaminated areas. Given the UK public reaction to mass slaughter during foot and mouth disease, disposal of carcasses must be carefully considered. Furthermore, the stigma created by foot and mouth disease persisted for some time, including for local farming industries unaffected by the disease. Public perception of the affected area is unlikely to be favourable, irrespective of how effectively carcasses are managed. Drying off without the use of synthetic hormones would be unacceptable to farmers with high yielding cows because of animal welfare concerns. Further research is required to establish the most appropriate methods of drying off dairy animals at different stages of lactation.

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Return to decision-aiding look-up tables for food production systems in section 6.1
Return to index of protective actions for food production systems in Annexe A1

Annexe A2. Datasheets for drinking water supplies

Index to datasheets for drinking water supplies

Three links are provided at the bottom of each datasheet, one that returns the user to the main datasheet index in section 4, one that returns the user to the decision-aiding look-up tables in section 6.2, and one that returns the user to the datasheet index in this annexe.

25. Alternative drinking water supply	
General	
Objective	To reduce ingestion doses to consumers by providing an alternative supply of potable drinking water in the event of activity concentrations in supplied (treated) water exceeding drinking water quality levels.
Other benefits	None
Protective action description	**Public supplies** If restrictions are placed on the use of public drinking water supplies due to activity concentrations exceeding UK action levels, alternative sources of water would need to be provided for drinking water and water used for food preparation. This may include, but is not limited to – bottled water, tankers, bowsers, static tanks, direct water injection into mains or service reservoirs. It is likely that alternative water supplies to vulnerable or sensitive people (such as schools, hospitals, and nursing homes) would be provided in the form of bottled water. Water companies should follow their normal procedures for identifying and providing vulnerable customers with alternative supplies. Water to the general public would be provided via bottled water collection points, static tanks, and bowsers, although these arrangements may vary depending on the availability of supplies, availability of resources and the location and distribution of the population affected. Water undertakers already have procedures in place to ensure the smooth deployment of alternative supplies across their supply area and mutual cross-regional agreements with other water undertakers should additional equipment be required. Undertakers have a pre-planned list of appropriate locations to place static tanks and bowsers, taking into account accessibility for consumers, risk of vandalism and contamination, and suitability for filling and re-filling by tanker. The method of deployment of alternative water supplies would be at the discretion of the water company, taking into account advice regarding sheltering and safe areas. If a network is known to be contaminated the water may still be able to be used for sanitation purposes – washing, flushing toilets and so on. However, such use will be difficult to control. Therefore, although the risk from such use may be low, it is likely that a contaminated supply may need to be isolated to meet customer expectations. The need for network isolation would be risk assessed on a case-by-case basis, taking account

	25. Alternative drinking water supply
	of factors including the isotopes involved and activity levels; the impact on exposure to householders; the opinion of the affected population; and the status of the network, for example, how far the contamination has spread into the network; whether the system is pumped or gravity fed; whether the distribution network remains pressurised. If a network is isolated, emergency handwashing facilities, such as sanitary bags that are placed over a toilet facility and then disposed of via an approved waste disposal route, may be required. Alternatively, facilities may be established in local leisure centres that are not impacted by the contaminated network. **Private supplies** If restrictions are placed on the use of private drinking water supplies due to activity concentrations exceeding UK action levels, alternative sources of water would need to be provided for drinking water and water used for food preparation. This may include, but is not limited to bottled water, tanker, bowsers, and static tanks. Local authorities are advised to meet with local water companies to identify the local options available for the provision of alternative water supplies to consumers dependent on private water supplies, following an emergency. These discussions should lead to the setting up of framework agreements between local authorities and water companies so that arrangements are in place and available to be called upon immediately when needed. This could include use of a designated standpipe when required, or bottled water, or water in tankers or bowsers. These frameworks should identify gaps in provision that may need to be filled by other means (such as private providers of emergency water supplies).
Target	Public and private drinking water supplies.
Targeted radionuclides	Known applicability: All radionuclides.
Scale of application	Small, medium or large. Alternate supply of drinking water would have to be provided, irrespective of scale. There are collaborations between water companies via the call out contracts, that have already been set up under the Water UK mutual aid scheme for emergency situations. This provides some resilience but cannot be relied on as concurrent events within water companies may limit the ability for the mutual aid scheme to respond.

25. Alternative drinking water supply	
	Initially, within the first 24 hours of the public water supply being disrupted, 10 litres per person per day would be provided to households. This meets the obligations set out in The Security and Emergency Measures (Water and Sewerage Undertakers and Water Supply Licensees) Direction 2022 for suppliers. This rises to 20 litres after 120 hours (5 days) in order to provide customers with some scope to address broader hygiene and other needs, when there is total failure of the piped supply. Every effort should be made to ensure alternate supplies are provided. If supplies could not be maintained, Defra would escalate the situation and host cross-government department calls for an appropriate remedy to be found.
Timing of application to optimise effectiveness	Early to long-term. This protective action will need to be in place for the duration of any drinking water restrictions.
Constraints	
Legal	All water undertakers to have plans in place for the provision of water by alternative means should the piped water supply fail (for example, The Security and Emergency Measures (Water and Sewerage Undertakers and Water Supply Licensees) Direction 2022) (SEMD). Enough water would need to be provided to meet any legal obligations placed on the water supplier. Alternative drinking water supplies would need to meet the quality standards for normal drinking water supplies given in water supply regulations (see, for example, guidance from DWI (1) and DWQR (2), and the devolved equivalent regulations). Bottled water shall meet the requirements of the Water Supply (Water Quality) Regulations (2016), and the equivalent devolved regulations. Provision of bottled water shall meet the requirements as set out as per the ‘Scale of application’ below accounting for the use of alternative supplies from the start of the incident (this may mean that by the recovery phase 20 litres per day is provided). If water is supplied in bottles and containers and it is not controlled under the Natural Mineral Water, Spring Water and Bottled Drinking Water (England) Regulations 2007, the water must be monitored for Group A and Group B parameters in accordance with the Private Water Supplies

	25. Alternative drinking water supply
	(England) Amendment Regulations 2018, and the equivalent devolved regulations. Water via tankers and bowsers shall meet the requirements of the Water Supply (Water Quality) Regulations 2016 (and the equivalent devolved regulations) as per DWI guidance on tankers and bowsers. The requirements for sampling tankers, static tanks and bowsers is covered under Regulation 6 of the Water Supply (Water Quality) Regulations 2016 and their equivalents in the devolved administrations ("the Regulations"), with further information given in the guidance to these Regulations issued by the Drinking Water Inspectorate in 2016. Direct water injection – that is, water tankered to the injection point shall in England meet the requirements of the Water Supply (Water Quality) Regulations 2016 (as amended) (Statutory Instruments 2016 No 614); in Wales meet the requirements of The Water Supply (Water Quality) Regulations 2018 (Welsh Statutory Instrument 2018 No 647 (W.121); in Scotland meet the requirements of The Public Water Supplies (Scotland) Regulations 2014; and in Northern Ireland meet the requirements of The Water Supply (Water Quality) Regulations (Northern Ireland) 2017 (Northern Ireland Statutory Rules 2017 No.212). Prior to injection samples shall be taken for analysis to demonstrate maintenance of water quality during transport and network samples shall be taken to demonstrate continued maintenance of water quality in distribution. Requirements for private water supplies in England - The Private Water Supplies (England) (as amended) Regulations 2016 (Statutory Instruments 2016 No 618) and amendment; in Wales – The Private Water Supplies (Wales) Regulations 2017 (Statutory Instruments 2017 No 1041 (W. 270)); in Scotland – The Water Intended for Human Consumption (Private Supplies)(Scotland) Regulations 2017 (Statutory Instruments 2017 No 282) and amendment; in Northern Ireland – The Private Water Supplies Regulations (Northern Ireland) 2017 (Statutory Instruments 2017 No 211). Disposal of contaminated water would be covered by The Environmental Permitting (England and Wales) Regulations 2016. Scotland – the Environmental Authorisations (Scotland) Regulations 2018. Northern Ireland – The Radioactive Substances Act 1993.

25. Alternative drinking water supply	
Physical environment	Location of alternative supply must specify or consider site location and aspect, public approach roads, time or days of operation, site access, capacity (no of vehicles), pedestrian access, lighting, environmental considerations, housing and nearby, security. Inclement weather could lead to disruption in the provision of alternative supplies. Remote areas may not be able to receive alternative supplies. Widespread contamination could mean alternative supplies are limited. Drought conditions may mean alternative supplies are limited. In the event of contamination of a water supply during another emergency situation (such as a pandemic) the normal and well-rehearsed alternative supply arrangements may not be appropriate. In this situation, water companies may choose not to use 'hubs' where large numbers of people gather to wait for supplies.
Effectiveness	
Protective action effectiveness	If the alternative supply is free from contamination, and the restricted contaminated water is not used, then this protective action will be 100% effective in preventing consumption of contaminated water. Bottled water will be free from contamination, as it would have been bottled before the radiation emergency and will probably come from an unaffected area. Water provided in tankers, bowsers, static tanks and via direct water injection into mains or service reservoirs would either need to be tested or known to have come from uncontaminated areas, for these options to be 100% effective.
Technical factors influencing effectiveness of protective action	Compliance with advice to not drink tap water. Some people may ignore restrictions and continue to drink the contaminated water. Other people may not be aware that restrictions are in place and that an alternative supply is available. However, much has been done to expand the range of media used for communication, by door to door visits, text messages, social media, radio and leafletting. DWI's guidance for water companies communicating in emergency situations is contained in Drinking Water Safety: guidance to health and water professionals 2021. There may be devolved equivalents. Shortages of alternative supplies could lead to people drinking contaminated water, if the area affected involves large numbers of people, and supply does not meet demand. However, it is

	25. Alternative drinking water supply
	likely that some people will travel to get supplies, irrespective of official guidance.
Resourcing	
Specific equipment	Tankers, static tanks, and bowsers. Lorries for distributing bottled water.
Ancillary equipment	Containers for the transport of water from the distribution point to homes.
Utilities and infrastructure	Infrastructure for the planning, co-ordination, and distribution of supplies. Some water companies may have their own tankers or bowsers or may have service level agreements with companies to provide such equipment in the event of an incident. The Water UK mutual aid scheme includes support agreements (call out contracts) across the water industry whereby people and equipment are moved into different water company areas to support local emergencies. In large scale incidents, resources beyond those available to individual or groups of water companies may be needed, for example, by using military support. For public supplies, water companies should make reference to the DWI's Advice Sheet 9, Emergencies: use of equipment and disinfectants which includes the requirements for products not normally used to transport drinking water. Sampling programme for water supplied in tankers, static tanks and bowsers. In extreme circumstances, or to manage restrictions imposed by other circumstance, a police presence for crowd control may be required at distribution points. Enough drivers to transport the water and/or staff to hand out large quantities of bottled water. Suitable road networks required for distribution via large vehicles or tankers. If a network is isolated, sanitation facilities may be established in local leisure centres that are not impacted by the contaminated network.
Consumables	Bottled water – potentially millions of bottles. Single use bulk water containers (1,000 litre bags). If a network is isolated, emergency handwashing facilities, such as sanitary bags that are placed over a toilet facility and then disposed of via an approved waste disposal route, may be required.

	25. Alternative drinking water supply
Skills	Suitably trained staff for collections and distribution of alternative supplies. Skill dependent on supply. All staff working on Restricted Operations (reservoirs, water pumping stations, water treatment works, wells, springs, boreholes as well as working on the network of water mains and service pipes) must hold a National Water Hygiene registration ('blue card') from the Energy and Utility Skills Register (EUSR).
Work rates and operator time	Travelling time for drivers, possibly unsociable hours (weekends or outside normal working). If bowsers are used, there is a requirement to sample the water in them every 48 hours and analyse for contaminants as prescribed by the regulations. This may involve a number of additional personnel and significant impact on resources in the laboratory depending on the number of bowers or tanks required. There may be a requirement to subcontract sample analysis to other suitable laboratories. Possible need for security at storage areas and distribution points.
Radioactive waste	
Type	Contaminated water, already in the system. Disposal of contaminated water may need to be considered if it is not suitable for sanitation however this will need careful consideration as isolation may not be possible and the volumes will be very large. Advice from the environment agencies must be sought and additional controls may be needed if water is to be discharged into the environment.
Transport	Wastewater could be transported by tankers if unsuitable for direct discharge to sewers or watercourses at point of generation.
Treatment	If water cannot be discharged direct to the environment due to radiological impact, then consider using settling agents which can be added to remove suspended particles and other impurities from the water. This would separate some of the radioactive particles from the water leaving a solid or sludge waste which would need disposal. For very large volumes of highly contaminated liquids, filtration or ion-exchange systems should be considered to separate radioactive material from liquid. The concentrate and contain principle should be applied.

25. Alternative drinking water supply	
	If levels of contamination are lower, then treatment using normal sewage treatment works processes may be deemed adequate to removal levels of radioactive material. Treatment processes would generate additional solid waste which would need to be managed such as sludges and filtration media. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Water may need to be isolated and stored within the water distribution network.
Disposal	Subject to the outcome of a radiological impact assessment, wastewater may be suitable for disposal via a radioactive substance activity permitted discharge route for aqueous waste, disposal to a STW (sewage treatment works) or disposal directly into the environment (river or sea). Advice from the relevant environment agency must be sought, as additional controls may be needed. Refer to the protocol for the disposal of contaminated water and associated wastes at incidents.
Pathways of exposure to implementers and the public	
Exposure pathways	Doses to implementers: • external gamma doses from material on the ground and other surfaces Doses to those involved at a wastewater or sewage treatment works: • external gamma doses from sedimentation tanks It should be noted that these additional doses to implementers would be significantly smaller than the doses to people living in the affected area. Nevertheless, suitable personal protection equipment, such as gloves or facemasks, may be effective in reducing the potential doses for the tasks undertaken depending on the radionuclides involved. Members of the public: none.
Impact of protective action	
Environmental impact	None if plastic bottles are recycled.
Agricultural impact	There may be an agricultural impact if water was diverted from agricultural use, which could lead to a shortage of water for irrigation, particularly in conditions of limited water resources.

25. Alternative drinking water supply	
	Licenses to abstract water for agricultural use may be withdrawn.
Practical experience	
Evidence	Water companies in the UK have experience in providing water using tankers or bowsers in emergency situations involving other contaminants and natural disasters (such as floods). Notable large-scale events include Storm Desmond in 2015 and Mythe WTW flooding in 2007, where it became necessary for neighbouring water companies to tanker in supplies. There are extensive bottled water resources in the UK.
Key references	
	1. DWI (2022). Guidance on Alternative Supply Operations 2. DWQR (2022). Guidance on the implementation of the public water supplies (Scotland) Regulations 2014 (as amended)
Comments	
	Although water may not be acceptable for use as drinking water, it may still be suitable for sanitation, especially if the radionuclide has a short half-life. However, if contaminated water continues to be provided for sanitation purposes this may result in issues with long-term contamination of the distribution systems. This would have to be agreed based on confirmation and verification of the contaminant (and level of contamination) and the highest-level decision between DWI, UKHSA and water company with the relevant ministerial (or higher) approval. Non-radioactive waste would include plastic water bottles and plastic bulk supply bags. Potential for collection of plastic bottles with household recycling waste, with an increased frequency of collection if appropriate. Bulk bags disposed or recycled by water company.

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26. Changes to water abstraction point or location of water source	
General	
Objective	To reduce ingestion doses to consumers by reducing radioactive contamination in drinking water in the event of activity concentrations in the normal water supply (treated) exceeding UK action levels.
Other benefits	None.
Protective action description	Changes in abstraction points may be possible within a reservoir or river. It may also be possible to use alternative water sources or move water within distributed water networks. Changes made to water supply sources need to be linked very closely to a detailed monitoring programme, with appropriate consideration to the security of the supply. **Reservoir abstraction** It can take several days or more for contamination to be evenly distributed through the water column of reservoirs due to their size and depth or climate (for example, ice cover, hydrological cycling). If reservoir mixing equipment is present (impellors or by air bubble plumes or curtains) this may reduce time of contaminant mixing and halting this equipment could be recommended as a preliminary action. It may be possible to use water from deeper parts of a reservoir before contamination has reached it by opening deeper intake draw-offs, using water that has not yet been contaminated. **River abstraction** Water could be abstracted upstream of any contamination if several abstraction points are available. Water could be used from downstream of the contamination if the abstraction point is sufficiently far away that the contamination has not reached there yet. **Alternative water sources** It may be possible to change to alternative sources of water depending on the site's design (such as a change from river abstraction to bore holes or large-scale raw water transport). It may be possible for water companies to use other reservoirs under their responsibility that have not been contaminated, however raw water quality would have to be adequately sampled beforehand to ensure suitability of adequate treatment processes at the site (Regulation 15, Water Supply (Water Quality) Regulations 2016, and equivalent devolved regulations).

26. Changes to water abstraction point or location of water source	
	Movement of water within networks It may be possible for other nearby water companies to share uncontaminated water if there is sufficient spare capacity and distributed networks exist to transfer the water to the desired location. Localised overland pumping connecting networks could be an option.
Target	Public drinking water supplies. Not appropriate for private drinking water supplies in general (see ‘Comments’ section below).
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Small to medium. The water companies or suppliers could apply this option, provided that (a) sufficient drinking water supplies can be maintained; and/or (b) until the contamination has been sufficiently dispersed or diluted.
Timing of application to optimise effectiveness	Early phase. As soon as contamination of a water source is suspected, changes to abstraction points or the selection of alternative water sources should be considered as a precautionary measure. Water supply regulations state that new sources, or those that have not been in use for 6 months or more, normally need testing and authorisation one month before use. However, if the source is to be used for emergency purposes, then it may be used once a risk assessment report has been submitted. Even under emergency measures, the introduction of a new abstraction point could take weeks. Water companies should engage with the DWI/DWQR (Drinking Water Quality Regulator in Scotland) and with environment regulators. Once confirmed, these changes can be in place for a few days or weeks, until contamination is fully mixed (for example, in reservoirs) or until contamination has spread to the new abstraction point (for example, in rivers, if the new abstraction point is downstream of the release). Unlikely to be used in the longer-term unless switching to an abstraction point in a river upstream of the release, or deep boreholes unaffected by surface water contamination is an option. Priorities for monitoring and analysis of existing and potential alternative water abstraction points need to be decided depending on the vulnerability of water supplies to the radiological emergency. Surface water supplies, such as rivers and reservoirs, are likely to be of higher priority than boreholes in the short term and this should be taken into account when formulating a monitoring strategy and identifying supplies of

26. Changes to water abstraction point or location of water source	
	potential concern. In the longer term, monitoring and the implementation of this option may need to focus more on ground water sources, such as boreholes.
Constraints	
Legal	Any drinking water supplies would need to meet the normal quality standards for drinking water, which in England meet the requirements of the Water Supply (Water Quality) Regulations 2016 (as amended) (Statutory Instruments 2016 No 614); in Wales meet the requirements of The Water Supply (Water Quality) Regulations 2018 (Welsh Statutory Instrument 2018 No 647 (W.121); in Scotland meet the requirements of The Public Water Supplies (Scotland) Regulations 2014; and in Northern Ireland meet the requirements of The Water Supply (Water Quality) Regulations (Northern Ireland) 2017 (Northern Ireland Statutory Rules 2017 No.212). The Water Supply (Water Quality) Regulations (above) require water suppliers to identify every abstraction point from which water is drawn for domestic or food production purposes. Water supply regulations require that new sources, or those that have not been in use for 6 months or more, normally need testing and authorisation one month before use. However, if the source is to be used for emergency purposes, then it may be used once an appropriate risk assessment report has been submitted. Any disposal of contaminated water would be covered by The Environmental Permitting (England and Wales) Regulations 2016. Scotland – the Environmental Authorisations (Scotland) Regulations 2018. Northern Ireland – The Radioactive Substances Act 1993.
Physical environment	Widespread contamination and/or water shortages during periods of drought could result in fewer opportunities for changing abstraction points. There are large areas of the UK where water is not available for abstraction for a high percentage of time, and climate change and demand will only make this worse (see Ofwat publication 2011 page 12). In some instances, it may not be feasible to provide an alternative abstraction point. Local conditions, availability and demand of water, available infrastructure and time of year will all influence what is feasible regarding change of abstraction point or water source. If a water treatment works is reliant on river sources, it may only be feasible to turn off the usual abstraction point for a

26. Changes to water abstraction point or location of water source	
	limited period of time before impacting on the availability of drinking water supply. In many areas it will not be feasible to change from river abstraction to a groundwater supply, possibly because of the yield of the borehole. Discussions are ongoing about shipping raw water from other sources, for use at coastal locations, but would require verification.
Effectiveness	
Protective action effectiveness	As it may take time to carry out monitoring of different abstraction points and alternative water sources, some contaminated water might reach public supplies. Otherwise, if the water at the new abstraction point or alternative water source is uncontaminated, then this protective action would be highly effective in reducing activity concentrations in supplied drinking water (up to 100%). Reservoir mixing modelling analysis may enable higher resolution predictions and aid decision making. There is a possibility of treating water for radiological contamination in the surface reservoir, this would very much depend on the design, flow dynamics and dosing capability for such reservoirs. If new abstraction points are from surface waters, contamination may be present but at lower levels than the current supply. This will be different in every scenario and depend on how widespread the contamination event is and whether the new abstraction point is within the contamination area. A widespread event would most likely impact all surface sources in a similar way. In these situations, the effectiveness might be much less than 100%. The effectiveness of changing abstraction points in surface reservoirs is likely to be low, due to the likelihood of contamination moving reasonably quickly through the available supply and the practical difficulties in controlling clean abstraction due to the limited volume of these man-made tanks. In deep lakes, with an established thermocline, abstraction at lower levels should be effective and not limit quantity, although water quality could be impacted. Short term cessation of the use of measures such as bubble curtains as mitigation for algae or manganese control could be considered.
Technical factors influencing effectiveness of protective action	The extent to which the water at the new abstraction point or water source is contaminated. Changing from river abstraction to deep boreholes may be time-limited if the boreholes only have a limited capacity set by the relevant environment agency licence. If the treatment works is not

26. Changes to water abstraction point or location of water source	
	designed to treat borehole water, then water quality would be impacted.
Resourcing	
Specific equipment	None in the short term.
Ancillary equipment	Additional monitoring will be needed at new abstraction points to ensure contamination has not reached the abstraction point and/or supplied water is below UK action levels.
Utilities and infrastructure	Water companies or suppliers would have to have a sufficiently flexible and integrated system of water supply control to allow them to change abstraction points and/or water sources while maintaining sufficient supply to a water treatment plant. An adequate infrastructure is not dependent on the size of the supplier, the requirements will be dependent on the nature of the incident and which sources are contaminated. It may not be feasible to provide an alternative abstraction point without significant engineering, for example if this protective action is being considered as a longer-term option (switching to deep boreholes) then pipe work or infrastructure may be needed. New boreholes may be required, together with additional abstraction licences, environmental studies, and commissioning treatment to ensure the water met the relevant quality regulations. Long term strategy plans are in motion to allow greater flexibility and movement of raw water transferring across regions.
Consumables	None.
Skills	No specific skills required other than those already employed by the water company or supplier.
Work rates and operator time	Time required for monitoring staff to travel to or undertake monitoring at potential new abstraction points. Time for laboratory staff to undertake analyses of samples
Radioactive waste	
Type	Depending on the circumstances, disposal of some contaminated water may be required.
Transport	n/a
Treatment	Treatment of contaminated water that is released from storage may result in contaminated wastes arising from water treatment
Storage	Contaminated water in a reservoir may be left to recover by radioactive decay.

26. Changes to water abstraction point or location of water source	
Disposal	Some water may be slowly released to the environment thus aiding dilution of the remaining contaminant as the reservoir refills naturally. The impact of such a release will depend on the specific situation and where the water is discharged. Decisions made will need to be informed by a radiological impact assessment and the environment agencies should be consulted. For example, if water is released into a river, care must be taken to ensure that release of contaminated water does not impact on downstream abstraction points or result in unacceptable radiological risks to people or wildlife. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	The implementation of this option is very unlikely to give rise to any exposures.
Impact of protective action	
Environmental impact	Selection of new abstraction points and the removal of potentially large volumes of water could adversely impact natural water sources, reducing support to fish and other aquatic life downstream from the abstraction point, resilience to drought, and human wellbeing and recreation. This would be exacerbated during the summer months when water levels are generally at their lowest.
Agricultural impact	There may be an agricultural impact if water was diverted from agricultural use, which could lead to a shortage of water for irrigation, particularly in conditions of limited water resources. Licenses to abstract water for agricultural use may be withdrawn.
Practical experience	
	While there is only limited experience following incidents involving radioactive contamination, with no experience in the UK, changes to water abstraction are implemented routinely as part of the management of drinking water supplies for other hazards. For example, temporary cessation of abstraction from a reservoir has been necessary due to algal blooms. Temporary changes to the raw water blend at a water treatment works have been made in order to provide water that did not taste earthy or musty due to geosmin and 2-methylisoborneol. There are examples of ceasing abstraction into raw water storage to avoid pesticides (such as metaldehyde) or the cryptosporidium parasite. Changes in

26. Changes to water abstraction point or location of water source	
	abstraction have been implemented when spills have occurred into rivers, for example from loss of containment on farms or airfields. Following the incident at Buncefield, changes were made to supply arrangements to ensure drinking water supplies were maintained (3). The implementation of this protective action in in Kyiv, following the Chornobyl accident provides practical experience and, although it is now thought to have been done wrongly, by opening the surface water inlet draw-off valves of reservoir, it highlights the importance of choosing new abstraction points wisely and for the right reason (1). Changes in abstraction within the greater Vancouver area, where water supplies are taken from 3 reservoirs, have sometimes been implemented to remove one of the reservoirs from service when winter storms produce increased turbidity (2). Considerations would have to be made regarding statutory compensation flows from reservoirs. Discussion with the relevant environment agency is recommended.
Key references	
	1. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). 'A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs' Journal of Environmental Radioactivity: volume 56, numbers 1 to 2 2. Wai, Gu and Burton (2010). 'Challenges and opportunities in modelling a regional water system with interchangeable resources' Proceedings of the World Environmental and Water Resources Congress 2010, pages 2,132 to 2,141 3. Buncefield Major Incident Investigation Board (2006). The Buncefield Investigation. Second Progress Report (11 April 2006)
Comments	
	Private supplies: Changing water source or abstraction points is far less likely to be an option for private water supplies since it is unlikely that a second source of uncontaminated water would be available. However, some private water supplies do have an additional source of supply where one source can dry up during the summer, so this must be considered on a case-by-case basis. It should be noted that the water from the alternative source is often not very palatable and so probably could not be used in the

26. Changes to water abstraction point or location of water source	
	long-term. Public water supplies may be used to support provision of drinking water where needed.

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27. Controlled blending of drinking water supplies	
General	
Objective	To reduce ingestion doses to consumers by dilution of radioactive contamination in drinking water in the event of activity concentrations in the normal water supply (treated) exceeding UK action levels.
Other benefits	None
Protective action description	Contaminated water could be mixed with uncontaminated or less contaminated water if more than one raw water supply is available at the point of water treatment. Water sources include surface water (rivers and lakes) and ground water supplies. Alternatively, blending could take place post treatment in the water network. Careful consideration needs to be given to ensure that any impact of mixing potable water of different chemical and biological compositions with existing supplies are both fully understood and are proactively managed (see Bilateral markets, water trading and protection of public health (pdf)). This is critical as changes to water composition, resulting from the blending of supplies, can have a material impact on: • customer acceptability (such as taste and odour) • compliance with water quality parameters at customers taps or water corrosivity to both iron mains and plumbing metals (lead and copper) – which may present a risk to public health • confidence and acceptability (such as discolouration) • on networks (scouring, reverse flow, pressure, hardness) Monitoring after the point of blending or mixing would be required to ensure that contamination levels have been reduced sufficiently. Risk assessment of the blend, assets and network would be required.
Target	Public drinking water supplies. Unlikely to be viable for private drinking water supplies due to lack of a secondary water supply and large holding tank or other blending facilities, as well as monitoring complexities.
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Small to medium. This could be used on a medium to large-scale depending on the options available for blending different water sources, either after or before treatment, and the capacity of laboratories to undertake monitoring of water quality. Blending should not reduce the amount of drinking water produced, though a widespread event may be a challenge for monitoring laboratories and thus affect the amount of drinking water available to supply to

27. Controlled blending of drinking water supplies	
	homes. Abstraction licences should be reviewed beforehand. Abstraction licences cover all sources and can be seasonally specific in volume requirements and/or days abstracted from.
Timing of application to optimise effectiveness	Early to medium-term phases. Blending would be used as soon as contamination of a water source had been confirmed and implemented quickly. Blending would be required for the duration of time that a contaminated water source was above the action level.
Constraints	
Legal	The Water Supply (Water Quality) Regulations 2016, PART 8 Water treatment, s.26/6 For the purposes of this regulation, “adequate treatment process” means a process of blending or purification treatment which removes or renders harmless the concentration or value of any property of water, or organism or substance in water, so that supplies do not constitute a “potential danger to human health”. Any drinking water supplies would need to meet the normal quality standards for drinking water, which in England meet the requirements of the Water Supply (Water Quality) Regulations 2016 (as amended) (Statutory Instruments 2016 No 614); in Wales meet the requirements of The Water Supply (Water Quality) Regulations 2018 (Welsh Statutory Instrument 2018 number 647 (W.121); in Scotland meet the requirements of The Public Water Supplies (Scotland) Regulations 2014; and in Northern Ireland meet the requirements of The Water Supply (Water Quality) Regulations (Northern Ireland) 2017 (Northern Ireland Statutory Rules 2017 number 212).
Physical environment	Widespread contamination or water shortages during periods of drought could result in fewer opportunities for blending.
Effectiveness	
Protective action effectiveness	The effectiveness of this protective action in reducing contamination levels in water depends on the extent to which the contamination has been diluted. It can be an effective method of reducing activity concentrations in water and is done when required for other contaminants, such as nitrates or metals, pesticides, turbidity.
Technical factors influencing effectiveness of protective action	The availability of alternative (less contaminated) drinking water sources and the extent to which the cleaner source of water is free from contamination. The speed with which blending can be implemented.

27. Controlled blending of drinking water supplies	
	Whether the contaminated supply can be diverted away from all consumers prior to blending. The distance and complexity of getting the contaminated supply to the correct network area or configuration, which may cause additional contamination to storage and treatment facilities downstream of the source prior to blending. The condition of the network to allow blending effectively, how suitable is the connecting pipework and properly flushed and maintained to allow this action.
Resourcing	
Specific equipment	The correct configuration of the network including pipes, valves and monitoring, and installation capability for the required blending in the network.
Ancillary equipment	Monitoring will be needed after blending to ensure contamination has not reached the consumers tap and that the supplied water is below UK action levels.
Utilities and infrastructure	The water company or provider must have access to different water sources or supplies and be able to adjust the amount of water from each that enters the distributed drinking water supply.
Consumables	None.
Skills	No specific skills are required other than those already employed by the water company.
Work rates and operator time	It is possible to undertake blending during normal work practices, alternate network configurations that allow blending may require closer around-the-clock monitoring and operation of the network to ensure flows are balanced and pressures are maintained, depending on the type of network. Therefore, work would be conducted outside normal operating hours. Any additional monitoring required after blending will require additional time for monitoring staff to travel to or undertake monitoring after blending, and for laboratory staff to undertake analysis of samples. There may also be additional time costs for the operator due to the need to undertake a full risk assessment to ensure that the re-zoning of supplies would not create another problem, such as the supply of discoloured water or causing bursts in distribution pipes.
Waste	
Type	Flushed water from closed network sections.

27. Controlled blending of drinking water supplies	
	There is also a chance that blended water may contaminate the distribution network, but this is likely to be at a very low level and not require disposal of parts.
Transport	Pump to sewer, dechlorination may be required.
Treatment	Sewage treatment works.
Storage	Dependent on location and specifics
Disposal	Discharge to river only if cleared by environment agencies.
Pathways of exposure to implementers and the public	
Exposure pathways	The implementation of this option is very unlikely to give rise to any significant exposures, as blending will be managed to bring activity concentrations in drinking water to below UK action levels. Dilution does not remove the contamination however, so there is potential for a greater number of people to receive lower exposures.
Impact of protective action	
Environmental impact	None as this option involves treated water being moved around networks.
Agricultural impact	This will depend on the industrial users on networks, that is, if specific treated water parameters are needed for the process. Limitations may be required depending on the level of draw on the network. The only impact on agriculture would be greenhouse irrigation.
Practical experience	
	Some water companies already have experience in, and facilities for, blending and mixing water supplies and this protective action is carried out when required for other contaminants, such as dilution of high nitrate groundwater sources with low nitrate river water. Some water companies have had to invest significantly in facilities to ‘blend’ polluted water with water from a low nitrate source or in processing plants to remove nitrate (see UK Progress on Reducing Nitrate Pollution: Environmental Audit Committee) Water companies would have to decide if the contaminated source could be diluted sufficiently, given their available water sources and water network configurations. This protective action was widely used in the former Soviet Union following the Chornobyl accident (2) Management of radioactivity in drinking water supplied from the deep sandstone aquifer in Southern Jordan (1).

27. Controlled blending of drinking water supplies	
Key references	
	1. El-Naser H, Smith B, Kilani S, Abdeldin I, Howarth B and Seleh B (2016). 'Blending as the best compliance option for the management of radioactivity in drinking water supplied from the deep sandstone aquifer in Southern Jordan' Journal of Water and Health: volume 14, issue 3, pages 528 to 548 2. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). 'A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs' Journal of Environmental Radioactivity: volume 56, numbers 1 to 2
Comments	
	Problems may occur with mixing of very soft and very hard water. May have an adverse influence on customer confidence and acceptability. A good example of this took place in June 2017 in Cumbria (mainly within Copeland Borough Council area), when United Utilities introduced a 50:50 blend with local borehole sources. Public acceptability of blending supplies needs to be considered.

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28. Continue normal water treatments (public supplies) supported by a monitoring programme	
General	
Objective	Continuing the use of normal water treatments to remove or partially remove radioactive contamination in drinking water. This will reduce ingestion doses to consumers.
Other benefits	No disruption to public water supplies.
Protective action description	There are several stages in the treatment of drinking water before it enters the public supply. These can include storage; primary filtration; flocculation and coagulation; clarification; secondary filtration; tertiary filtration; ion exchange; disinfection; ozone; granulated activated charcoal (GAC) or Powdered Activated Carbon. The processes used will depend on the quality of the raw water. Not all water treatment works will offer the same set of treatments and not all treatments will remove radionuclides. Surface water may be kept in storage reservoirs so that solid contaminants can settle to the bottom and floating objects such as leaves may be removed by passing the water through metal grilles before undergoing the following main treatment processes for removing radionuclides: • flocculation and coagulation • clarification • filtration (primary and secondary) • ion exchange • oxidation-reduction treatments – less common • reverse osmosis – rarely used In general, treatment works that combine flocculation, clarification and primary filtration will be effective at removing the majority of radionuclides from drinking water. **Flocculation and coagulation** Coagulant chemicals such as aluminium sulphate or ferric sulphate are used to remove very fine suspended particles and organics from incoming water. The aluminium or ferric sulphate form a precipitate when added to the water, which coagulates with the suspended particles to form a floc. A polyelectrolyte mixture is often added to aid flocculation. Polyelectrolyte is a long-chain synthetic polymer which increases, stabilises, and can aid larger floc formation. Flocculation is important for removing radionuclides that attach to solid particulate material. Occasionally oxidation prior to flocculation, can cause soluble metals to drop out and be amenable to this process.

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	In-line coagulation is a process whereby the coagulant and pH correction chemicals are injected into the forward flow. In line coagulation may be used as part of suspended ion exchange and ceramic microfiltration. **Clarification** Clarification is used to separate floc from water. The floc is either allowed to sink by gravity in sedimentation tanks or high-rate clarification processes such as Actiflo treatment (for example, by mixing flocs with a micro sand) or flocs are floated and removed using dissolved air floatation (DAF). **Filtration: Primary filtration** This involves passing water through filtration media at an optimal pH range. The media can be sand, anthracite or carbon, or combinations of all 3. Sand filters are conventionally used in drinking water treatment processing. A sand filter not only separates suspended solids and particles from the water but also other chemical constituents. Sand filtration can be slow, with a typical filtration rate of 0.1 to 0.2 m/h, or rapid with a typical rate of 5 to 7.5 m/h. Carbon filtration can be granular or powdered. Both use highly porous material with a large surface area to which contaminants may adsorb. Granular activated carbon (GAC) can be included in filtration media or added as a separate stage post-filtration. Alternatively, membrane filters can be used. Membrane filters use microfiltration (used to remove suspended solids), ultrafiltration (used to remove dissolved organic molecules) or nanofiltration (used to soften water with low total-dissolved-solids) technologies. Primary filtration will remove radioactive particles not removed during the initial clarification. It also specifically targets certain radionuclides, such as isotopes of caesium and some chemical forms of iodine, that are largely unaffected by flocculation. **Filtration: secondary filtration** Secondary filtration can be a repeat of the primary filtration process but can also differ in using contactor media to remove soluble metals such as manganese or focus on other parameters. **Ion exchange** Ion exchange removes ions from water by the exchange of cations or anions between the contaminants and the exchange medium. The ion exchange material is usually resin made from a

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	synthetic organic material that contains ionic functional groups to which exchangeable ions are attached. Suspended ion exchange is also available and typically used at the start of the treatment process, followed by inline coagulation and ceramic filtration. In this process, an anion exchange resin is injected into the raw water feed and remains suspended in a contact tank containing baffles and mixing paddles to distribute flow and ensure effective mixing. After passing through 2 tanks, the resin settles and is removed for regeneration and reuse. A full monitoring programme is needed to support normal water treatment to confirm that the processes in place are effective for removing the radionuclides of concern and to ensure that activity concentrations in treated water are below UK action levels. **Oxidation-reduction treatments** Physical-chemical oxidation of drinking water supplies can be used for precipitating dissolved compounds (iron, manganese, sulphides and heavy metals). The choice of oxidant will be dictated by selectivity for the radionuclides present and costs of associated treatments. Physical-chemical reduction is rarely used and has very specific applications. **Reverse osmosis** Reverse osmosis is a water purification process that uses a partially permeable membrane to remove many types of dissolved and suspended chemical species, including radionuclides (particularly monovalent ions). The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. Reverse osmosis is most commonly known for its use in drinking water purification from seawater. There is currently only one water company in the UK that uses reverse osmosis. It is an expensive option. **Additional treatments** Ultraviolet (UV) light is commonly used in water treatment for disinfection but does not reduce levels of radioactivity in the water supply.
Target	Public drinking water supplies at water treatment plant. Some private drinking water supplies may include treatment that would reduce levels of radioactivity, for example, membrane plants, sand filtration, or cartridge filters.
Targeted radionuclides	Known applicability: all.

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
Scale of application	Small to large. All drinking water supplied by water companies undergoes some form of treatment, though the amount of treatment will depend on the type of supply. Surface water usually has more treatment steps than groundwater, as it is naturally exposed to more environmental contaminants. A pristine groundwater supply may only be subject to treatment by chlorination.
Timing of application to optimise effectiveness	Early to long-term phases. As there are no changes to existing practices, water treatment will continue to remove or reduce levels of radionuclides in drinking water.
Constraints	
Legal	Any drinking water supplies would need to meet the normal quality standards for drinking water, which in England meet the requirements of the Water Supply (Water Quality) Regulations 2016 (as amended) (Statutory Instruments 2016 No 614); in Wales meet the requirements of The Water Supply (Water Quality) Regulations 2018 (Welsh Statutory Instrument 2018 No 647 (W.121); in Scotland meet the requirements of The Public Water Supplies (Scotland) Regulations 2014; and in Northern Ireland meet the requirements of The Water Supply (Water Quality) Regulations (Northern Ireland) 2017 (Northern Ireland Statutory Rules 2017 number 212). In the event of a radiation emergency, radionuclides, and radioactivity in drinking water after treatment need to be below UK action levels; this includes a legal obligation for monitoring of drinking water supplies throughout the treatment process including source to final sample point, consumer's tap.
Physical environment	None.

28. Continue normal water treatments (public supplies) supported by a monitoring programme

Effectiveness

Protective action effectiveness

A review of the literature on the effectiveness of drinking water treatments on radionuclide removal has enabled a matrix of efficiency factors to be compiled for a number of radioactive isotopes likely to be of concern following a radiation emergency (1, 2, 3, 4, 5).

The matrix (presented in the table below) only considers chemical removal efficiencies. Removal due to physical properties would be incidental. The data provided in the matrix are presented as ranges of removal efficiencies to reflect the large variation for most types of treatment. This is due to the physical and chemical characteristics of the elements and the types of raw water used. Furthermore, the chemical conditions and types and combinations of treatments affect efficiency.

Generally, the chemical conditions for treatment are varied, often involving step changes in pH (extremes in pH can affect pipework). pH is usually returned to a suitable range for network distribution after disinfection. More weight has been given in the literature review to information gathered from full-scale plant operations, rather than laboratory experiments.

For a single treatment, the activity concentration of a particular radionuclide in the water following treatment is calculated as follows:

Activity concentration in water post treatment = activity concentration in water pre-treatment x F (where F = 1 – (removal efficiency / 100))

Water treatment removal efficiencies as a function of element and treatment process [note 1] [note 2]

Element alphabetical	Flocculation, coagulation or clarification %	Filtration: rapid and slow %	Filtration: activated carbon %	Ion exchange %
Americium	>70%	10-40	41-70	>70
Barium	>70	41-70	11-40	>70
Caesium	11-40	11-40	0-10	41-70
Cerium	>70	>70	11-40	>70
Cobalt	41-70	11-40	11-40	41-70

28. Continue normal water treatments (public supplies) supported by a monitoring programme

Iodine	11-40	11-40	41-70	41-70
Iridium	41-70	11-40	11-40	41-70
Lanthanum	>70	41-70	11-40	>70
Molybdenum/ Technetium	41-70	41-70	11-40	41-70
Niobium	>70	11-40	11-40	>70
Plutonium	>70	11-40	41-70	>70
Radium	11-40	41-70	11-40	>70
Ruthenium	41-70	11-40	11-40	41-70
Selenium	41-70	11-40	11-40	41-70
Strontium	11-40	11-40	0-10	41-70
Tellurium	41-70	11-40	11-40	41-70
Uranium	>70	0-10	11-40	>70
Ytterbium	41-70	41-70	0-10	41-70
Zirconium	>70	11-40	11-40	>70

Notes

[note 1] Most water treatment works have more than one of the processes listed. Where this is the case, the effective removal from successive processes is multiplicative, such that the second or subsequent treatment will only act on the fraction of the element that remains.

[note 2] Removal efficiencies for reverse osmosis for all of the listed radionuclides is more than 70% (3).

Technical factors influencing effectiveness of protective action	Raw water quality. This determines the level of treatment required. Very clean sources of water (such as ground water) with low turbidity require minimal treatment and for these sources it is unlikely that there will be any significant removal of radionuclides. Other water quality parameters such as pH, temperature, and alkalinity may dictate effectiveness of the coagulation-filtration process, and reverse osmosis whilst turbidity influences the effectiveness of filtration and disinfection. Chemical and physical properties of the radionuclides. **Physical characteristics** Radioactive isotopes of some elements can be attached to particulate material in raw water. In this case clarification and filtering processes will largely remove them, depending on the

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	settling qualities and particle size. The presence of large amounts of particulate matter in water will also aid precipitation processes such as flocculation. **Chemical characteristics** Elements that form insoluble hydroxides at pH 4 to 7 will precipitate out during the flocculation process and can be removed. Sr does have an insoluble hydroxide but requires a pH greater than 7 to precipitate fully. However, it may start to co-precipitate with other elements at lower pH. Compounds and particulates may also be complexed with organic materials and be removed during various treatment processes such as activated carbon filtration. The ionic properties of a molecule will determine whether it can be removed or reduced by ion exchange. Contact time during filtration. The passing of water through slow sand filters allows more time for adsorption of radionuclides onto sand particles, compared to rapid gravity filtration. Frequency of replenishing filter media, filters or membranes and so on.
Resourcing	
Specific equipment	Nothing extra. Existing practices.
Ancillary equipment	Monitoring equipment to detect alpha, beta and gamma emitting radionuclides in drinking water, filter media and sludge.
Utilities and infrastructure	Design and implementation of a monitoring and sampling programme. Laboratory capability to analyse samples. When reasonably practicable, engineering and design features and administrative controls should be used to restrict the levels of exposure from the treatment of contaminated water and any waste generated. These may include shielding, warning signals, containment, ventilation systems, time restrictions.
Consumables	Implementers and those carrying out sampling likely to encounter contamination should be provided with personal protective equipment, appropriate to the type of work being undertaken. PPE may include (3): • Gloves to protect against external beta doses to the hands • Overalls to protect against external beta doses to the skin • Respiratory protective equipment to protect against inhalation of resuspended material. This included face masks with filters (reduction in exposure by factors of 5 to 1,000) and powered respirators that clean the air before it

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	is inhaled (reduction factors of 10 to 2,000). The large variability in the effectiveness of respirators is due to the fit of the equipment, length of time on the face, work rates and mobility • Personal dosimeters, if appropriate, to record any doses received
Skills	Nothing extra. Existing practices.
Work rates and operator time	While continuing normal water treatment could be the same as existing practice, the use of respiratory protective equipment for some tasks may affect work rates by up to a factor of 3. There could be additional operator time if operations were performed more frequently due to build-up of contamination on filter media and so on. The additional monitoring of drinking water supplies and contaminated filter media, sludge and so on at the treatment plant will require additional personnel, possibly from other organisations or agencies.
Radioactive waste	
Type	Waste is produced following water treatment. Radioactive contamination that is removed by flocculation and clarification will accumulate in waste sludge. For a given level of water throughput, higher levels of turbidity will give rise to more sludge per unit volume of water being processed. Filtration of water will give rise to the filter media (such as sand) becoming contaminated. The activity concentration in filter media per unit mass are likely to be significantly lower than could be expected in sludge for the same activity concentration in input water due to backwashing removing contamination. Radionuclides will also concentrate in the resins or regeneration waste used for water treatments involving ion exchange. These will have to be replaced and the contaminated ion exchange media will require disposal. Wastewater is generated from the backwashing of filters or the de-watering of floc. In some waste treatment works, wastewater is recycled to the beginning of the treatment process to minimise losses of water. This is commonly referred to as a supernatant return which should be additionally considered to determine whether this should be temporarily halted. If halted, there would need

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	to be an alternative route for disposal, for example, through sewer, which would require consultation with the environment agencies.
Transport	**Sludge** Could be transported as a solid or, if there is low solid content, as a liquid via tanker. If transported by road, waste should be covered or contained using leak-proof vehicles and containers. **Filter and ion-exchange media** Suitable for transport via road. **Wash water or wastewater** If no sewer connection at point of generation, removal by tanker and transport by road.
Treatment	**Sludge** Dewatering could be considered, centrifuging, gravity belt thickening (GBT) or drum thickening. **Filter and ion-exchange media** Carbon filters can sometimes be regenerated by specialist contractors and re-used. Contain in Isofreight container or suitable bag or drum. No specific treatment is required for disposal to LLW incinerator or landfill. May be suitable for supercompaction, the compatibility of treatment wastes depends on their form. Disposal is possible with or without supercompaction, for example, bulk ion-exchange resins are not suitable for supercompaction but can still be disposed of to LLWR. **Wash water or wastewater** Likely to be treated on site and the bulk recycled to head of treatment. The solids are either sent to sewage treatment works via sewer or undergo further dewatering. Levels of contamination will determine whether further treatment is needed. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	**Sludge** Waste should be stored in dedicated specialist containers which prevent escape of liquids or odour. **Filter and ion exchange media** Suitable waste bin, LLWR approved container or Isofreight stored and managed near point of generation. To minimise the spread of contamination, attempt to store waste directly in the container that will go to landfill or incinerator.

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	Wash water or wastewater Unlikely to be stored but, if necessary, it should be stored in leak proof tankers on hardstanding which allows the separation and collection of run off. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	**Sludge** Preferred solution is permitted incinerator. Alternative routes include disposal to LLW permitted landfill. Land spreading may also be possible subject to a radiological impact assessment. **Filter and ion-exchange media** Preferred solution is to a permitted incinerator. Alternative route would be disposal to permitted landfill. Disposal to permitted landfill may not be possible if the waste is classified as hazardous as well as radioactive. Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. **Wash water or wastewater** Disposal directly to natural water sources or sewers subject to a radiological impact assessment. Refer to the protocol for the disposal of contaminated water and associated wastes at incidents, Disposal of contaminated water (May 2018). Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	For implementers at water treatment works the primary exposure pathways are (2, 3): • external exposure from contamination in sludge or filter media (beta and gamma emitters) • external exposure from contact with sludge or filter media (beta emitters) • external exposure from contaminated water (beta and gamma emitters) • inhalation of resuspended material (sludge or filter media) in air (mainly alpha emitters)

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
	The types of tasks giving rise to exposure include general maintenance and inspection (including backwashing of filter beds, dissolved air flotation units, membrane-reverse osmosis-ion exchange unit maintenance); cleaning settling tanks; transporting sludge; working with processed sludge, maintaining sludge pumping equipment or operating a sludge press. Of these, working with processed sludge and sludge press work contribute most exposure from gamma and alpha emitters. For sludge handling tasks, external gamma exposure is by far the most important contributor to total dose for all gamma emitting radionuclides. Inhalation of resuspended sludge is by far the most important contributor to the total doses for alpha emitting radionuclides and isotopes of Sr if the sludge is dry. Where sludge is not handled, filter media maintenance, including changing of reverse osmosis membranes, and inspection of back washing filters contribute the highest exposures from gamma and alpha emitters. However, these dose rates are at least 10 times lower than the corresponding dose rates from working with sludge (2). If it is suspected that implementers are going to be subject to exposures due to a radiation emergency, then it is important that the risks of undertaking the work are assessed and appropriate measures taken to reduce exposures and monitor total exposure (personal dosimeters). The Water Company should seek specialist radiation protection advice. For members of the public, there are no pathways of exposure from the water treatment plant. However, the subsequent management of any contaminated waste produced (such as, sludge) and possible aggregation may give rise to additional doses, depending on the disposal route.
Impact of protective action	
Environmental impact	Utilisation or disposal of radioactive sludge needs to be considered as the activity concentrations in the sludge may be above the levels permitted for normal use.
Agricultural impact	Sludge and sludge sent for additional processing. ‘Digested’ (anaerobically treated) sludge may not be acceptable for amendment of agricultural soil so reduction in provision of sludge for agricultural use.
Practical experience	
	This datasheet focuses on normal water treatment processes.

28. Continue normal water treatments (public supplies) supported by a monitoring programme	
Key references	
	1. Baeza A, Salas A, Guillén J, Muñoz-Serrano A, Corbacho (2019). 'Removal of radium in a working drinking water treatment plant: radiological hazard assessment and waste management' Journal of Hazardous Materials: volume 371, issue 5, pages 586 to 591 2. Brown J, Hammond D and Wilkins BT (2008). 'Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives' HPA-RPD-040 3. Brown J, Hammond D and Wilkins BT (2008). 'Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives: supporting report' HPA-RPD-041 4. Goossens R, Delville A, Genot J, Halleux R and Masschelein WJ (1989). 'Removal of the typical isotopes of the Chernobyl fall-out by conventional water treatment' Water Research: volume 23, issue 6, pages 693 to 697 5. United States Environmental Protection Agency (no date given). Drinking Water Treatability Database (TDB) | US EPA (accessed 22 December 2023)
Comments	
	The use of natural zeolites has not yet been introduced into the water industry. There is a BSEN standard available (BSEN 16070:2014): it is classified as "Under consideration, please seek advice from DWI". This is due to it being a new standard and not yet used. The use is classed as being "used as a cation exchange for removal of dissolved pollutants such as NH_3, Radioactive compounds and heavy metals. Filter media for mechanical filtration of water as an absorbent to remove compounds such as NH_3, HS and some organohalogens and radioactive compounds". This can be kept in as a source of treatment and may be suitable if needed.

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29. Flush distribution system	
General	
Objective	To reduce ingestion doses to consumers of drinking water by draining contaminated water and flushing the water distribution network with uncontaminated water to reduce activity concentrations in consumed water.
Other benefits	While a loss of water pressure is common, this may remove need to shut down the system.
Protective action description	Flushing is a routine operation that water companies use to remove sediments that may affect the water's taste and colour and it is an essential preventive maintenance strategy for the water distribution system. It could also be used to flush through contaminated water once the affected part of the distribution system is isolated or to provide reassurance that the water distribution system is 'clean' of radioactivity following a radiation incident. Flushing of the distribution system should continue until the contamination has been completely removed from the distribution system or diluted to a level that is below the safe water quality limits for the parameter of concern, or an agreed level which does not pose a long-term risk to health. While flushing is carried out and the subsequent effectiveness is being determined, it may be necessary to provide an alternative source of drinking water (datasheet 25). This protective action should be supported by a suitable monitoring strategy to demonstrate that water quality standards are met.
Target	Public drinking water supplies. May also 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
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Small or medium. Will depend on the size of the water network or distribution system contaminated. Likely to only be practicable for localised contamination events in a distribution system rather than widespread atmospheric release.
Timing of application to optimise effectiveness	Primarily early phase but may be used later to provide reassurance on water quality following the earlier passage of contaminated water through the distribution system.

29. Flush distribution system	
Constraints	
Legal	Flushing the distribution system is part of normal operations for a water company. Any drinking water supplies would need to meet the normal quality standards for drinking water, which in England meet the requirements of the Water Supply (Water Quality) Regulations 2016 (as amended) (Statutory Instruments 2016 No 614; in Wales meet the requirements of The Water Supply (Water Quality) Regulations 2018 (Welsh Statutory Instrument 2018 number 647 (W.121); in Scotland meet the requirements of The Public Water Supplies (Scotland) Regulations 2014; and in Northern Ireland meet the requirements of The Water Supply (Water Quality) Regulations (Northern Ireland) 2017 (Northern Ireland Statutory Rules 2017 number 212). Any discharge to water courses would require notification to the relevant environment agencies.
Physical environment	In most cases the contaminated water will most likely be sent to a foul sewer to eventually pass through a sewage treatment process, in occasions of storm flows (above 3 times dry weather flow), diluted contaminated waste could be stored in storm tanks, which in prolonged rainfall events overflow to river. However, despite best endeavours, it may not be possible to divert contaminated water into the foul sewer and the flow could be directed into a water course. If this happens, the EA in England, Natural Resources Wales, SEPA in Scotland or Northern Ireland Environment Agency will take the appropriate action to mitigate the effect on the environment.
Effectiveness	
Protective action effectiveness	Flushing the affected part of a distribution system will be effective at removing or reducing contamination levels in the system. Flushing would also need to remove all sediment deposited during calm network operation as well as biofilm build up, as this could hold radioactive material.
Technical factors influencing effectiveness of protective action	Availability of sufficient sources of clean water. Understanding of the distribution network and access at appropriate points to flush contaminants without spreading contamination further. The level of inner lining build-up of organics or biofilms or manganese, flushing may increase effectiveness, although some containment of the flushed sediment may be required.

29. Flush distribution system	
Resourcing	
Specific equipment	Normal valving equipment, other specialist equipment may be required for older or seized valves. Petrol small pumps and pipes required to remove contaminated water to sewer from chambers.
Ancillary equipment	Monitoring will be needed to determine effectiveness and ensure contamination in supplied water is below UK action levels. Ancillary monitoring capabilities may be required such as in pipe instruments that can relay levels remotely. Monitoring will also be required to ensure that turbidity is below required standards to avoid blockage of services and domestic equipment in the case that water with high turbidity is supplied.
Utilities and infrastructure	Public supply: None Private supply: Sufficient water required for flushing, or else a tanker of water from an alternative supply to be pumped into a private distribution network to flush the system. Either supply: If flushed water is to be drained directly to a water course, dechlorination facilities will be required
Consumables	Alternative water supply may be required, especially if the procedure and associated monitoring are protracted (see datasheet 25: 'Alternative drinking water supply').
Skills	No specific skills are required other than those already employed by the water company or supplier.
Work rates and operator time	Monitoring will require additional time for monitoring staff to travel to or undertake sampling and monitoring after flushing and for laboratory staff to undertake analysis of samples. Field staff monitor water quality during flushing too (turbidity and chlorine levels) If alternative drinking water supplies are required, additional time for drivers to deliver alternative supplies.
Radioactive waste	
Type	If flushing, the water will need to be disposed of – this could be via surface water drains, or through sewer network. Management will depend heavily on contamination levels in the water and the outcome of a radiological impact assessment.
Transport	Ideally not needed if water can be pumped back into sewage treatment works or surface water drains close to point of removal. If water cannot be discharged into the environment or sewage network due to radiological impact, then it should be tankered away for storage.

29. Flush distribution system	
Treatment	If water cannot be discharged direct to the environment due to radiological impact, then consider using settling agents which can be added to remove suspended particles and other impurities from the water. This would separate some of the radioactive particles from the water leaving a solid or sludge waste which would need disposal. For very large volumes of highly contaminated liquids, filtration or ion-exchange systems should be considered to separate radioactive material from liquid. The concentrate and contain principle should be applied. If levels of contamination are lower, then treatment using normal sewage treatment works processes may be deemed adequate to reduce levels of radioactive material. Treatment processes would generate additional solid waste which would need to be managed such as sludges and filtration media. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Stormwater tanks, although these are not available to 'water-only' companies. If volume is small enough, then consider intermediate bulk container (IBCs) or tankers in bunded areas.
Disposal	Subject to the outcome of a radiological impact assessment, wastewater may be suitable for disposal via a radioactive substance activity permitted discharge route for aqueous waste, disposal to a STW or disposal directly into the environment (river or sea). Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances). Refer to the protocol for the disposal of contaminated water and associated wastes at incidents – see Disposal of contaminated water (May 2018).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • exposure could be received by individuals in connection with disposing of any contaminated water and associated sediment, and in dismantling pumping equipment Members of the public:

29. Flush distribution system	
	If contaminated wastewater ends up in a water course (rather than a sewer), very low doses may be received from • external exposure during swimming • inadvertent ingestion of river water, according to the radionuclides present
Impact of protective action	
Environmental impact	None.
Agricultural impact	None.
Practical experience	
	Water companies will have considerable experience in flushing water systems and networks following pipe repairs or maintenance, or inspecting aqueducts or large diameter trunk mains, albeit on a relatively small scale and part of planned work.
Key references	
	None.
Comments	
	Normal practice would be to inform customers by letter, media, post, email or text. If swabbing was to be included in this proposal, then mains relining would require consideration for any ductile iron mains prior to return to service.

Return to index of protective actions in section 4
Return to decision-aiding look-up tables for drinking water supplies in section 6.2
Return to index of protective actions for drinking water supplies in Annexe A2

Annexe A3. Datasheets for inhabited areas

Index to datasheets for inhabited areas

Number	Protective actions: inhabited areas
30	Cover contaminated soil and grass
31	High pressure washing including water jetting
32	Natural attenuation with monitoring
33	Ploughing methods and mechanical digging techniques
34	Prohibit public access
35	Reactive liquids (domestic chemicals)
36	Remove and replace road and paved surfaces
37	Remove building surfaces
38	Remove grass after cutting
39	Remove plant material
40	Remove topsoil (and turf)
41	Store and cover personal and precious objects
42	Strippable coatings
43	Temporary relocation
44	Tie down
45	Vacuum cleaning (indoor and outdoor)
46	Water-based cleaning

Three links are provided at the bottom of each datasheet, one that returns the user to the main datasheet index in section 4, one that returns the user to the decision-aiding look-up tables in section 6.3, and one that returns the user to the datasheet index in this annexe.

30. Cover contaminated soil or grass	
General	
Objective	To reduce external doses by shielding the population from contamination on areas of grass or soil within inhabited areas. To reduce inhalation doses by acting as a covering.
Other benefits	Reduce secondary contamination, the movement of contamination into clean areas by wind or top surface human action. If an impermeable layer is used, it will reduce leaching of radioactive material into groundwater resources.
Protective action description	A layer is placed on top of contaminated soil or grass to act as a shield to external exposure and to suppress resuspension. The layer may be permeable such as soil, sand or gravel, or non-permeable such as asphalt, bitumen, concrete or a multi-layer cap constructed using compacted filler underneath a geomembrane, a layer of compacted clay, another geomembrane and a layer of topsoil. This option may be applied to residual contamination on a soil surface after removal of a topsoil layer and it may also be applied to piles of removed contaminated soils. Covering can also be used for tie-down of contaminated soil to reduce the resuspension hazard to members of the public. In the first instance, use of a crop sprayer to dampen down (not wet) the contamination within the first few hours would be beneficial. This can be repeated every 12 to 24 hours until covering materials are put in place. **Permeable covering (soil, sand, gravel)** A 5 to 10 cm layer of radiologically clean material is applied. Depending on the area, very large quantities of materials are required, which would need to be transported and spread. **Impermeable covering (asphalt, concrete, multi-layer)** A layer of covering material can be applied over small areas adjacent to buildings, particularly as soil very close to a building may, in some cases, be more contaminated due to run-off from the building. Generally, the procedure would involve applying a layer of stabilising gravel, then asphalt (using shovels and other hand-tools) and finally the use of a roller to consolidate. Resurfacing using asphalt may also be carried out by applying a thick layer of gravel, on to which is sprayed a thin sealing asphalt emulsion layer and finishing with a thin layer of gravel). Areas with high footfall, would lend themselves to application of bitumen or asphalt. Use of a concrete covering offers a medium-term solution, but there would be a requirement to check for leaching of

30. Cover contaminated soil or grass	
	contamination in the long term due to its porous nature and topside and underside wetting.
Target	Grass or soil surfaces in inhabited areas. Typically, coverage with clean soil will be targeted at gardens, parks, playing fields and other open spaces, while use of asphalt, concrete or paving stones will be targeted at small to medium-sized open areas, often around residential buildings, schools and so on, where people generally spend much of their time while outdoors.
Targeted radionuclides	All long-lived radionuclides that give significant external or resuspension doses (benefit would be minimal for gamma emitters).
Scale of application	Permeable coverings: best suited to small areas. Impermeable coverings: small areas focussed on boundaries around buildings.
Timing of application to optimise effectiveness	Shielding: likely to be effective for a long time after deposition, although soils should not be used for shielding beta or gamma emitters. Tie-down: maximum benefit is achieved if carried out soon after deposition when most of the contamination remains on the ground surface and resuspension is likely to be high. Other surfaces may lose contamination to soil after the initial deposition by either natural processes, such as, leaf fall in parks, or when actions are applied to those surfaces, for example, tree pruning. It may be optimal to remove this material before covering the soil.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • provide the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition)

30. Cover contaminated soil or grass	
	• providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage
Physical environment	Weather conditions: • cold weather • wind and rain The option cannot be applied to a surface covered in snow or standing water. The option cannot be applied to very steep slopes. The condition of the underlying area may affect the ability to cover, for example, mud cannot easily be covered with asphalt or soil. Vehicle access should be controlled so as not to turn the underlying ground to mud. Presence of trees and shrubs that may need lopping or felling.
Effectiveness	
Reduction in contamination on the surface	The decontamination factor (DF) for this option is 1, as no contamination is removed.
Reduction in surface dose rates	A reduction in external gamma dose-rate above the clean soil, concrete or asphalt of 30% to 80% (DF 1.5 to 5) could be expected depending on the energy of the gamma rays emitted and the depth and density of the covering material (that is, 1,500 kg/m^3 for soil, 1,300 kg/m^3 for asphalt, and 2,400 kg/m^3 for concrete. RFs of 5 are at the upper end of what is achievable.
Reduction in resuspended activity in air	Resuspended activity in air above the soil (or grass) surface will be effectively reduced by 100%. Dust creation during implementation is unlikely to be a problem therefore management options to reduce resuspension hazard to workers will not be necessary (unless the resuspension hazard in the area is deemed significant). However, there can be some variability depending on how the option is applied.
Technical factors influencing effectiveness of protective action	Design of the cover - this may need to be adjusted to the specific features of a site such as, amount of rainfall, traffic and so on. Permeability, type, thickness, and density of layer (see 'Reduction in surface dose rates' section above). Evenness of ground surface. Number of plants, shrubs, and trees in area.

30. Cover contaminated soil or grass	
	Secondary contamination on or off the affected area.
Resourcing	
Specific equipment	**Soil** Spades, bobcat mini bulldozer, rake, plywood for surface compaction, sprinkling equipment, transport vehicles for equipment and soil. **Asphalt, bitumen, other coatings** Small asphalt roller, shovels, specialist rakes for planing, gravel or asphalt layers, trucks for transport of roller, asphalt, and stabilising gravel.
Ancillary equipment	Transport vehicles for equipment.
Utilities and infrastructure	Roads for transport of equipment and materials.
Consumables	Layer material, such as, top-soil, asphalt, sand, gravel concrete, (suitable topsoil may be difficult obtain in large quantities). Fuel and parts for equipment and vehicles. PPE.
Skills	To deploy this option, people (public or contractors) will need to work and move in contaminated environments. Hence, ideally, they should be skilled and experienced with working in PPE or RPE within hazardous environments. An alternative, would be offer a brief and light touch training for individuals to show how they would work, including in light PPE On a small scale, using spades, covering with soil can be implemented by unskilled workers. This option could be implemented as a self-help measure. It requires hard physical work, which not all persons would be capable of. Skilled workers will be required to operate equipment if covering a larger area with soil, if implementing a more sophisticated soil cap, or if covering with asphalt.
Work rates and operator time	Work rate depends on access and openness of area and equipment used. Soil – small areas: 10 m^2 per team hour (team size: 1 person). Soil – larger areas: 400 m^2 per team hour (team size: 2 people). Asphalt: 15 m^2 per team hour (team size: 4 people).
Waste	
Type	None.
Transport	n/a

30. Cover contaminated soil or grass	
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Implementors: • external dose from the deposited radionuclides • inhalation from resuspension Members of the public: none.
Impact of protective action	
Environmental impact	Disruption or loss of flora and fauna may be unacceptable for natural ecosystems or plant collections. Asphalt and concrete will prevent natural ecosystems re-establishing after disruption. Use of incompatible topsoil may impact type of vegetation that can subsequently develop on soil. Aesthetic consequences of landscape changes, particularly from soil to asphalt. There will also be an impact in areas from where soil is obtained, potentially affecting the quality or quantity of arable land available. Possible flooding risk in areas where large scale application of asphalt is used to cover contaminated land. As contamination is not removed, radionuclides under a permeable layer may leach deeper into the soil and impact on groundwater resources.
Practical experience	
	Covering decontaminated and non-decontaminated soil surfaces with a layer of clean soil and sand was an option widely applied in the Former Soviet Union after the Chornobyl accident. Asphalting was also used (1, 2, 5). Following the Fukushima accident, covering decontaminated and non-decontaminated soil surfaces with a layer of clean soil was applied to gardens, unpaved roads, school yards and parks. (4). During clean-up following the Goiânia incident, a concrete or soil layer was applied to areas where contaminated soil was removed, and where the rubble from demolished houses were removed (3).
Key references	
	1. Balonov MI, Golikov VY, Yerkin VG, Parkhomenko VI and Ponomarov AV (1991). 'Theory and practice of large-scale decontamination of populated areas in the Bryansk region after

30. Cover contaminated soil or grass	
	the Chernobyl accident' In: 'Proceedings of International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents' Caderache, Commission of the European Communities, pages 397 to 415 2. Fogh CL, Andersson KG, Barkovsky AN, Mishine AS, Ponamarjov AV, Ramzaev VP and Roed J (1999). 'Decontamination in a Russian Settlement' Health Physics: volume 76, issue 4, pages 421 to 130 3. IAEA (1988). 'The Radiological Accident in Goiânia' IAEA STI/PUB/815 4. Ministry of Environment (2013). 'Decontamination guidelines second edition' Ministry of Environment, Japan. 5. Roed J, Andersson KG, Barkovsky AN, Fogh CL, Mishine AS, Olsen SK, Ponamarjov AV, Prip H, Ramzaev VP and Vorobiev BF (1998). 'Mechanical decontamination tests in areas affected by the Chernobyl accident' Denmark. Forskningscenter Risoe. Risoe-R-1029(EN)
Comments	
	This option leaves contamination in place so will severely complicate subsequent removal of the contamination if this is subsequently required. Ongoing controls may be required where topsoil is used as the covering material, as contamination may be available for uptake by crops. Subsequent disturbance of the clean layer, by whatever means, will reduce the effectiveness of the option.

Return to index of protective actions in section 4
Return to decision-aiding look-up tables for inhabited areas in section 6.3
Return to index of protective actions for inhabited areas in Annexe A3

31. High pressure washing including water jetting	
General	
Objective	To remove some or all contamination from (mostly outdoor) surfaces in inhabited areas and therefore reduce doses from external irradiation and inhalation of resuspended material to levels deemed acceptable for dose and re-habitation.
Other benefits	Will remove bulk contamination from treated surfaces and therefore limit redistribution of contamination. Implementing this action outdoors will make an area look clean and may provide reassurance to public.
Protective action description	Water jetting or rinsing can be used in many ways to deliver decontamination. A plethora of combinations of pressure, flow, and means of deployment exist. To appreciate the selection criteria for water jetting or rinsing options, simplistically the following may be helpful, but does not replace the requirement to seek expert advice, based on site specific conditions: 1. Flow can be considered as the means to carry debris or contamination away from the target area without cause for recontamination of the decontaminated surface 2. Pressure represents the ability to 'cut' through the debris, contamination or coating and fragment that material such that the flow can carry it to a waste route 3. Jet type is key to how aggressive the water jet is. A choice of wide-angle sprays (low aggression) to highly collimated ones (very aggressive) 4. Distance from the substrate has a dramatic effect. Normally water jets are 10 to 30 mm from the target to ensure most effective use of the energy before it can dissipate Water jetting can be deployed manually or remotely and spans from a gentle wash from a hose through to (ultra) high pressure water jetting necessary for coatings or cutting of concrete. Beyond the power of a domestic jet washer (approximately 100 bar at 4 to 5 litres per minute), readily available specialist equipment, personnel with Water Jetting Association training photocards are required. Water jetting and fire hosing should be directed in a top-down manner. For domestic situations a hosepipe should suffice in the first instance to reduce bulk radiation dose and resuspension potential. After this initial action, patio cleaner style attachments for jet washer units can be used for paths and where possible vertical surfaces. This represents the credible limit of public self-help.

<table>
<tr><th colspan="2">31. High pressure washing including water jetting</th></tr>
<tr><td></td><td>In the later phases, weathering will have occurred such that (ultra) high pressure systems will be required to overcome ingress of contamination. This can cause damage to property, such as by potentially peeling off the surface of objects. Surfaces should be checked in advance with advice from a specialist (7).
High pressure (or ultra-high pressure) jet nozzles can be used to clean roads or paved surfaces, blasting contamination from cracks when mounted on a lorry and used in conjunction with high performance water filtered vacuum or suction water collection system.
Wastewater
Large volumes of wastewater will be generated by this method. Where possible, measures shall be taken to prevent the dispersion of the cleaning water, that is:
1. For walls, hanging PVC sheets may be used to direct water into metal troughs sealed to the base of the wall with pitch
2. For roofs, modified guttering and drainpipes may be used to feed wastewater into collection tanks
3. For roads and paved areas, bunds may be used to constrain water in an area so it may be pumped into tankers
Various methods have been developed by US EPA and Argonne National Laboratory for collecting and treating contaminated wastewater (for example, IWATERS (6)).
Any wastewater that is not collected will pass into drains (public sewers or highway drainage) or onto grass or soil verges. In order to contain the wastewater, drains can be blocked, and pumps used to collect most of the surplus water where possible (scale and time dependent).</td></tr>
<tr><td>Target</td><td>Highly contaminated external walls and roofs of buildings, outdoor hard surfaces such as roads and paved areas, surfaces in semi enclosed areas, and vehicle exteriors. Some internal floors and walls with large area hard surfaces (such as, within public buildings such as railway stations) may be robust enough to withstand high pressure hosing.
It may be beneficial to give particular focus to schools, nurseries, hospitals, and other buildings frequented by large numbers of people.
High-pressure water jets can also be used to decontaminate train tracks and gravel or pebbles.</td></tr>
</table>

31. High pressure washing including water jetting	
Targeted radionuclides	All long-lived radionuclides. Should only be used for short-lived radionuclides if implemented quickly.
Scale of application	Small to large scale.
Timing of application to optimise effectiveness	In the early phase (first week), bulk removal of loose contamination can be achieved with very low pressure (high flow) systems, such as, domestic hose pipes and fire hoses for industrial or commercial structures that are used in a manner to avoid resuspension. In the later phases, weathering will have occurred such that (ultra) high pressure systems will be required to overcome ingress of contamination.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • provide the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Severe cold weather (snow and ice may cause problems and water would need to be heated). Note, frozen surfaces may react differently to the sudden impact of water at higher temperatures, for example, more susceptible to crumble or collapse and so on, advice should be sought before applying heated water to frozen surfaces. Surfaces must be waterproof and must resist water at high pressure.

31. High pressure washing including water jetting	
	Run-off to soils or vegetation should be avoided. May need to bund a path or road to prevent run-off recontamination of the areas.
Effectiveness	
Reduction in contamination on the surface	The decontamination factor (DF) achieved depends on the time of application. A higher DF will be achieved if there is no rainfall or significant 'traffic' on the surface before implementation. Where a range of DFs is given, higher DFs tend to be achieved following dry deposition than after wet deposition. Additionally, performance is heavily influenced by the time from deposition and other factors. Use of high-pressure jet washing in Japan following the Fukushima accident has delivered reductions in surface contamination presented in the following table (8). The data are based on initial decontamination work (mainly during 2011) conducted by the national and local governments mainly in areas with relatively high radiation levels in Fukushima Prefecture. [table below] In the short term, the quoted DF can be considered to be the same for almost all radionuclides. Important exceptions are elemental iodine and tritium where, for impermeable surfaces, thorough washing can lead to virtually complete removal. Where a range of DFs is given, higher DFs tend to be achieved following dry deposition then after wet deposition. For loose contamination the DFs would be at the upper end of the ranges shown. Dry and wet deposition tests carried out by US EPA (11) demonstrated that delayed pressure washing may lead to decreased removal of Cs from the surface due to the subsurface

Surface	Reduction in surface contamination
Exterior walls (concrete)	20 to 80% (DF=1.25 to 5)
Roof surfaces	40 to 80% (DF=1.6 to 5)
Paved areas (concrete or asphalt)	30 to 70% (DF=1.4 to 3.3)
Roads	10 to 50% (DF=1.1 to 2)
Rain gutters and roadside gutters and so on	60 to 80% (DF=2.5 to 5)

31. High pressure washing including water jetting	
	penetration. For asphalt, Cs removal in the liquid phase was dominant, and the removal efficacy increased with increased water pressure up to 7,000 psi. The water pressure (6,000 to 7,000 psi) provided high decontamination efficacy (50% to 80%) with minimal surface degradation. In the case of brick and concrete, test results showed a minimal increase (less than 10 % increase) in Cs removal as a function of pressure in the range of 4,000 to 7,000 psi. However, analysis of the data showed that increased removal efficacy for brick and concrete were related to removal of solid materials by the high-pressure stream. Extensive layer removal from brick and concrete surfaces is expected to increase the removal efficacy because of subsurface penetration and Cs sorption on the removed surfaces. UK Nuclear experience with higher pressure systems have seen much greater performance, spanning a range of exposure times.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated surfaces will be reduced by a factor similar to the DF. Experience of high pressure washing of roofs following the Goiânia incident gave about 20% reduction in dose rates (3).
Reduction in resuspended activity in air	Resuspended activity in air following decontamination will be reduced by the value of the DF.
Technical factors influencing effectiveness of protective action	Each of the following will have a significant influence upon decontamination performance. Pressure – ability to cut through the fouling material. Flow – sufficient flow to carry debris. Too little, contamination can penetrate the substrate and any cracks, crevices and so on to leach contamination in the future. Stand-off – too far away and the surface will be wetted as the energy of the water jet is dissipated. Jet type – the effective spray angle of the water jet, too wide and the energy density on the substrate is too low resulting in poor performance. Adhesion and depth of contamination – If contamination is bonded onto the surface of the substrate, a high-pressure system is required. If loose contamination, then a low energy system is required. Should contamination be at depth, ultra-high pressure systems are needed. Exposure time and weathering will propagate and enhance mobility of contamination into substrates.

31. High pressure washing including water jetting	
	Skilled personnel – for systems more than 100 bar, for safety and performance, the supply chain should be used who are trained, equipped, and have the operational experience. Consistent application of water over the contaminated area (that is, operator skill which will influence consistency of nozzle distance from surface and time spent per unit area). Furthermore, it has been found that short exposure times to the water spray can lead to incomplete surface removal and drive contamination further into the building material (5). Hence, exacerbating the overall decontamination challenge. Care in application. Special care must be taken over areas where contamination accumulates, that is, roof gutters, drainpipes, and road gutters, in addition to the conventional safety of the user or operator. Type, evenness, and condition of surface. Rough surfaces, for example, roof tiles, may trap contamination which is harder to remove. The mechanical strength of the material will influence surface mass removed during washing. Argonne National Laboratory reported high pressure washing to be an ineffective method for cleaning hard brick surfaces. However, UK nuclear experience suggests that using the right 'water jet' in the right way, at the right standoff, can give excellent performance. Time of implementation. The longer the delay, the less effective the action will become. Weathering will reduce surface contamination over time. Contamination will also become more fixed to the surface over time. Rainfall can increase the penetration of contamination into the surface. Some studies (10) show that the increased penetration is less on asphalt than on brick or limestone and so a delay in cleaning roads may not be as significant and for building and walls.
Resourcing	
Specific equipment	Equipment will depend on the exact method chosen. (Ultra) High-pressure washing**:** greater than or equal to 100 bar pressure washer; generator; gully sucker. Fire hosing**:** fire-tender or hydrant with pump if required; fire hose; PVC sheets, hydraulic platform with mounted hoses if required for reaching buildings.
Ancillary equipment	Transportation vehicles for equipment and waste; filter; spare pump; scaffolding with roof ladders or mobile lift for roof access if required for buildings.

31. High pressure washing including water jetting	
	Possible extras: high pressure (or ultra-high pressure) jet nozzles, brushes; high-performance, water-filtered vacuum or suction water collection system, trough, tanks, bunds,
Utilities and infrastructure	Roads for transport of equipment and waste. Water and power supplies. Public sewer or highway drainage system. Containers for effluent, either bowsers or IBCs if not suitable for the public sewer.
Consumables	Fuel and parts for generators and transport vehicles. Water. Surface treatment if required for roofs.
Skills	Skilled personnel essential to operate pressure washing equipment and gully suckers or fire engines and hoses.
Work rates and operator time	High pressure washing: 30 to 60 m^2/h for buildings (1). Japanese experience indicates that high pressure washing can be performed at 10 to 40 m^2/h, with a higher rate on roads than for buildings (8), and assuming a 7 hour working day to convert from m^2/day to m^2/hour. Fire hosing: up to 100 m^2/h for roads (2). Estimates are given per team, where a team may consist of 2 to 3 people, or more in some situations, such as working at height. Additional people may also be needed if water is collected and filtered prior to disposal. Depending on the PPE used individuals may need to work restricted shifts. Times include setting up scaffolding, if required.
Waste	
Type	Dust and water. High pressure washing: 0.2 to 0.4 kg/m^2 solid and 20 l/m^2 water (2). Fire hosing: 0.1 to 0.2 kg/m^2 solid and 250 l/m^2 water (2).
Transport	Possible use of sump pumps to collection vessels, for example, IBCs, or a tanker to remove wastewater. Typical articulated tanker has a maximum volume of 30,000 litres.
Treatment	Consider using settling agents which can be added to remove suspended particles and other impurities from the water. This would separate some of the radioactive particles from the water leaving a solid or sludge waste which would need disposal. For very large volumes of highly contaminated liquids, filtration or ion-exchange systems should be considered to separate

31. High pressure washing including water jetting	
	radioactive material from liquid. The concentrate and contain principle should be applied.
Storage	Wastewater should be stored in IBCs or tankers in bunded areas. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Wastewater can potentially be suitable for disposal via a radioactive substance activity permitted discharge route for aqueous waste or disposal to a STW (advice from environment agencies must be sought).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground (as dust or spray) and other surfaces • inadvertent ingestion of dust (can be avoided by correct use of PPE) Those transporting and managing waste may also be subject to external exposure. Washing contamination to the public sewer has the potential to give a non-trivial dose at the wastewater works. The aeration process can be a source of airborne contamination. Members of the public: none.
Impact of protective action	
Environmental impact	Contaminated wastewater, if not collected, will run on to other surfaces or directly down drains into public sewer or highway drainage systems. Potential for run off to adjacent soils or vegetation. Potential for run off from adjacent soils, vegetation or roads and paths. Disposal of wastewater to drains may have an environmental impact. Some water will enter the public sewers and be treated at the sewage treatment works (STW) from which monitoring and control of any subsequent disposal can minimise the environmental impact. Surface water that enters a highway drainage system may be drained through a sustainable urban drainage (SUD) system, which will offer some control. However, some highway drainage systems will direct to a local water course. Where wastewater can

31. High pressure washing including water jetting	
	be disposed via a STP or SUD, the environmental impact may be easier to control and monitor than long term run-off produced by rainfall.
Practical experience	
	Treatment of walls and roofs have been tested on realistic scale in the Former Soviet Union and Europe after the Chornobyl accident (2, 9). Used following the incident in Goiânia (3). Used in Japan following the Fukushima accident to clean roofs and outer walls; eaves, roof gutters, storm water catch basins and street gutters (after removing deposited material); parking lots, roads and other paved surfaces (in combination with washing and surface removal) (4, 8). Small-scale tests on the treatment of roads and paved areas have been conducted in other countries, for example in the US, under varying conditions (10, 11). The authors report lower DFs to the ones quoted above. This may reflect the choice of deposition methods and surface type. The fate of removed Cs (dissolved or particulate portion of the wastewater) was strongly influenced by surface type. High and ultra-high pressure water jetting has been effectively used in the nuclear industry for surface cleaning, cutting and coatings or concrete removal. The DFs are much higher than US trials. Higher water flows rates over 12 litres per minute are necessary to prevent recontamination of a surface with and without aerosol extract systems.
Key references	
	1. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). 'Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas' Risø-R-1396(EN)' Risø National Laboratory, Roskilde, Denmark 2. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovitch V (1996). 'Strategies of decontamination' Experimental Collaboration Project 4, European Commission, EUR 16530 EN, ISBN 92-827-5195-3 3. IAEA (1988). 'The radiological accident in Goiânia' STI/PUB/815 ISBN 92-0-129088-8

31. High pressure washing including water jetting	
	4. IAEA (2014). 'The follow-up IAEA International Mission on remediation of large, contaminated areas off-site the Fukushima Daiichi Nuclear Power Plant, Tokyo and Fukushima Prefecture, Japan, 14 to 21 October 2013' IAEA NE/NEFW/2013 23 January 2014 5. Jolin WC, Magnuson,ML and Kaminski MD (2019). 'High pressure decontamination of building materials during radiological incident recovery' Journal of Environmental Radioactivity: 208 to 209, 105858 6. Kaminski, M (2015). 'Irreversible wash aid additive for cesium mitigation: small scale demonstration and lessons learned' Argonne National Laboratory Report ANL/NE-15/12 [includes IWATERS design and implementation details]. Contact: kaminski@anl.gov 7. Ministry of the Environment, Japan (2013). 'Decontamination guidelines, second edition' 8. Ministry of the Environment, Japan (2018). 'Decontamination projects for radioactive contamination discharged by Tokyo Electric Power Company Fukushima Daiichi nuclear power station accident' Editorial Committee for the Paper on Decontamination Projects, Ministry of the Environment, Japan, March 2018. ISBN978-4-600-00139-1 9. Roed J and Andersson KG (1996). 'Clean-up of urban areas in the CIS countries contaminated by Chernobyl fallout' Journal of Environmental Radioactivity: volume 33, issue 2, pages 107 to 116 10. US EPA (2014). 'Fate and transport of cesium RDD contamination - implications for cleanup operations' US Environmental Protection Agency, Washington, DC. EPA/600/R-14/250 11. US EPA (2015). 'Effect of pressure washing conditions on the removal of Cs from urban surfaces: assessment and evaluation report' US Environmental Protection Agency, Washington, DC. EPA/600/R-15/076
Comments	
	If run-off to ground surfaces occurs, the implementation of options to the surrounding ground surfaces should also be considered after fire hosing or high-pressure hosing has been implemented. If the implementation of any other options to the surrounding ground surfaces is planned, high pressure hosing of walls and roofs should be implemented first.

31. High pressure washing including water jetting	
	Secondary contamination may require subsequent clean-up and therefore this action should be implemented before other decontamination actions in the same location. If the impact of secondary contamination is substantial, alternative water-based cleaning methods should be considered. Precautions are needed to ensure that people making connections to mains water supplies do not inadvertently contaminate the water supply, for example, by back-flow from vessels containing radioactivity or other contaminants, or operate hydrants in a way that disturbs settled deposits within the water main system.

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32. Natural attenuation (with monitoring)	
General	
Objective	To allow contamination in the environment to decrease through natural processes, including radioactive decay and migration, such that doses to members of the public reach levels that have been agreed as acceptable.
Other benefits	No active implementation of protective actions other than monitoring. Avoids creation of large volumes of waste.
Protective action description	Natural weathering via rain may lead to downward migration of mobile radionuclides in structures, soil profiles and so on, leading to reduced dose rates due to dilution and increased shielding provided by increasing thicknesses of overlying soil. Less mobile radionuclides will still migrate but at a much slower rate so decreasing the effectiveness provided by natural weathering. In addition, natural decay of radionuclides will occur with time. When the contamination involves a radionuclide that has a short half-life or is mobile in the environment, then it may be sufficient to allow activity concentrations to decrease naturally without active implementation of any other protective actions. For example, after time equal to 4 half-lives has passed the activity present will be reduced by a factor of about 10, while after time equal to 10 half-lives has passed the activity present will be reduced by a factor of about 1,000. A very strong justification and equally robust monitoring programme should always accompany remediation by natural attenuation. That programme should confirm that nuclides are dispersing as expected. Collection or accumulation of contamination in drains, becks, dykes, streams, sewers and water treatment plants must be considered and confirmed by monitoring. For some situations, no other protective actions are applicable so that natural attenuation becomes the default option. In this situation, the risks from secondary contamination of clean or freshly remediated sites from wildlife, run-off and weathering, need to be monitored and assessed. Where there is a high demand to maintain or allow access to areas where the land has a high commercial or social use (housing; hospitals; religious buildings and so on), more aggressive remediation technologies such as removal or burial may be justified to reduce activity concentrations more quickly on surfaces.
Target	Environmental media (such as, soil) and on artificial surfaces (for example, bricks and paving) to reduce doses from external gamma

	32. Natural attenuation (with monitoring)
	irradiation and inhalation of suspended material in places where people spend their time.
Targeted radionuclides	Radionuclides with very short half-lives: ^{75}Se (half-life: 120 days); ^{131}I (half-life: 8 days); ^{192}Ir (half-life 74 days) and even then, caution and expert guidance would be required before implementation.
Scale of application	Small to medium scale according to availability of site security processes as well as monitoring equipment and personnel. The UK could not sustain large scale monitoring over a long period of time as monitoring resources would be rapidly exhausted, regardless of the specific scenario.
Timing of application to optimise effectiveness	Early to intermediate phase.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate
Physical environment	Affected areas need to be accessible to monitoring teams. Physical environment may limit opportunity for taking representative samples of environment media, for example, soils for laboratory analysis
Effectiveness	
Protective action effectiveness	Does not actively remove the radionuclide from the environment but instead relies on radioactive decay and/or physical and chemical processes to reduce activity concentrations. The effectiveness of the action is related to environmental and weather conditions, as well as the elapsed time, supported by an appropriate monitoring programme.
Technical factors influencing effectiveness of protective action	Physical half-life of the radionuclide. Weathering rates of individual elements in different materials. Accessibility for monitoring. Mobility in the environment. Mobility of elements is very dependent on the texture and organic content of soil (3), on the porosity and chemical composition of artificial surfaces, and on the timing and quantity of rain (1).
Resourcing	
Specific equipment	None. Although not essential, vehicle mounted large area monitors can prove very useful.

32. Natural attenuation (with monitoring)	
Ancillary equipment	Sampling and monitoring equipment as appropriate for the radionuclides and environmental media of concern.
Utilities and infrastructure	Laboratory to undertake analysis of samples. Administrative support for data handling, recording and interpretation.
Consumables	None.
Skills	Statistician to create a robust sampling and monitoring plan Hydrologist, soil scientist, material scientist, and chemist with an understanding of the local surface and subsurface hydrology to predict movement of radionuclides. Trained personnel to carry out monitoring and sampling.
Work rates and operator time	Monitoring staff, time required to: • travel to or from an area • set up sampling and monitoring equipment • take samples of environmental media (if appropriate) • maintain equipment and vehicles Laboratory staff: • time required to carry out sample preparation and analysis
Waste	
Type	None if allowed to fully decay under some form of authority control.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Monitoring operatives: • external exposure while working in a contaminated area • inhalation of material resuspended by the wind Members of the public when combined with restricted access: • limited potential for exposure
Impact of protective action	
Environmental impact	None.
Agricultural impact	None.

32. Natural attenuation (with monitoring)	
Practical experience	
	Environmental media samples are regularly taken to support routine monitoring programmes by both operators and the regulators (4, 5). Vehicle mounted systems for large area monitoring have been used on several beaches around the Dounreay and Sellafield sites for more than 20 years (2).
Key references	
	1. Brown J, Ewers L and Youngman M (2016). 'An experimental study on natural weathering of radionuclides from urban surfaces for aerosols deposited in wet and dry conditions' Radioprotection: volume 51, pages S109 to S112 2. Etherington G, Youngman MJ, Brown J and Oatway WB (2012). 'Evaluation of the Groundhog Synergy Beach monitoring system for detection of alpha-rich objects and implications for the health risks to beach users' HPA, Chilton (UK), HPA-CRCE-038 3. IAEA (2010). 'Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments' IAEA technical report series number 472 4. 'Radioactivity in Food and the Environment (RIFE) report' (2019) 5. Sellafield Ltd (2018). 'Monitoring our environment: discharges and environmental monitoring annual report 2017' Sellafield Limited
Comments	
	Public acceptance (or lack thereof) may be an issue as the natural attenuation option could be viewed as inaction. Some form of information campaign may be necessary to ensure stakeholder agreement. Can be used in conjunction with: • decisions on lifting restriction of access or relocation

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33. Ploughing and mechanical digging techniques	
General	
Objective	To reduce inhalation and external doses from contamination in outdoor areas covered in grass or soil.
Other benefits	None.
Protective action description	All ploughing and mechanical digging techniques move contamination at or near the top of the soil column down the soil column. The increased depth of soil shields those above from contamination and reduces external dose; the reduced contamination at the surface decreases resuspension. Ploughing can be carried out at a range of depths, depending on the equipment used. A standard single-furrow mouldboard plough can be used to a depth of 250 to 300 mm, or to a deeper depth of 450 mm. A special deep plough that tills the soil to a depth of 900 mm may also be available but will require a more powerful tractor than is commonly available. Mechanical digging using power driven rotovators under manual control till to a depth of about 150 mm. Rotovating mixes the upper soil layers uniformly within a relatively shallow depth. Alternatively, mechanical digging using excavators in which the top 100 mm is dug and placed to one side; the lower 200 mm is then dug out and also placed to one side. The first layer of soil is replaced at the bottom of the excavation and the second layer at the top (3, 4). Removal of plants and shrubs may be necessary before ploughing or digging. Afterwards, replanting, replacing grass and fertilising and rolling the land may be required. A long-term monitoring programme, including the sampling of vegetation and water courses should be carried out to investigate whether contamination has penetrated the water table, due to flooding and/or migrated to any nearby water courses. This option is likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation. Water dampening will ease the ploughing action and to limit the resuspension hazard.
Target	Ploughing: grass and soil surfaces in which it is feasible to manoeuvre a tractor and plough, for example, large parks, playing fields and other open spaces. Mechanical digging: grass and soil surfaces in gardens, and other small open spaces.
Targeted radionuclides	Predominantly short-lived radionuclides, in this case 2 years or less.

33. Ploughing and mechanical digging techniques	
Scale of application	Ploughing is suitable for large, continuous areas only. Mechanical digging is more suitable for small areas.
Timing of application to optimise effectiveness	Early and intermediate, particularly to prevent resuspension. The action is effective because it moves the contamination to the lower layers of the soil much more quickly than by natural downward migration. Ploughing is a technique that should only be applied once, repeated ploughing may bring contamination back to the surface. Other surfaces may lose contamination to soil after the initial deposition by either natural processes, such as leaf fall in parks, or when actions are applied to those surfaces, for example, tree pruning. It may be optimal to remove this material before ploughing the soil.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage
Physical environment	Ploughing is hampered by frozen soil, tree roots, pipes, cables, stones, high water table and standing water. It may not be possible, or damaging to the soil, to drive a tractor on excessively moist soil. The surface must not be too steep for the tractor. The efficiency of the technique will reduce in smaller areas or areas with a lot of obstructions, because there will be edges and corners the plough cannot reach and more time will be spent aligning and manoeuvring the plough. In these situations, it is more appropriate to use mechanical diggers.

33. Ploughing and mechanical digging techniques	
	Appropriate depth for ploughing or digging should be considered, that is, is there a shallow depth to bedrock, will ploughing introduce contamination into a high water-table, or is there a hardpan that should not be breached.
Effectiveness	
Reduction in contamination on the surface	This option has an overall reduction factor (RF) of 1 because it removes no contamination. However, surface contamination RFs will be 10 to 100 (90 to 99% reduction).
Reduction in surface dose rates	Depending on gamma energy and natural downwards migration, an external gamma dose rate reduction factor of between 50% to 85% (RF of 2 to 7) can be expected for shallow ploughing and between 80% to 90% (RF of 5 to 10) for deep ploughing. Reductions after using an excavator have been estimated to be in the range of 65% to 85% (that is, RF of 3 to 7). Rotovating is less effective as it does not bury contamination under a clean soil layer but mixes it homogeneously over the treated depth, reductions of 50% to 70% are likely (that is, RF of 2 to 3). Beta dose rate reduction is likely to be significantly higher, effectively stopping beta emitters.
Reduction in resuspended activity in air	By burying most of the contamination, resuspended activity in air above the surface will be reduced by a factor significantly larger than the external gamma dose rate reduction.
Technical factors influencing effectiveness of protective action	If the soil has already been disturbed by ploughing or digging or some other action since deposition, then ploughing will have no further benefit and may bring contamination back to the surface. Depth of ploughing. Buried obstacles. Water table, courses or flows. Vertical migration in the soil profile, which will vary according to radionuclide, soil type, weathering and so on.
Resourcing	
Specific equipment	A suitable plough for the required depth and a suitable tractor to pull the plough. Deep ploughing will require a powerful tractor. Rotovators, or larger excavation equipment.
Ancillary equipment	Transport vehicles for equipment. Restoration equipment such as tractor-drawn rollers.
Utilities and infrastructure	Nothing specific.

33. Ploughing and mechanical digging techniques	
Consumables	Fuel and parts for transport vehicles and tractor. Fuel: around 15 litres/ha for ploughing. Replacement tyres or sacrificial ‘socks’ for tyres to prevent spread of contamination when on public roads and tracks. Mild decontamination reagents for plough. Replacement plants and grass.
Skills	Personnel skilled in ploughing can be used but must be instructed carefully about the objective. For rotovating and mechanical excavators, trained workers are required.
Work rates and operator time	Operator times for ploughing and mechanical digging are subject to many variables including the environment, weather conditions, the skills and equipment available.
Waste	
Type	None.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Implementors: • external dose from the deposited radionuclides This option could raise dust, potentially exposing implementors and public to a resuspension hazard, so application of water to dampen the surface or the use of a tie-down material might be considered.
Impact of protective action	
Environmental impact	Soil erosion risk (may be reduced by reseeding of grass). May bring contamination closer to groundwater. Loss of soil fertility (if deep ploughing is carried out) may be unacceptable but remedied by application of fertilisers. Soil may need to be rolled afterwards before use.
Practical experience	
	Tested widely in the Former Soviet Union after Chornobyl and on limited scale in Denmark (1). Ploughing was generally applied in agricultural settings to reduce crop uptake in Japan following the Fukushima accident. However,

33. Ploughing and mechanical digging techniques	
	it was also used to reduce external doses to those who worked or lived near the nuclear power plant (4). Mechanical diggers were used to interchange topsoil and subsoil following the Fukushima accident (2).
Key references	
	1. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovich V (1996). 'Strategies of decontamination' Experimental Collaboration Project number 4. Final Report. European Commission, EUR 16530 EN 2. IAEA (2011). 'Final report of the international mission on remediation of large, contaminated areas off-site the Fukushima Dai-ichi NPP, 7 to 15 October 2011, Japan' NE/NEF/2011 3. Japan Atomic Energy Agency (2015). 'Remediation of contaminated areas in the aftermath of the accident at the Fukushima Daiichi nuclear power station: overview, analysis and lessons learned part 1: a report on the "decontamination pilot project"' JAEA-Review 2014-051 4. Ministry of Environment (2013). 'Decontamination guidelines second edition' Ministry of Environment, Japan 5. Roed J, Andersson KG and Prip H (1996). 'The skim and burial plough: a new implement for reclamation of radioactively contaminated land' Journal of Environmental Radioactivity: volume 33, issue 2, pages 117 to 128
Comments	
	This action leaves contamination in situ, if a decision is subsequently made to remove the contamination, ploughing will increase the difficulty and the amount of waste generated. Subsequent ploughing or digging can bring contamination back to the surface so ongoing controls may be required. There is the potential for contaminated equipment to be classed as waste if it cannot be decontaminated sufficiently. A technique called skim and burial ploughing, was specifically developed in Denmark for managing contaminated soil. It buries the contamination more efficiently below the root zone and protects soil fertility (5). This type of plough is not available in the UK.

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34. Prohibit public access	
General	
Objective	To prevent external doses and intakes via inhalation and ingestion of material from surfaces within contaminated areas, including recreational areas.
Other benefits	Other protective actions can be implemented more easily whilst the population are absent from the area, for example, by minimising the hazard from using heavy machinery. Eliminates ingestion doses from consuming wild foods collected from recreational areas, such as, woods, countryside. Prohibiting public access offers protection of people and property Reduces the potential spread of contamination by human activities.
Protective action description	Depending on where the land is, the way it has or could be used and the potential for trespassing, prohibiting access may require passive measures (barriers, cameras) and/or active security patrols to be put in place. As the effectiveness of the process depends on acceptance by the community, an information campaign may also be required that, depending on the community, may range from simple signage placed around the site to community driven events such as workshops, drop-in sessions, and helplines. There may be some flexibility for example, early decontamination may offer a degree of flexibility in meeting local issues in defining areas subject to restricted access, particularly if a well-used path is affected. Recreational areas are unlikely to have a high priority for clean-up and so restricting access may be necessary prior to any clean-up being implemented. Temporary prohibition of access may be enforced while clean-up is being implemented.
Target	Businesses and people living in contaminated areas.
Targeted radionuclides	All radionuclides. Short-lived radionuclides will require shorter duration access restrictions.
Scale of application	Any scale but may be more acceptable and easier to enforce on a smaller scale.
Timing of application to optimise effectiveness	Shall be applied to affected areas early for maximum benefit and during implementation of other (decontamination) measures. Later application will yield a diminishing return due to cross contamination and so on.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activity: • preventing or controlling access to the affected areas, or to impose restrictions on living conditions in these areas

34. Prohibit public access	
Physical environment	Larger areas will either require extensive signage and/or fencing to capture all possible ingress.
Effectiveness	
Protective action effectiveness	This option will not reduce contamination levels in the restricted area. However, with public compliance, prohibiting access will prevent exposure where resuspension is an inherent risk. Furthermore, the spread of contamination will be reduced.
Technical factors influencing effectiveness of protective action	Success of barriers, fences and other control processes (if used). Compliance: an effective public information strategy will be essential.
Resourcing	
Specific equipment	None.
Ancillary equipment	Fencing, cones, security cameras.
Utilities and infrastructure	Security and communication.
Consumables	Notices, signs, barriers and so on.
Skills	None.
Work rates and operator time	Time required to: • travel to or from the area to establish access restrictions • erection of fences and signage and their maintenance • provide on-site security • develop and implement an approach to public information
Waste	
Type	Some signage and fencing may require decontamination or disposal.
Transport	n/a
Treatment	n/a
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	For those establishing cordons and restricting access: • external exposure from deposited activity. Members of the public: none
Impact of protective action	
Environmental impact	None.
Agricultural impact	None.

34. Prohibit public access	
Practical experience	
	Access restrictions following the radiological accident in Goiânia, Brazil (1) Chornobyl exclusion zone in Ukraine (2) Difficult to return areas close to Fukushima NPP in Japan (3) Restricted public access (since 2011) to areas of beach at Dalgety Bay, Scotland due to presence radium coated residues from military aircraft from WW2. Following completion of remediation works in 2023, to remove radioactive contamination from the foreshore at Dalgety Bay, a period of 2 years of post-works monitoring has commenced. The aim is to restore unrestricted public access to public open space areas after acceptance of the completed monitoring programme (see Dalgety Bay from the Scottish Environment Protection Agency). General experience of restricting access (building sites, nuclear licensed sites, hazardous areas, landfill controls, quarries and so on).
Key references	
	1. IAEA (1988). 'The radiological accident in Goiânia' STI/PUB/815 ISBN 92-0-129088-8 2. IAEA (2006). 'Chernobyl's legacy: health, environmental and socia-economic impacts and recommendations to the governments of Belarus, Russian Federation and Ukraine' 3. Ministry of Environment, Japan (2018). 'Decontamination projects for radioactive contamination discharged by Tokyo Electric Power Company Fukushima Daiichi nuclear power station accident' Editorial Committee for the Paper on Decontamination Projects Ministry of the Environment, Japan, March 2018. ISBN978-4-600-00139-1
Comments	
	Restricted access allows the control of the area either for decay for short half-life radioisotopes or enabling other remediation methods that in themselves may be hazardous and hence, require restrictions.

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35. Reactive liquids: domestic chemicals	
General	
Objective	Reduce hotspot contamination (and associated doses) from a variety of internal and external non-porous surfaces, by public and other unskilled personnel.
Other benefits	The (partial) removal of contamination from the area will limit or prevent the redistribution of contamination and hence resuspension potential. Will reduce doses and resuspension potential in dusty environments.
Protective action description	Use of simple domestic or light industrial chemicals to remove surface contamination from available surfaces by: chemically impregnated wipes; spraying, light physical action and absorption onto solid media; immersion. This datasheet specifically excludes any moderately or very aggressive chemicals, those solutions that are radionuclide specific and those focusing on chelating with radionuclides. These all require a degree of skill and or infrastructure to manage the wastes safely and appropriately, that is, these are unsuitable for disposal via the domestic sewer in bulk. Where required, support form official sources will be made available for use in controlled circumstances. It also excludes fabrics. This measure considers primarily surface contaminated non-porous materials, for example, metals, glass, painted or varnished surfaces. As most contamination is likely to result in fine particulate, bulk removal of loose contamination by vacuuming or similar is prudent to reduce the time spent decontaminating, volume of chemical and ultimately, total wastes generated. Chemicals will have greatest effect after the first cycle, with declining relative performance after several cycles, primarily sprayed onto a surface from a hand spray bottle in small areas. If, after 3 cycles of chemical decontamination, official advice should be sought. It is often better to use diluted domestic or light industrial chemicals 2 or 3 times than use in a concentrate form. When combined with light scrubbing action, to make best use of their surfactant properties. It is equally important to have the chemicals either absorbed or flushed from the surfaces after treating a small area. On external painted surfaces, for example, children's playgrounds, handrails, doors and so on. chemically impregnated wipes are useful. There are other more medium aggressive and very aggressive chemical options available. However, a plethora of availability,

	35. Reactive liquids: domestic chemicals
	deployment, safety, consequence, and disposal difficulties must be assessed by experts before any use.
Target	The following structure types containing a high proportion of non-porous surfaces: Buildings and features with bulk non-porous materials where access is required or risk of resuspension, for example, HVAC systems. Dwellings. Small or medium-sized offices or light industrial units and retail environments. Larger enclosed structures, but otherwise open structures such as warehouses, stations, will be subject to specific advice based on higher cost but faster methods of decontamination. In all cases, care should be exercised on chemical compatibility of decontamination chemical against the substrate, the known chemical form of the contamination and the impact on liquid disposal. May also be useful for glass, window frames and windowsills inc. associated rubber. Only more persistent contamination should other domestic products such as oven or floor cleaning products be used. Even then, only sparingly.
Targeted radionuclides	**Understanding the radioisotopic mix** An understanding of the radioisotope mix from official sources is necessary to identify the disposability of any resultant wastes. Radioisotopes that emit predominantly alpha particles and neutrons such as, U, Pu amongst others; can lead to undesirable consequences if made damp or wet or allowed to accumulate in bulk such as drains, effluent tanks or catch pots or pollution control devices. Additionally, many of these radioisotopes harbour chemo-toxic properties that would be inappropriate to discharge to the drainage system. Those isotopes that emit predominantly beta and gamma radiation, for example, Cs, Sr, Co; are less restrictive, although as noted above, may also be chemo toxic. **Understanding the chemical form** The chemical form is just as important as the radionuclide. Handling metallic particulate contamination, for example, U, can lead to considerable heat generation. Chlorides, nitrates and hydroxides are generally more soluble that impacts the effluent or

	35. Reactive liquids: domestic chemicals
	waste disposal routes, whereas oxides are less so and are more suited to other physical methods of removal. Hence the use of reactive liquids for decontamination needs to be appropriate to the chemical form to be effective.
Scale of application	**Bulk or sensitive structures or items** Use of bulk chemical treatments of building structures with acids or alkalis is strongly discouraged. Any compromise of the depth of concrete, rebar or fire alarm systems will have serious consequences. **General scope** The intent for chemical decontamination is to focus on internal structures and immovable features of dwellings and office or light industrial areas. In most cases, the contamination is expected to be a fine particulate, that should in the first instance be removed by vacuuming and or use of strippable coatings. Any requirement to decontaminate with reactive liquids will largely be the result of some form of entrainment of contamination by movement of vehicles, other objects and human interactions that create residual 'hotspots' after for example, vacuuming. **Urban environments** Bulk use of chemicals that discharge to the sewer system (subject to approvals) or widespread use in a town or village where chemicals are absorbed onto solid media for example, onto cloth or tissues; will generate considerable waste volumes requiring some sequencing if used in built up areas. The emphasis of use should be in enclosed human access or high touchpoint areas as a mitigation to secondary contamination spread, in conjunction with other decontamination options. **Small-scale immersion (under 100 litres)** Chemical decontamination requires a chemical reaction to bind the contamination, as such impacts the surface finish or integrity. Some items requiring decontamination can present very complex geometries. Sentimental items, jewellery and so on are considered in a separate datasheet. Immersion and gentle scrubbing with a nail brush or similar, followed by rinsing are expected to offer bulk removal. If an ultrasonic bath is available, it may offer an advantage. Traditional washing up of domestic crockery and utensils should be sufficient. **Outdoor items** Complex geometry items found in public spaces are likely to be best decontaminated (if appropriate) manually. As with the COVID-

	35. Reactive liquids: domestic chemicals
	19 responses, features such as playgrounds, door handles to retail or commercial structures and high touchpoint areas would lend themselves to repeated decontamination to maintain cleanliness. This may also be used alongside other methods for bulk surfaces.
Timing of application to optimise effectiveness	Early action is necessary to mitigate the ingress of contamination into a substrate. After a period of weeks-months, contamination has a propensity to be absorbed into the near surface of most substrates (including paints, brick, concrete). Moisture or high relative humidity can accelerate this process (weeks). Once contamination is removed from the surface, there is a residual risk of contamination leaching back out of the substrate in a loose or transportable form by touch or contact.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • handling of chemicals • management of radioactive waste and management of radioactive water to the public sewer system Chemicals shall not be allowed to enter soils or water courses. Disposal via the sewer system may be permitted in controlled volumes to avoid impact to waste-water treatment plants.

	35. Reactive liquids: domestic chemicals
Physical environment	The weather can have a marked impact on the mobility of contamination at the surface and ingress into nooks, cracks and absorption into near surface of substrates (porous and non-porous). Widespread use for decontamination of external walls is not recommended.
Effectiveness	
Reduction in contamination on the surface	Surface decontamination of loose contamination often yields DFs 2 to 100 (50% to 99% reduction). The value is often much less for any fixed contamination.
Reduction in surface dose rates	Dose rates will reduce commensurate with extent of loose versus fixed contamination.
Reduction in resuspended activity in air	Commensurate with the DFs for loose contamination removal.
Technical factors influencing effectiveness of protective action	As noted earlier, the porosity of the substrate and physio-chemical form will offer differing levels of decontamination performance. It is highly likely that bulk partial decontamination will be achieved for loose and marginal changes for fixed contamination. Any wetting, weathering, or physical entrainment (for example, vehicles, moving objects, footfall) will result in hotspots necessitating alternative and more aggressive options delivered by trained personnel. Ideally, carryout vacuuming activities beforehand to reduce bulk loose contamination and hence reduce risk to individuals. **Internal** As a rule of thumb, a single 100 cm^2 moist wipe should be used to wipe down 1 m^2 before disposal. Thereafter there is real potential for contamination to be smeared rather than removed. **Spraying** Localised hand spray and gentle rubbing onto absorbent media is effective. As a caution, do not a rub too hard or use scouring materials, for example, wire wool. **External** Likely to have use for all door handles and touch points. **Immersion** Films, greases, and organics can mask contamination, particularly alpha emitting radionuclides. Furthermore, films and organics can float on top of the liquor in an immersion bath to refoul items on their withdrawal.

35. Reactive liquids: domestic chemicals	
Resourcing	
Specific equipment	Domestic cleaners.
Ancillary equipment	Secondary equipment that may be required (for example, monitoring equipment).
Utilities and infrastructure	Utilities (for example, water and power supplies) and infrastructure (for example, buildings and distribution networks such as road and rail links).
Consumables	Moist wipes. Hand bottle sprayers. Absorbent media. Small light abrasive brush (for example, nail brush). PPE applicable to the contamination levels.
Skills	Members of the public would have the necessary skills or can be readily trained.
Work rates and operator time	Time required to implement the option per unit of the target that is treated. Operator times are subject to many variables including the environment, weather conditions, the skills and equipment available. It is noted that working with radioactive material is often more time consuming than normal cleaning operations due to the restrictions of working with PPE and other requirements for protection of workers, public and the environment.
Waste	
Type	Contaminated moist wipes and absorbent materials, PPE and other equipment. Liquid wastes – contaminated cleaning agents (these are unlikely to be present as bulk liquids and are more likely to be associated with other cleaning materials such as wipes and absorbent material).
Transport	Suitable for transport via road in Isofreight container or suitable bag or drum. Bulk liquids will need leak proof containers.
Treatment	Wastes should be characterised to inform disposal route. Wastes should be sorted and segregated based on radiological and chemical properties. Contain in Isofreight container or suitable bag or drum. No specific treatment required for disposal to permitted LLW incinerator or landfill. Suitable for super compaction which will reduce volume.

	35. Reactive liquids: domestic chemicals
	Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Store in a suitable waste bin or Isofreight container, stored and managed near to the point of generation. To minimise the spread of contamination, attempt to store waste directly in the container that will go to landfill or incinerator. Liquid wastes: containers should be leak proof and stored on hard standing with bunding to prevent escape of contaminated liquids. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Nuclear waste services (and radiation waste advisers) can advise on viability of disposal routes if information is provided on waste characteristics and volume. Wipes and so on: preferred solution is to a permitted incinerator. Alternatively, disposal to landfill or the low-level waste repository can be considered. Liquid wastes: preferred solution is to permitted incinerator. Alternatively, disposal to permitted landfill may be possible. Disposal to landfill may not be possible if the waste is classified as hazardous as well as radioactive. Disposal to LLWR is unlikely to be possible for domestic cleaning products due to complexing behaviour. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers • inhalation of resuspended contamination • direct skin contamination from handling contaminated items from absence of or damage PPE (for example, suit, gloves and so on) Public • inhalation of resuspended contamination

35. Reactive liquids: domestic chemicals	
Impact of protective action	
Environmental impact	Chemicals must be prevented from entering soils or water courses, due to potential for environmental damage.
Practical experience	
	Management of loose contamination is well understood within the UK nuclear industry and represented by the advice within this datasheet.
Key references	
	Nothing available in the open literature. Input for this datasheet was provided by Alex Jenkins, decontamination expert at Sellafield Ltd, UK
Comments	
	Changing the chemicals to something more aggressive, for example, acids, increases the need for controls, skills and experience, to mitigate the exponential consequences of mis-application or situational issues that would encourage an alternative approach. Disposal via the sewer system may be permitted in controlled volumes to avoid impact to waste-water treatment plants. Large scale use of chemicals will transport large quantities of radioactivity that will require some form of abatement to prevent dispersal into the wider environment that will be guided by the official recovery effort.

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36. Remove and replace road and paved surfaces	
General	
Objective	To remove contamination from outdoor surfaces in inhabited areas and therefore reduce doses from external irradiation and inhalation of resuspended material.
Other benefits	Will remove contamination from treated areas and therefore prevent redistribution of contamination. Implementing this action will make an area look clean and may provide reassurance to public.
Protective action description	The most common forms of hard outdoor surfaces will be tarmac or concrete slabs. **Road surface stripping or planing** Bitumen surface dressing may be applied initially to tie down contamination (see datasheet 44: 'Tie down') to allow time for other remediation priorities to be addressed. Subsequently, if necessary, controlled removal of the asphalt road surface can be carried out using standard machinery. A rotating drum with cutting teeth conveys planed material (about 40 mm thick) to the middle of drum where it is pushed on to a conveyor belt and from there to a flatbed truck. If machines do not have brushes for debris collection, this should be added, or else manual sweeping carried out. Water is sprayed continuously on to the drum to suppress dust. Typical highway maintenance machinery can remove a width of about 2 m per pass. In small areas, a jackhammer may be used in place of heavier machinery to break up the surface. Replacing or resurfacing asphalt and concrete roads can be undertaken using standard equipment (such as, hot rolled asphalt or a concrete paving machine). For replacement in small areas, manual methods are likely to be used, that is, asphalt concrete is deposited in several places and spread by shovel and rake, then tamped. Removal of street furniture (for example, lights) will improve accessibility. Restrict access to the public (in vehicles or on foot). **Centrifugal shot blasting** As an alternative, but less favourable option due to noise, and risk due secondary release potential, that is, from the breakdown of the shot and impact on the surface. This can cause wider secondary contamination. Hardened steel shot is rapidly propelled at contaminated surfaces to fracture the surface, resulting in small dust-sized particles that can be vacuumed and removed for proper

36. Remove and replace road and paved surfaces	
	disposal. The surface remaining is relatively smooth and can be recoated and reused. Centrifugal shot blasting can remove light coatings on concrete surfaces up to 0.3 to 2.5 cm deep, though it is ideally suited for removing surfaces between 1.6 to 3.2 mm in depth. The speed of the system, the size of the shot and the amount of shot released into the system can be varied based on the degree of removal required. The shotblast unit relies on a dust collection system to remove abraded dust and particles, and to reduce airborne contaminants. Used shot is separated from debris and recycled in the system. Contamination and smaller pieces of shot that are worn from repeated use are gathered in a collection drum. Note that water jet scabbling is simpler and faster to deploy than shot blasting (see datasheet 31: 'High pressure washing including water jetting'). **Pavement** Small areas (approximately 10 m^2) can be removed by hand using a crowbar or similar to lift the slabs. For areas greater than this, a mechanical method should be used, for example, a small excavator or bobcat to remove concrete slabs. Attention must be paid to removing radioactive materials in the gaps between the blocks. These actions are likely to give rise to dust, so application of water to dampen the surface or the use of a tie-down material is recommended prior to implementation to limit the resuspension hazard. Operators should wear suitable PPE, including hard hat, safety goggles and respiratory protection.
Target	Hard outdoor surfaces (roads, pavements, paths, playgrounds and so on) including those within semi-enclosed areas.
Targeted radionuclides	All long-lived radionuclides. Should not be used for short-lived radionuclides alone.
Scale of application	Small to large scale. Theoretically any sized road or paved area could be treated but costs, time or the number of workers may become a problem as the area increases.
Timing of application to optimise effectiveness	Maximum benefit if carried out soon after deposition when maximum contamination is on the surface (unless a bitumen surface tie down dressing was applied). If it is carried out later, there will be a natural decrease in contamination levels from washing in, footfall or vehicular movements. In which case, it may be best to monitor airborne or loose contamination to justify undertaking the work or employ designated walkways or routes.

36. Remove and replace road and paved surfaces	
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	If the surface of the road is cambered the removal depth will not be uniform. Access for equipment and materials.
Effectiveness	
Reduction in contamination on the surface	A reduction in the amount of contamination of 80% to 90% (DF of 5 to 10) is achievable (1). Experience in Japan found a 70% to 90% reduction (DF of approximately 3 to 10) in surface contamination following stripping of some asphalt surfaces (such as parking lots) (6). In a pilot project, it was found that surface stripping could lead to a 95% reduction (DF of 20) while shot-blasting was 60% to 95% effective (DF of 2.5 to 20) (4). Reduction factors will be up to a factor of 4 higher following wet deposition (2).
Reduction in surface dose rates	External gamma and beta dose rates above a treated surface will be reduced by the value of the DF. Experience in Japan found that following shot blasting of roads and streets, the ambient dose rate at 1 m above the ground was

36. Remove and replace road and paved surfaces	
	reduced by up to 66% (RF of approximately 3) for dose rates of 10 μSv/h or higher (7). Note that the secondary contamination risk is high.
Reduction in resuspended activity in air	Resuspended activity in air above the surface will be reduced by the value of the DF. There may be localised and short-lived elevated levels during works.
Technical factors influencing effectiveness of protective action	Evenness and condition of roads. Consistency in effective implementation of option over a large area (that is, operator skill). Effectiveness of removal of contamination around drains and in gutters. Removal of loose debris from surface. Depth of surface removed – most of the radiocaesium in dense asphalt pavements was presented within the top 2 to 3 mm of the surface. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Whether the surrounding ground areas onto which secondary contamination may have been transferred are subsequently decontaminated.
Resourcing	
Specific equipment	The equipment used will depend on the size of the area being treated. Small areas: small scale planer, jackhammer, shovel, tamper, wheelbarrow, lorry. Large areas: planer with conveyer, paving machine, road sweeper, roller, excavator, lorry. Shot blasting: blasting system; air compressor; depending on the media, a HEPA filtration system may be required. Generator or power source.
Ancillary equipment	Transport vehicles for equipment and waste. Appropriate PPE (gloves, overalls, masks, and eye protection).
Utilities and infrastructure	Roads (transport of equipment, materials, and waste).
Consumables	Asphalt, concrete or concrete paving slabs. Tungsten carbide teeth. If shot blasting used, steel shot and HEPA filters. Fuel and parts for equipment, generators, and vehicles.

36. Remove and replace road and paved surfaces	
Skills	Skilled personnel essential to operate equipment. Road maintenance workers will already have required skills but would need suitable training on how to work with radioactively contaminated materials.
Work rates or operator time	Road or pavement surface removal and resurface: 250 m/day (road only); 160 m/day (road and both pavements). Typical road width 8 metres. Total of 10 people (3). Planing asphalt road surface: 1,000 m^2/h per team of 4 operatives (1). Shot-blasting (of surfaces including paved roads): 30 to 40 m^2/h per team of 4 operatives (6).
Waste	
Type	Asphalt, concrete and paving slabs. Asphalt removal: about 50 kg/m^2 for top 2.5 cm (3) Asphalt stripping: about 15 kg/m^2 per cm removed (1). Shot-blasting of asphalt: 3 l/m^2; surface stripping of top 5 mm approximately 8 l/m^2 (4). Paving slabs (concrete): about 30 kg/m^2 per cm removed. Waste volume depends on thickness removed and density of material. Additional waste considerations: Equipment may become contaminated and produce secondary waste. Contaminated PPE may be generated.
Transport	Suitable for transport via road or for large volumes it may be most efficient to consider transport via rail (Nuclear Transport Solutions can advise). Waste must be covered for transport.
Treatment	Consider crushing and screening and other demolition waste management techniques. Consider size reduction to facilitate characterisation and subsequent sorting and segregation. Not suitable for compaction. Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. May consider the backwashing of material to recover special nuclear material (SNM) and/or re-categorise the waste.

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	Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Watertight or IP2 containers in a secure compound. Ideally stored on hardstanding with appropriate drainage. If containing SNM, this will have to be on a nuclear licensed site. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Preferred route: permitted LLW landfill (mainly non-hazardous waste). Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground (as dust or spray) and other surfaces • inadvertent ingestion of dust (can be avoided by correct use of PPE) Those transporting and managing waste may also be subject to external exposure. Members of the public: none.
Impact of protective action	
Environmental impact	The disposal or storage of waste arising from the implementation of this option may have an environmental impact which should be minimised through the control of any disposal route and relevant authorisations.
Practical experience	
	Following the Fukushima accident, parking lots, roads and paved surfaces were treated with high pressure water in combination with surface removal. However, due to the increased cost, time and waste associated with scraping away the surface, this was only

36. Remove and replace road and paved surfaces	
	recommended in residential areas and where the dose could not be adequately reduced through other means (5). UK Civil nuclear experience shows areas of contaminated concrete and tarmac (roads) have been successfully removed. Similarly localised areas of concrete and paving slabs adjacent to plants have been decontaminated.
Key references	
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Comments	
	Disruption of access if people remain in the area.

36. Remove and replace road and paved surfaces	
	Road and pavement condition may be improved providing tarmac or concrete has been laid properly. This option is costly so only credible for areas with the highest levels of contamination or areas of very high footfall or traffic.

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37. Removal of building surfaces: blasting, grinding, scabbling	
General	
Objective	To remove contamination from external walls and some floors, of buildings in inhabited areas and therefore reduce radiation doses and inhalation of resuspended material.
Other benefits	Will remove contamination from treated surfaces and therefore prevent future redistribution of contamination. Implementing this action outdoors will prepare substrates for painting or finishing to improve aesthetics and may provide reassurance to public. Reduces or eliminates secondary contamination from weathering.
Protective action description	Surface removal techniques include blasting, grinding, scabbling and spalling. Contamination is removed by virtue of the removal of the surface coating or near surface layer. Contamination ingress into concrete can vary markedly due to the chemical and physical form of the contamination event; extent of cracks and fissures and so on, where depth profiles are typically less than 15 mm, but range from 1 or 2 mm to 50 mm along cracks is not uncommon when left for many years. **Blasting options** These options remove a thin surface layer, together with the associated contamination, using a range of blasting media. The descriptions are mainly based on information provided by NCRP (5) and industrial experience. The principle of abrasive blasting considers the acceleration of a media into a high velocity stream before impacting a substrate. There are a number of trade names, but in principle include, sand blasting, grit blasting, shot blasting, ice blasting (frozen water in pellets), dry ice blasting (frozen carbon dioxide that sublimes to a gas), pellets (4 mm in diameter and up to 25 mm in length (usually 10 mm), snow (macerated pellets), sponge jet. **Principles of blasting options** Each of the methods above impart kinetic energy to a blast medium before impacting a surface to cause surface damage or cracking of paints, coatings or oxides to leave a rough surface. Variation of the blasting media to softer material, such as, grit to sponge, will result in a less aggressive decontamination. Increasing the propellent pressure, flow or speed, for example, compressed air, water, kinetic throwing wheel rpm, will give a more aggressive effect.

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	Each of these systems have their issues. Common to each is the need for a robust and high-volume HEPA filtered vacuum or capture system to overcome the wide angle of high speed ejected contaminated propellent, contaminated blast media and coating or oxide being removed; to prevent secondary contamination. Capture systems if incorporating a back-end cyclone, can allow for recycle of hard blast media. Despite the optimisms of the supply chain, experience has shown that typical purge rates of 30% to 60% are needed. For ice and dry ice blasting, this is 100%. If areas are properly contained, for example, tenting or extracts or are housed in a purpose-built ex-situ decontamination facility, safety, wastes and materials can be best handled. Each of these blasting methods are most effective on simple geometry items where the surfaces are readily accessible. Complex items may be left with no or incomplete decontamination. There are a number of safety issues that render these methods suitable only for an expert professional rather than members of the public. These systems are not suited to delicate materials, such as, fabrics, art works, electrical systems; with the exception of dry ice blasting using 'snow' instead of pellets. **Other surface removal options** The following must be considered and deployed with skilled personnel to ensure appropriate deployment assessments are made. **Water jet scabbling** Also known as hydro-demolition for cutting of concrete. Uses high or ultra-high pressure water jets (up to 2,800 bar) deployed with a spinning head to breakup depths of concrete from 1 to 15 mm in a single pass. Performance can be adjusted by pressure, flow rate, jet type and distance from substrate (usually 20 mm). This is a repeatable method and can be used to expose, without damage, rebar if desired to 'key' new concrete. Requires an effluent vacuum capture and solids separation system (similar to that used for settling soils from effluent or ship hull paint removal systems). Effluent can go through local ion exchange if unsuitable for discharge to the sewer. This can be hung on wires and remotely operated. Has many analogies with ship hull paint removal that is remotely carried out. The following mechanical methods can impact rebar and initiate cracking into bulk concrete. Engineering assessments will be

37. Removal of building surfaces: blasting, grinding, scabbling	
	necessary for structural features, for example, to establish the depth of rebar. **Concrete grinder** A diamond grinding wheel in a lightweight hand-held device removes surfaces 1.5 to 3 mm deep to create a relatively smooth surface on flat or slightly curved surfaces with little vibration. A dust collection system including HEPA filtration removes dust generated by the grinding process. **Concrete shaver** This approximately 150 kg device is an electrically driven system, using a drum embedded with diamonds as a cutting head for removing contamination from concrete floors. Variable shaving depths from 0.01 to 1.3 cm can be achieved. Commercially available concrete shavers are good for large, wide open concrete floors and slabs. This can be scaled up to include road planers subject to suitable extract. **Concrete spaller** Holes are drilled in the concrete surface to be decontaminated. A spaller bit is then inserted into a drilled hole and expanded hydraulically, breaking off chunks of the surface up to 5 mm thick and 18 to 41 cm in diameter. A spaller can be used on flat or slightly curved surfaces. It can be used on large areas or as a tool for hot spots and decontamination of cracks in concrete. A metal shroud with a HEPA filtration system can collect concrete and control dust. **Scabblers** Scabbling tools break down a concrete surface, typically by mechanically impacting the surface causing shattering or fragmentation. A needle scabbler can produce finer decontamination in smaller areas. A remote-control robotic wall scabbler uses grit blasting and is specially designed to work on flat surfaced walls using high performance vacuum for suction that can also work on floors and ceilings. All of these scabblers will produce waste material, which should be collected by vacuum and stored for disposal, thus minimising airborne contamination. Alternatives include electro-hydraulic scabbling, microwave scabbling and laser scabbling which are more complex than the other methods described above and carry technical risks.
Target	Areas where there is extensive contamination of external walls of buildings, including those within semi-enclosed areas and large

37. Removal of building surfaces: blasting, grinding, scabbling	
	internal floor areas or walls with hard surfaces (for example, within public buildings such as railway stations). Concrete shaver is specifically for floors. Should not be used where bulk loose contamination is present.
Targeted radionuclides	All radionuclides. Use for short-lived radionuclides alone will only be for urgent restoration of critical national infrastructure and then, only after other decontamination methods have failed. These methods should not be used for bulk loose contamination due to risk of gross resuspension inhalation or secondary contamination.
Scale of application	All of these methods are intended for large areas with simple geometry, hence are unsuited to complex and or undulating surfaces.
Timing of application to optimise effectiveness	Whilst there is no requirement to deploy at the earliest opportunity, they are best deployed in the intermediate or long-term phase to allow prioritisation of other affected areas. The effectiveness of the method may dip over time for a single pass, many are repeatable to achieve a given outcome. Continued exposure and weathering will see contamination penetrate deeper in paints and concrete or brick over time. It is recommended that any treatment of walls is implemented before decontamination of surrounding ground areas.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including

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	on listed or historical sites, conservation areas and areas of cultural heritage • providing the leading authority with the power to seize, dispose of, destroy, or damage possessions, including furniture and furnishings, clothing and vehicles, where these are shown or believed to be contaminated • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Each of these systems requires a degree of infrastructure to operate, access equipment to deploy and waste capture and packaging. Specific attention is drawn to the specialist nature, safety and containment requirements for these high energy systems. Particular care is required during selection for appropriateness, PPE and toxicity of blast media used. Some technologies, such as, shot blasting or concrete grinder, may not be suitable for use outside in rainy conditions.
Effectiveness	
Reduction in contamination on the surface	Effectiveness for some technologies (for example, dry ice and soft media blasting) decreases with time after deposition as the contamination penetrates deeper into the material and becomes harder to remove (1). A default DF of 10 (90% reduction) can be assumed, with higher DFs approximately 100 (99% reduction) applicable to the first few weeks after contamination and lower values after a year (DF of approximately 3, and reduction of 67%) (3). Sandblasting of clay brick walls of buildings contaminated after Chornobyl gave DFs of between 6 and 20 (83% to 95% reduction) (7). Sandblasting and iron shot blasting of concrete and mortar surface of large buildings in Fukushima were found to be at least moderately effective. Shot blasting of concrete in Fukushima has been seen to produce a DF of approximately 10 (approximately 90% reduction) (4). Concrete grinding in Fukushima gave a DF of between 2.5 and 5 (60% to 80% reduction). Dry ice 'snow' (not pellets) is very useful for controlled use on delicate surfaces and electrical equipment, where it is undesirable to induce cracking in the PVC insulation. It is applied in very short durations for loose contamination removal.

37. Removal of building surfaces: blasting, grinding, scabbling	
	Very high DFs have been achieved with scabbling or shaving (including water jet scabbling) of concrete in UK civil nuclear decommissioning.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated external walls of buildings will be reduced by a similar factor as the DF.
Reduction in resuspended activity in air	Resuspended activity in air will be reduced by the same value as the DF (provided loose contamination was not present).
Technical factors influencing effectiveness of protective action	Technology used: prior assessment of the depth required will determine the method. Choice of media (for example, type of sand, grit or soft media). Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Type, evenness, and condition of surface. Pressures and flows. Distance from substrate (that is, stand-off distance). Care in application: consistent application (that is, operator skill) and care needed to remove contamination from walls and not just move the contamination around the surface. Lower parts of walls need to be cleaned very carefully as this is the surface that will provide the greatest dose to an individual in the vicinity of the building.
Resourcing	
Specific equipment	The equipment required depends on the technology used. **Sandblasting** 150 bar (2,000 psi) pressure washer; dry abrasive feeder. Depending on whether wastewater is collected or filtered the following equipment may also be required: sheeting; tanks; troughs; filters; spate pump; gully sucker. **Grit, shot, soft media blasting** Blasting system; air compressor; Depending on the media, a HEPA filtration system may be required. Generator or power source. **Dry ice blasting** Dry ice blaster unit, lance and gun, thermal storage containers, air compressor. **Concrete grinder** Grinding unit, dust collection system, HEPA filtration system. **Concrete shaver**

37. Removal of building surfaces: blasting, grinding, scabbling	
	Shaver unit. **Concrete spaller** Drill, spaller, metal shroud and hose, HEPA filtration system (if required). **Water jet scabbling** (Ultra) high pressure water jet pump (approximately 2,800 bar at 15 to 20 litres per minute flow rate), water jetting hoses, solids separator (silt buster), wet vacuum system. **Robotic wall scabbler** Robot, recycling unit, filter, vacuum unit.
Ancillary equipment	For tall buildings: scaffolding, lifeline, and safety helmets. Appropriate PPE (gloves, overalls, respiratory protection including masks and eye protection). Access equipment (scaffold, mobile elevated work platform and so on).
Utilities and infrastructure	Power supply or generator. Roads and vehicles (transport of equipment, materials, and waste). Water supply may be required. HEPA vacuum system with cyclone or separator. Waste handling and disposal route. Public sewer system may be required. Dry ice only: supply of dry ice and thermally insulated storage. Dry ice pellets can be stored for 2 to 3 days before degrading.
Consumables	Depending on technology used, sand, water, abrasive pellets, steel shot, dry ice pellets, soft media, grinding wheel, cutting blades, drill and spaller bits, grit, pistons, HEPA filters and hoses may be required. There are restrictions on the type and chemical characteristics of the abrasives used in grit blasting due to presence of silicon dioxides or heavy metals. Fuel and parts for generators and transport vehicles. Respiratory protection may be required. Bags or containers for waste will be required. In addition, scaffolding or roof ladders or mobile lifts for additional roof access may be required.
Skills	Skilled personnel essential to operate equipment.
Work rates and operator time	This depends on the technology and type of equipment used; weather; building size; access; proximity of water supplies; use of personal protective equipment (PPE).

37. Removal of building surfaces: blasting, grinding, scabbling	
	Sandblasting (dry): 20 m^2/h (6). Waterjet scabbling 10 m^2/h. Scabbling: 5 m^2/h (2). Concrete grinding: 5 m^2/h based on 8 hour day (that is, 40 m^2/d). Shot blasting: 20 m^2/h based on 8 hour day, that is, 170 m^2/d (4). Dry ice blasting 2 to 20 m^2/h.
Waste	
Type	The waste generated will depend on the technology used. Grit blasting has primary waste generation and filtration system Dry ice blasting generates very little solid waste, but aerial discharge is large. Typically, contaminated dust or debris will be collected by the system and must be appropriately disposed of, subject to conditions depending on the activity levels and other properties of the waste. Sandblasting will typically generate around 3 to 5 kg/m^2 solid waste (dust and sand) (1). Need to characterise early to identify if low specific activity (LSA), surface contaminated objects level 1 (SCO-1) or surface contaminated objects level 2 (SCO-2). This will determine the transport package requirements.
Transport	Suitable for transport via road. Dusty materials should be double bagged and where possible placed into drums.
Treatment	Unlikely that secondary treatment will add any value from these waste forms. Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Suitable waste bin, LLWR approved container or Isofreight stored and managed near point of generation. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Preferred solution will depend on waste type. Disposal will most likely need to be to permitted incinerator, permitted landfill or

37. Removal of building surfaces: blasting, grinding, scabbling	
	LLWR. Disposal to landfill may not be possible if the waste is classified as hazardous. Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground (as dust or spray) and other surfaces • inadvertent ingestion of dust (can be avoided by correct use of PPE) Although many technologies include systems to reduce airborne contamination, the breakdown of concrete surfaces may increase the dust loading and lead to an increased inhalation dose during the period of operation. Those transporting and managing waste may also be subject to external exposure. Members of the public: none.
Impact of protective action	
Environmental impact	Repair work on some walls may be required. Where generated, contaminated wastewater, if not collected, will run on to other surfaces or directly down drains into public sewer or highway drainage systems.
Practical experience	
	Sandblasting was tested on realistic scale on selected walls in the Former Soviet Union and Europe after the Chornobyl accident (7). Sanding or planing and shot blasting were tested in Japan following the Fukushima accident. UK nuclear industry uses: • grit blasting to remove very robust paints from nuclear transport packages to allow inspection of the flask as well as prepare it for the multiple coatings that are applied

37. Removal of building surfaces: blasting, grinding, scabbling	
	• dry ice 'snow' (not pellets) for loose contamination removal from electrical equipment (very short durations) • scabbling or shaving (including water jet scabbling) of concrete for nuclear decommissioning of ponds, buildings and 'early' facilities (high DFs)
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38. Remove grass after cutting	
General	
Objective	To reduce inhalation and external doses from contamination that has been intercepted by grass within inhabited areas.
Other benefits	Prevents contamination reaching underlying soil if deposition occurred under dry conditions. Return of local amenity, such as, for gardening, leisure and sport. Promotes self-help among lawn owners.
Protective action description	Grassed areas are mown, and grass cuttings are collected. The cutting height should be set to remove the maximum length of grass. The action can be carried out on a large-scale using tractor drawn mowers with collection facility to prevent secondary contamination of the soil. This action is likely to give rise to dust, and therefore protective equipment is recommended for implementers to limit the inhalation of any contaminated material that is resuspended into the air. To reduce resuspension, a light dampening (that is, misting) of the surface will help prevent resuspension but not risk moving the contamination from the grass onto the underlying soil. It may also be possible to set up screening around areas being mown to prevent movement of contamination onto adjacent surfaces. This action could also be implemented as a self-help measure by lawn owners who are likely to already have mowers, although such equipment must include an attachment for collecting the grass cuttings. Advice will be necessary on personal protective equipment, the importance of collecting the cuttings in black bags, and what to do with the waste, which would ultimately be collected by the local authority. Furthermore, for people, organisations and authorities required to handle contaminated grasses and so on, there will need to be clear communications, with respect to washing hands, wearing a mask, need for a paper suit and washing or disposal of contaminated equipment.
Target	Grassed surfaces with very low levels of contamination in gardens, parks, playing fields and other areas used for leisure purposes such as, golf courses, horse racing circuits.
Targeted radionuclides	All radionuclides, including short-lived, if implemented quickly.
Scale of application	Potentially suitable for any size of grassed area. Specialised heavier, larger, and less manoeuvrable machinery may be required, for example, for mowing long grass, which may not be suitable for smaller areas.

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Timing of application to optimise effectiveness	Maximum benefit if implemented soon after deposition, that is, within a few days and up to one week if no rain, when maximum contamination is on the grass. Effectiveness is significantly reduced after rain has washed contamination from the grass. A second cut may be possible in the summer months but in general repeated cutting will not improve effectiveness.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Water-logged or soft underlying soils may prevent the use of heavy machinery. Flooded or snow-covered grass cannot be cut but it will be important to recover the snow as soon as possible and before it can contaminate the grass. Dewy, wet, or frosted grass may be difficult to cut and have a slower cutting speed but will be beneficial to preventing airborne contamination. Uneven or rocky ground may be unsuitable for mowing. It may be difficult or impossible to use cutting machinery on steep slopes.

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	Grassed areas interspersed with, for example, flower beds, shrubs, trees and play equipment may constrain the type of cutting equipment that can be used (size and manoeuvrability). It may be best to strim and collect this material first as this represents the biggest secondary contamination risk should it rain.
Effectiveness	
Reduction in contamination on the surface	A decontamination factor (DF) of 3 (a 67% reduction) following dry deposition and a DF of 1.3 (approximately 20% reduction) following wet deposition can be achieved if this action is implemented within one week of deposition and before significant rain occurs (3). Average DF for grass cutting in Japan in the first few weeks was 1.2 (19% reduction), with a range in DF from 1 to 2.5 (of 0% to 60% reduction (7). IAEA (4) also cite DF values of up to 1.25 (60% reduction). Whilst these are relatively small decontamination factors, they do offer a sense of progress.
Reduction in surface dose rates	External gamma and beta dose rates immediately above grass surfaces arising from contamination on the grass will be reduced by approximately the value of the DF, that is, the dose reduction will be commensurate with the reduction in overall surface contamination.
Reduction in resuspended activity in air	Resuspended activity concentration in air immediately above a grass surface will be reduced by approximately the value of the DF, although there could be an initial increase whilst grass cutting.
Technical factors influencing effectiveness of protective action	Weather conditions, particularly at the time of deposition, and the amount of rain after deposition will affect the amount of contamination intercepted by the grass, and therefore the amount available to be removed and left on the underlying soil. Correct implementation: all grass cuttings must be collected to achieve the DF values quoted. Spread of contamination onto adjacent surfaces should be minimised. There is a need to lightly dampen the surface to reduce the risk of airborne contamination during cutting. Time of implementation: natural weathering will reduce the amount of contamination on the grass over time, so quick implementation will improve effectiveness. Length of grass: if grass is short at the time of deposition, contamination will reach the soil surface more readily, therefore cutting short grass will be less effective than cutting long grass.

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Resourcing	
Specific equipment	Grass mowers (various sizes, depending on the size of area), fitted with collection boxes to ensure total collection of grass cuttings. A tractor may be required to pull mowing equipment for large areas, which will require a grass collection system. Rakes or other collection equipment, if grass cutting equipment is not fitted with collection boxes as might be the situation when used in private gardens.
Ancillary equipment	Vehicles for transporting equipment and removing waste.
Utilities and infrastructure	Suitable sized roads for transport of equipment and waste.
Consumables	Fuel and replacement parts for grass mowers, rakes, and vehicles. Suitable waste disposal bags for biodegradable waste. Respiratory protection and protective clothes and gloves.
Skills	For small gardens, grass-cutting and collection could be implemented by inhabitants as a self-help measure, with instruction from authorities, provision of face masks and access to a waste collection system. Skilled personnel may be desirable if large scale equipment is used, that is, for larger area grass mowing.
Work rates/operator time	Up to 10,000 m^2/h per team, when carried out on large areas with commercial equipment (3). Much slower work rates of around 500 to 700 m^2/h when carried out on small areas with domestic equipment (1, 2). A doubling of the team size would be necessary for the damping down of grassed areas, prior to mowing. Typically, mowers have a single operator, but additional operators may be required for grass collection, equipment maintenance and transport. Work rates are affected by weather, topography, size of area, access, type of equipment, whether manual collection of cutting is required, use of personal protective equipment.
Waste	
Type	Grass: Amount: 0.0001 to 0.0007 m^3 per m^2 (less than 150 g/m^2) (depends on height of grass cut and density of grass cover). Waste amounts generated can be large. However, methods exist that can substantially reduce the volume of organic waste by up to a factor of about 100. Some of these methods (such as

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	composting) could be practised locally and could be very significant in reducing waste transport and storage problems. Additional waste types to be considered: Grass is putrescent material which may generate liquid waste during decomposition. The management of liquid waste should be considered. Contaminated equipment could be classed as waste if it cannot be decontaminated sufficiently, for example, used PPE, grass cutting equipment and collection systems.
Transport	Transport can be via road in large bulk carriers, such as, quarry lorries to a designated site. For very large volumes and/or long distances, it may be most efficient to consider transport via rail (Nuclear Transport Solutions can advise).
Treatment	Shredding and chipping may be considered as a means of reducing volumes for transport and disposal. It may be possible to undertake composting on or near to the point of generation. This will further reduce volumes and make disposal easier. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Early collection of bagged grass or vegetation is essential as any moisture used for damping down, will accelerate the degradation process and hence creation of leachates. Waste could be stored in dumpy bags or builders' bags. Where possible waste should be stored on hardstanding which allows the separation and collection of run off. Tarpaulins should be used to minimise rainfall infiltration. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Consider disposal to permitted LLW incinerator or landfill. For size-reduced green matter, consider ploughing in, local composting followed by local application to land subject to the outcome of a radiological risk assessment. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementors

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	• external dose from deposited radionuclides • inhalation hazard from resuspended radionuclides (dust) Public • inhalation hazard from resuspended radionuclides (dust)
Impact of protective action	
Environmental impact	Leakage of liquid waste from decomposition of grass cuttings if waste not managed during storage. Cutting meadows before annual plants have seeded may lead to reduced biodiversity and loss of habitat.
Practical experience	
	Tested on a small scale in Europe (5). Used in Japan following the Fukushima accident (4, 6, 7).
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	1. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). 'Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas' Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark 2. Andersson KG and Roed J (1999). 'A Nordic preparedness guide for early clean-up in radioactively contaminated residential areas' Journal of Environmental Radioactivity: volume 46, issue 2, pages 207 to 223 3. Brown J and Jones AL (2000). 'Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0' National Radiological Protection Board, Chilton (UK), NRPB-R315 4. IAEA (2014). 'The follow-up IAEA International Mission on remediation of large, contaminated areas off-site the Fukushima Daiichi Nuclear Power Plant, Tokyo and Fukushima Prefecture, Japan, 14 to 21 October 2013' IAEA NE/NEFW/2013 23 January 2014 5. Maubert H, Vovk I, Roed J, Arapis G and Jouve A (1993). 'Reduction of soil-plant transfer factors: mechanical aspects' Science of the total Environment: volume 137, pages 163 to 167 6. Ministry of the Environment, Japan (2013). 'Decontamination guidelines, second edition'

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39. Remove plant material	
General	
Objective	To reduce inhalation and external doses from contamination that has been intercepted by trees, shrubs, and plants within inhabited areas.
Other benefits	Prevents contamination reaching underlying surfaces, particularly if deposition occurred under dry conditions. Return of local amenity, for example, for gardening, leisure, and sport. Promotes self-help among garden owners.
Protective action description	Trees, shrubs, and other plants are either pruned or removed completely. If removed, the volume of waste is higher, and replanting may be required. Removal of fallen leaves, needles, pinecones, nuts, fruit, leaf litter, and other dead plant material laying on surrounding surfaces should also be considered. **Trees** When trees are in full leaf, the leaves will intercept a large proportion of the contamination and should be the focus for removal. If leaf fall is not expected soon after deposition, it can be induced by the application of chemical sprays (non-lethal defoliants) subject to their being no restrictions on the chemicals used. For practical reasons, chemical defoliation is more suited to small areas of recreational value (such as, parks), where it is relatively easy to collect fallen leaves on sheeting or netting. They can then be gathered up by manual or mechanical means (4). The felling of trees would be a last resort option due to the amount of waste generated and impact on soil erosion. In the case of evergreen plants, such as conifers, which shed their leaves and needles over a number of years, pruning (removal of top and windward side foliage) may be preferable to avoid the repeated collection of material. Removal or cleaning of tree bark (wiping or washing) may be used, primarily concentrating on the tops and sides of main trunks and branches. **Perennial shrubs and plants** Pruning of perennial plants should ideally take place in the dormant period, and the extent of pruning should be limited to minimise the impact on growth and plant health. Hard or incorrect pruning may kill the plant or increase the likelihood of infection. **Annual plants** When removing annual plants, consideration should be given to timing, that is, to allow the plants to seed if necessary.

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	Self-help Removal of plant material can be implemented as a self-help measure, in gardens, as owners are likely to have the necessary equipment. Advice will be necessary on personal protective equipment, the importance of collecting all material, and what to do with the waste.
Target	Trees, shrubs and plants in gardens, parks, and other green areas, particularly those that are highly contaminated with long-lived radionuclides, as a result of dry deposition at a time when they were in full leaf. Evergreen trees and plants, such as, most conifers, may contribute more to external doses in the long term as they don't lose their leaves or needles annually.
Targeted radionuclides	All radionuclides, including short-lived radionuclides if implemented quickly, that is, if the time between deposition and leaf fall is short. Some radionuclides, for example, caesium isotopes, will cycle through the forest system: falling on the ground with leaves, transferring to soil, and then being drawn up by the roots into the tree and leaves. Therefore, once radionuclides enter this cycle, ongoing monitoring will be necessary, and leaf collection and/or pruning may be necessary over subsequent years.
Scale of application	Any size. However, large quantities of waste can be generated, which may limit the area that can be treated, depending on the capacity of waste storage and disposal routes.
Timing of application to optimise effectiveness	Maximum benefit is achieved if implemented soon after deposition, that is, before rain and other weathering has moved contamination onto adjacent surfaces. Pruning or removal of shrubs and plants should be carried out within one week of deposition; tree felling should take place with the first month after deposition; leaves, needles, pinecones, nuts, and fruit should be collected in the autumn soon after fall to avoid them blowing onto other surfaces or becoming composted into the soil. This would be challenging for medium to large scale events.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings,

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	street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Steep slopes may prevent access for machinery and vehicles. Densely packed woodland or undergrowth may prevent access. Water-logged or soft underlying soils may prevent access for heavy machinery and vehicles. Care must be taken to prevent contaminated leaves becoming embedded in underlying soils. Snow-covered leaves will be difficult to collect. Windy weather will also impede their collection. Frosted ground may prevent effective removal of roots and impede replanting.
Effectiveness	
Reduction in contamination on the surface	If in leaf at the time of contamination, most contamination on trees, shrubs and plants will be on the leaves. For example, if a tree is in leaf at the time of deposition, then a very high decontamination factor (DF) of up to 50 (98% reduction), could be achieved under dry deposition (DF of 10 (90% reduction) under wet deposition), by felling the tree and collecting all the leaves (1). For a deciduous tree, a similar DF could be achieved by collecting all the leaves soon after fall; however, for evergreen conifers the factor will be much less (that is, DF 1.2 to 1.4 (17% to 29 % reduction)), even if collection of cones and needles is repeated several times. When the litter layer was also removed, the DFs increased to around 3 (67% reduction) (7). However, removal of litter layer can enhance soil erosion, particularly on steep slopes.

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	Pruning plants and shrubs can achieve a DF of 1.4 (29% reduction) if implemented within one week of deposition, before significant rain (2). After the Fukushima accident, removal of leaf litter and hummus resulted in DF of 1.3 to 2.5 (approximately 20% to 60% reduction) (3). Pruning and removal of low branches will only achieve a small decontamination effect on its own, but this will enable access for workers to remove topsoil.
Reduction in surface dose rates	The impact of pruning and removing leaves on overall doses will be reduced with time as there will be less contamination on the surfaces due to natural weathering. External gamma and beta dose rates from vegetation will be reduced by approximately the value of the DF. Trimming lower branches from forest trees has been found to reduce dose rates by 10% to 20%, while felling trees reduced dose rates by about 50%. Sequential removal of leaf detritus followed by stripping of hummus layer in Fukushima prefecture resulted in an average 50% reduction in hourly dose rate (5). Dose rates surrounding trees and shrubs will be significantly reduced if leaves are collected.
Reduction in resuspended activity in air	Resuspended activity in air adjacent to the trees, shrubs and plants will be reduced by a value similar to the DF. Removing leaves will maximise the reduction. If contamination remains on the surrounding soil, the reduction in resuspension will be less than the DF.
Technical factors influencing effectiveness of protective action	Weather conditions, particularly at the time of deposition, and the amount of rain after deposition will affect the amount of contamination remaining on the trees, shrubs and plants, and therefore the amount available to be moved and left on underlying surfaces. Windy weather will hamper attempts to collect leaves. Implementation: all material must be collected to achieve the DF value quoted, and therefore the degree of pruning and the effectiveness of leaf collection will determine the outcome. Spread of contamination onto adjacent surfaces should be minimised, as should trampling material underfoot or by vehicle, which will embed contamination into underlying soils. Time of implementation: weathering will reduce contamination over time so quick implementation will improve effectiveness. Once

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	leaves disperse or begin to compost, collection will be difficult, and therefore effectiveness will be reduced. If leaf litter is contaminated, and a subsequent fall of uncontaminated leaves occurs, collecting those leaves will expose the underlying contamination, and so dose rates will rise. Tree species and leaf type: the size, shape, and texture of leaves will affect the amount of contamination intercepted and retained, as will the amount of foliage present at the time of deposition. There will be a difference between deciduous and evergreen trees and plants. Soil properties and topography. See also, 'Physical environment' section, above, for constraints.
Resourcing	
Specific equipment	Equipment will depend on the type of vegetation to be pruned or removed, and may include: brush cutter, forage harvester, chainsaw, other saws, axe, hedge trimmer. Access to tall trees will be aided by ropes and ladders. Leaves and so on can be collected using rakes, shovels, wheelbarrows, sheets or nets placed under trees before fall. Garden vacuum equipment for small areas or perhaps municipal vehicles for slurry collection could be effective at sucking up leaves on over large areas, although workers would need to be protected from the possible resuspension hazard. Shredders or chippers could be used to prepare collected material for easier transport and disposal.
Ancillary equipment	Vehicles for transporting equipment and removing waste. Appropriate PPE.
Utilities and infrastructure	Suitably sized roads for transport of equipment and waste.
Consumables	Fuel and replacement parts for equipment and vehicles. Replacement plants, such as tree saplings, if replacement option is implemented. Waste bags, if used.
Skills	Simple pruning and leaf collection could be implemented by inhabitants as a self-help measure, with instruction from authorities, provision of safety equipment, and the provision of a waste collection system.

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	Skilled personnel will be required to operate machinery (for example, chain saw), and experience in climbing and felling trees may be required. Where this is carried out in highly contaminated areas, training in PPE and use of respirators would be necessary.
Work rates and operator time	<table><tr><th>Protective action</th><th>Work rates</th></tr><tr><td>Leaf collection</td><td>200 m²/h Team size: 1 person (12) If underlying humus is collected with leaves, then work rate will be considerably slower.</td></tr><tr><td>Shrub or plant pruning and removal</td><td>100 to 1,000 m² per team hour, depending on equipment used Team size: 2 people</td></tr><tr><td>Tree felling only</td><td>50 m²/team.h Team size: 2 people 10 m²/h (1)</td></tr></table>Typical team sizes are indicated, but additional people may be required to resupply consumables and transport collected material. Depending on the PPE used, individuals may need to work restricted shifts. Specific information for Japan about workforce requirements for (a) pruning coniferous trees and collecting pruned branches; (b) removal of understory vegetation and shrubs; removal of leaf litter and woody materials has been recorded by MoE based on the Fukushima experience (11).
Waste	
Type	Tree felling: 10 kg/m² wood and vegetation (1). Plant or shrub pruning and removal: 2 kg/m² vegetation and shrubby material. Trimming lower branches of forest trees: 1 to 3 m³ of waste per tree. Leaf collection: 0.5 kg/m². Treating the most heavily contaminated forests in Japan following the Fukushima accident produced an estimated 33 million cubic metres of waste. Depending on the actions performed, a wide variety of organic wastes will be produced: tree trunk, branches, twigs, shrubby

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	material, leaves, pine needles or cones, nuts, fruit, leaf litter, soft plant material. Waste amounts generated can be large. However, methods exist than can substantially reduce the volumes of organic waste by up to a factor of about 100. Some of these methods (such as, composting) could be practised locally and could be very significant in reducing waste transport and storage problems. Woody materials can be shredded or chipped on site prior to transport, but this process will generate large amounts of dust, so care must be taken to use PPE to reduce the hazard from resuspension. Raking, shredding or chipping of material for easier disposal is likely to generate dust, and therefore protective equipment is recommended for workers to limit the inhalation of any contaminated material that is resuspended into the air. To reduce resuspension, a light dampening (that is, misting) of the surface will help prevent resuspension but not risk moving the contamination onto the underlying soil or surrounding surfaces. Additional waste types to be considered: This is putrescent material which may generate liquid waste during decomposition. The management of liquid waste should be considered. Contaminated equipment could be classed as waste if it cannot be decontaminated sufficiently, for example, used PPE, cutting equipment and collection systems.
Transport	Transport can be via road or for large volumes it may be most efficient to consider transport via rail (Nuclear Transport Solutions can advise).
Treatment	Shredding and chipping may be considered as a means of reducing volumes for transport and disposal. It may be possible to undertake composting on or near to the point of generation. This will further reduce volumes and make disposal easier. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Early collection of bagged vegetation is essential as any moisture used for damping down, will accelerate the degradation process and hence creation of leachates. Waste could be stored in dumpy bags or builders' bags.

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	Where possible waste should be stored on hardstanding which allows the separation and collection of run off. Tarpaulins should be used to minimise rainfall infiltration. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Consider disposal to permitted LLW incinerator or landfill. For size-reduced green matter, consider ploughing in, or local composting followed by local application to land subject to the outcome of a radiological risk assessment. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementors: • external dose from deposited radionuclides on plant surfaces • external dose from radionuclides on contaminated equipment Removal of plant material could raise dust, potentially exposing implementors and public to an inhalation hazard from resuspended radionuclides. For implementors this may be enhanced over normal wind-driven levels, particularly in very dry conditions. Members of the public: none.
Impact of protective action	
Environmental impact	Adverse aesthetic effect. Possible adverse effect on ecology and plant health. May lead to reduced biodiversity, and loss of habitat. Removal of leaf litter from broad swathes of forest could lead to soil erosion or poor tree health. Replacement nutrients may be required. Removal of annual plants before they have seeded will lead to reduced biodiversity. Leakage of liquid waste from decomposition of leaves, if waste not managed.
Practical experience	
	Tree or shrub removal tested on a small scale in Europe after the Chornobyl accident (9). Tested on a semi-large scale in the Former Soviet Union after the Chornobyl accident (9).

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	Used in forests and residential gardens in Japan after the Fukushima accident (10, 11). The very different climate, topography, soil types and tree species in Japan versus north-western Europe make comparisons of effectiveness of litter and hummus removal difficult (8). Used following the incident in Goiânia (6).
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39. Remove plant material	
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Comments	
	Pruning and removal of low branches will enable access for workers to remove topsoil which in combination with branch trimming can give a DF of about 2.5 (reduction of contamination levels by about 60%). For maximum benefit, this action should be considered with other options, for example, to decontaminate surrounding surfaces such as lawns, flowerbeds, patios, paths, and roads. This is particularly important when wet deposition has occurred, as much of the contamination may wash straight off the trees, shrubs, and plants. The potential for forest fires due to climate change may be a factor influencing the timing or effectiveness of this protective action.

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40. Removal of topsoil and turf	
General	
Objective	To remove soil and grass surfaces in inhabited areas and therefore reduce doses from external irradiation and inhalation of resuspended material.
Other benefits	Removal of contamination will also reduce doses from inadvertent ingestion which may occur from certain activities (such as, leisure, gardening). Removal of contamination from allotments, kitchen gardens and adjacent grass areas will reduce uptake to locally grown vegetation and food.
Protective action description	**Topsoil removal** Removal of topsoil generally applies to the top 5cm, where most of the contamination is located following a recent atmospheric deposit. For example, in the short-term following deposition of radiocaesium, it has been found that around 80% is situated in the top 5 cm of soil. However, depending on the soil type and whether any soil mixing has occurred, radiocaesium may penetrate deeper into the soil in the longer term. The removal may be carried out manually or using road construction equipment such as a bobcat, mini-bulldozer, backhoe, or hammer-knife equipment. Dust suppression can be achieved by fine water sprays or the application of a soil hardener prior to removal. Depending on the environment a mixture of mechanical and manual methods may be required. For example, uneven surfaces will prevent stripping at a consistent depth using mechanical methods. Additionally, manual collection of soil and roots may be required, depending on the equipment used (such as, hammer knife mower). Replacement of the top layer of soil with ‘clean’ soil can increase effectiveness by burying the deeper contaminated soil strata. **Turf removal only** Turf removal alone is carried out using a turf harvester which skims off a thin layer of soil or root mat (a few cm) with the turf in rolls or slabs. These machines are available in various sizes. Turf harvesting is optionally followed by reseeding or re-turfing; reseeding may be combined with a new top layer of ‘clean’ soil, if available.
Target	Grass surfaces in parks, playing fields, gardens, and smaller open spaces.

40. Removal of topsoil and turf	
	While topsoil can be removed in areas where tilling has occurred since deposition, the volume of waste generated may be considerable due to the contamination existing to a greater depth as tilling would have mixed surface layers with those from depth.
Targeted radionuclides	All long-lived radionuclides. The action would be difficult to justify for short-lived radionuclides, unless in a priority area.
Scale of application	Small to large, though large areas may generate unmanageable volumes of waste, for example, a 5cm deep skim which will become partially aerated upon removal will result in a waste volume of 50 to 100 litres per m^2. The total volumes could become too great to store, treat and dispose of. Manual topsoil removal may only be suitable for small areas (such as, small gardens).
Timing of application to optimise effectiveness	Topsoil removal should be carried out as soon as possible (ideally before any rainfall to minimise volume of material removed), but significant reductions are still possible in the longer term for relatively immobile radionuclides such as plutonium and caesium (fixed in soils containing clay minerals). There is a tendency for the more mobile radionuclides such as strontium to move down the soil profile with time reducing the effectiveness of the technique unless greater depths of soil are removed. Turf removal should also be carried out as soon as possible, before weathering of contaminants from the grass to the underlying soil occurs. However, significant reductions are still possible in the longer term as some activity will remain in the root mat of the turf. However, in this case the radionuclides will remain available for transfer to the above ground vegetation. For both actions, depending on the local environment, it may be beneficial to wait until after the first rain so that more of the dust has washed off other outdoor surfaces and buildings on to soil and grass areas, otherwise protection barriers to prevent run off will be necessary.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures;

40. Removal of topsoil and turf	
	replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Water-logged or soft underlying soils may prevent the use of heavy machinery. It may not be possible to remove frozen topsoil or turf. Although, if frozen during deposition, it is unlikely that the contamination would have penetrated the soil profile. Therefore, a thinner skim can be made with a sharper blade. Topsoil or turf removal can be impractical on land that is uneven or rocky or that contains tree roots. Equipment may be damaged by rocks and stones. On uneven surfaces and areas with fixed obstacles (such as shrubs, trees, sheds, play equipment), manual stripping may be required in addition to mechanical removal. The size of domestic gardens may preclude the use of large equipment. Hotspots or patches where contamination may penetrate more deeply than elsewhere may complicate removing the expected proportion of contamination. For turf to be removed, grassed areas must be mature, that is, they must have an established root mat. Run off from other areas onto land where topsoil and turf have been removed and replaced can cause secondary contamination. Some form of barrier may be required. This action has the potential to generate very large volumes of problematic waste. Temporary and longer-term storage and disposal options will be required.

40. Removal of topsoil and turf	
Effectiveness	
Reduction in contamination on the surface	Reduction in soil contamination by decontamination factors (DFs) of 10 to 100 (90% to 100% reduction) can be achieved (5). Experience in Japan following the Fukushima accident reported DFs of 2 to 20 (50% to 95% reduction) from stripping the top layer of soil (6, 8). Mechanical topsoil removal can achieve higher DFs than manual removal or turf harvesting. Furthermore, replacing the top layer of soil with clean soil was shown to further increase effectiveness (by burying the deeper contaminated soil strata) (8). Turf harvesting can remove around 70% to 90% of the contamination, that is, DFs of 3 to 10 (1). The effectiveness of the action will reduce with time of implementation as contamination will gradually migrate down the soil column following deposition.
Reduction in surface dose rates	Dose rate reductions of up to 95%, equivalent to a DF of 20, have been reported in Japan following the Fukushima accident (4).
Reduction in resuspended activity in air	If the contamination is mobile and allowed to dry, resuspension remains a risk. Damp soils are low risk for resuspension whereas dry soils are friable and lead to resuspension.
Technical factors influencing effectiveness of protective action	Consistency of depth of topsoil removed (operator skill). Identification of hotspots where removal of greater soil depths may be required. Vertical and lateral radionuclide distribution. Weathering (start as soon as possible to be most effective). Soil texture and moisture content. Soil or turf unevenness and the presence of vertical cracks in the soil. Type of vegetation cover. Time between deposition and implementation (for downward and lateral migration).
Resourcing	
Specific equipment	Depends on the technique used and the size of the area being treated. Topsoil removal: spade, bobcat mini-bulldozer, back-hoe, mechanical digger. Turf harvesting: sod cutter or turf harvester (commercial and domestic sizes).
Ancillary equipment	Waste bags or containers for soil and/or turf. Wheelbarrow or vehicles for transporting equipment and waste.

40. Removal of topsoil and turf	
	Seeding machine (if required). Dust suppression spray machine (if used). Enclosed truck mounted waste containers.
Utilities and infrastructure	Suitable staging or disposal site. Road vehicles for transport of equipment and waste. Bulk waste handling plant.
Consumables	Fuel and parts for vehicles and equipment. Protective equipment, for example, respiratory protection if soil is dry and dusty. Water for spraying (if used). Replacement topsoil (if required). Plants and turf or grass seed (if required).
Skills	On a large scale, can be implemented by already skilled operators such as municipal workers; additional operators could be instructed within a day. On a small scale, manual topsoil or turf removal could be implemented by inhabitants of the affected area as a self-help measure (assuming they have the motivation). Appropriate training should be given, particularly about the risk of resuspension of contamination from dried out material.
Work rates and operator time	The work rates provided below, represent the maximum achievable in idealised conditions. In reality, affected areas could be of heterogenous and complex terrain. Furthermore, the complications of working in PPE and heat exhaustion as well as (de)robe times, suggest a reduction in work rates shown below of approximately 50%. **Manual topsoil removal** 10 m^2/h per team. Team size: 1 for topsoil and turf (1). **Mechanical topsoil removal** 100 to 400 m^2/h per team. Team size: 2 for topsoil and turf (1). **Turf harvesting** 150 to 1,000 m^2/h per team (depending on equipment used, for example, tractors with attached modern turf harvesters can strip about 1,200 m^2/h). Team size: 2 for turf (1). **Soil or turf replacement** 80 to 100 m^2/h per team, but likely to be much slower in small areas. Team size: additional 2 for soil replacement, additional 4 to 6 for re-turfing, additional 4 for reseeding.

40. Removal of topsoil and turf	
	If soil hardener is used there will be a delay to let topsoil harden prior to removal. Depending on the PPE used individuals may need to work restricted shifts.
Waste	
Type	Topsoil removal (50 mm depth removed): 55 to 70 kg/m^2 (soil and turf), depending on moisture content. (1). Turf harvesting (20 to 25 mm depth removed): 20 to 30 kg/m^2 (soil and turf) (1). This action has the potential to generate large volumes of waste. The waste produced will be organic and potentially difficult to dispose of.
Transport	Use sealed or lined 'hook and drop' style truck mounted containers for moving soils to a staging or treatment site. Can be transported in dumpy bags or conventional skips, for large volumes consider roll on roll off skips. Suitable for road transport or for very large volumes or long distances it may be most efficient to consider transport via rail (Nuclear Transport Solutions can advise).
Treatment	Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. Not suitable for compaction. May also consider backwashing prior to disposal to landfill if liquid wastes can be dealt with. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Where possible waste should be stored in bags or containers on hardstanding which allows the separation and collection of run off. Tarpaulins should be used to minimise rainfall infiltration. If disposal to LLWR is needed, dumpy bags should be loaded into an Isofreight container. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Permitted LLW Landfill (mainly non-hazardous waste), or LLWR can be considered dependent on waste properties.

40. Removal of topsoil and turf	
	Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Operative removing soil: • external exposure from contamination in topsoil • inadvertent ingestion of contaminated soil • inhalation of resuspended soil Those transporting and managing waste may also be subject to external exposure. Members of the public: • inhalation of resuspended dust
Impact of protective action	
Environmental impact	Risk of soil erosion due to disruption of soil structure. Impact on soil biota and associated decomposition processes. Possible loss of biodiversity and change in landscape (including loss of plants, shrubs and so on). Possible loss of soil fertility, nutrient and water retention. Potential for very large volumes of waste to be generated.
Practical experience	
	Used on inhabited areas in: USSR following the Chornobyl accident (large scale and more optimised on small scale) (2, 9). Brazil following the Goiânia incident (small scale) (3). Japan following the Fukushima accident (large scale) (4, 7).
Key references	
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40. Removal of topsoil and turf	
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41. Store and cover personal and precious objects	
General	
Objective	To reduce inhalation and external doses arising from contamination on personal and precious objects within inhabited areas. This option is likely to be implemented for assisting the public to return to 'normal'.
Other benefits	There are mental health and political or trust benefits to be obtained from ensuring that relocated populations and populations living in contaminated zones have the comfort and consolation of items of sentimental value. If items are large or fixed – removal or covering can protect objects from damage or further contamination while aggressive decontamination is undertaken to buildings.
Protective action description	Some objects may be too fragile to decontaminate. In this case, alternative options that introduce a suitable degree of separation, either time, distance, shielding, or a combination, between the object and people could be implemented. **Storage** Items can be stored within appropriately shielded facilities until the radioactivity has decayed sufficiently. Depending on the object function and nature of contamination, storage could be full-time, or the object could be removed periodically from storage to perform its function, for example, a painting or artefact could be brought out periodically for special viewings. Sometimes, removal of objects to safe storage may be recommended prior to building remediation, in which case objects would require cataloguing, pre and post condition reporting or photographs. **Covering** Some objects could be shielded or covered in situ. For instance, museum artefacts could be placed behind leaded glass or Perspex. Alternatively, or additionally, increased distance between the object and people could be achieved by adding or moving barriers. Sometimes, when objects are too large or immobile, they can be covered with PVC sheets and progressively decontaminated as the sheeting is partially removed. **Encapsulation** Material encapsulation technology, including embedding into acrylic blocks is readily available. Since removal from acrylic is difficult this is most suitable for items which have no function other than as keepsakes. Encapsulation methods would only be considered if

41. Store and cover personal and precious objects	
	decontamination was sufficiently ineffective, and the items was of such significant 'value' to be kept and monitored over time. For objects such as photographs and letters, copying and disposal of the original may or may not be acceptable. When dealing with personal objects it is important to understand that any object can have sentimental value. Tact, understanding and patient consultation about available options may be required.
Target	Precious objects, such as museum artefacts, tapestries, jewellery, paintings and so on, and personal objects such as photographs, toys, keepsakes, and letters and so on within buildings.
Targeted radionuclides	The cover option will be particularly suited to short-lived alpha and soft beta emitters – in this case 2 years or less. The storage option will be particularly suitable for short-lived radionuclides – in this case 2 years or less.
Scale of application	Commercial storage facilities are generally available and, depending on the degree and nature of contamination, could be utilised on a wide scale. These facilities will need to be capable of handling contaminated items and prevent cross contamination between items. Items would need to be packaged in an appropriate manner to withstand the storage period. Covering and separation, and copying could be utilised on a wide scale, subject to public acceptability.
Timing of application to optimise effectiveness	Covering or storage (including items ultimately cleaned or copied), should be implemented before the environs are decontaminated. Mental health and political or trust benefits will be maximised if actions implemented early and without the population having to campaign for them.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs

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	• providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	None.
Effectiveness	
Reduction in contamination on the surface	Contamination on the surface of objects will only be reduced as fast as natural decay.
Reduction in surface dose rates	Shielding and storage: reduces external gamma and beta dose rates; the degree of reduction will depend on the thickness and type of shielding used, for example, brick, lead, glass, plastic. Effectiveness will depend on the decay chain, and presence of future progeny. Distance: 1 to 2 m of air will reduce dose-rates to very low levels for weak beta emitters: a distance of up to 10 m would be needed to give high reductions in dose rate for high energy beta emitters such as $^{90}Sr/^{90}Y$.
Reduction in resuspended activity in air	A closely fitting container will stop all resuspension.
Technical factors influencing effectiveness of protective action	Effectiveness depends on the degree of separation (time, distance shielding) and any encapsulation method employed that can be achieved without compromising or negating the function or value of the object.
Resourcing	
Specific equipment	Specialist lifting equipment if object is to be moved into storage. Photographic logging and tracking systems, such as, barcodes (laser etched onto objects). Storage containers.
Ancillary equipment	Secondary equipment that may be required (for example, monitoring equipment).

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Utilities and infrastructure	Storage facilities.
Consumables	Shielding materials. Packing and containers. Encapsulation or copying materials.
Skills	Specialist handling skills.
Work rates and operator time	Work rates are very variable depending on objects to be stored or covered and methods used.
Waste	
Type	This protective action minimises waste production. Small quantities of PPE, contaminated encapsulation or copying equipment, contaminated containers, and packing or storage materials, copied originals.
Transport	Suitable for transport via road.
Treatment	Contain in Isofreight container or suitable bag or drum. No specific treatment required for permitted incinerator or landfill. Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Suitable package to contain contaminated items for the prescribed period, ideally stored within a secure facility near the point of generation. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	The contamination on packaging should be trivial, most likely suitable for the domestic or commercial disposal sites. For other waste, one solution is disposal to permitted incinerator. Alternative route – disposal to permitted landfill. Disposal to permitted landfill or LLWR may not be possible if the waste is classified as hazardous as well as radioactive. Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE.

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	Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementors: • external exposure from deposited radionuclides • inhalation of resuspended material, both on the objects and in the environs Members of the public: none.
Impact of protective action	
Environmental impact	The quantities of waste should be small, and any impact can be minimised through the control of any disposal route and relevant authorisations via a centralised facility.
Practical experience	
	The Litvinenko poisoning incident involved the contamination or many premises. Westminster City Council, within whose boundaries many of them were situated, developed a strategy that recognised the need for consultation with owners of personal or high value items within those premises. The strategy identified decay storage of such items as an option given the short half-life of the radionuclide involved (2). Several months after the Fukushima incident and following unauthorised entry to the relocated zones, the authorities made provision for relocated populations to return to their homes on short visits, usually a few hours, to retrieve personal items as well as fulfil other personal obligations (from newspaper accounts such as The Japan Times (2011)). Evacuees briefly return home in no-go zone. The authorities provided buses, and on occasion protective clothing and personal monitoring for those making visits (1).
Key references	
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Comments	
	Contamination may remain on stored, covered, separated or encapsulated items so ongoing controls may be required. The remote storage of precious objects may present a risk of theft.

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42. Strippable coatings	
General	
Objective	To temporarily contain and when peeled off, remove loose contamination from indoor and outdoor surfaces in inhabited areas, thereby reducing external exposure and inhalation of resuspended material. It may also be used as a protective sacrificial coating.
Other benefits	Will remove loose contamination from treated surfaces and therefore reduce redistribution of contamination. While in place, strippable coatings will produce a tie-down effect (see datasheet 44: 'Tie down') and reduce exposure to implementers (while implementing other recovery options) and any members of the public. The removal of the coating in some circumstances can be considered optional. Has other applications including suppression of dusts and fibres, including asbestos. Can also be used as a sacrificial coating to keep an item clean when entering a contaminated area, which when removed, reveals a clean surface.
Protective action description	The application of strippable coatings to a surface entrains contamination into the matrix or body of the coating when cured, such that when the coating is removed, loose surface contamination is removed with it. As well as contamination adhering to the coating, there may also be chelating agent properties in the coating, that bind organic chemicals to a metal ion, bringing them into solution and increasing removal from the surface. However, these have significant disposal issues and should be avoided unless there are no alternative products. Strippable coatings have the additional benefit of providing a tie-down effect), while the coating is in place, typically 12 months before cracking or UV degradation is observed. Subsequent applications may be applied to extend the tie-down effect for a longer duration, for example, where there is wear or breakup of the coating. Coating thickness is critical to ease of retrieval. Nominally, 1 litre of raw material will cover 0.5 to 2 m^2 and still be retrievable. The coatings can be applied to the surface by spray, brush or roller. Reinforcing netting material applied to the coating whilst wet and over-coated with more coating has been shown to be very effective way of peeling the coating, particularly for complex geometry items, such as, coarse net curtain material and coarse Kevlar matting. Most coatings are not mechanically robust for foot fall or vehicles and so on, hence additional protection from rubber

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	mats and so on can protect and extend the useful lifetime of the coating. Removal of the strippable coating from the surface involves stripping or pulling the coating away from the surface. The coating can be rolled as it is removed for ease of handling and to further entrap any contamination on the surface of the coating. The coatings are frequently water-based organic polymers to minimise organic vapour releases. Some damage may occur to less robust surfaces for example, when removing paint from walls. If a coating is intended for external use, consideration of hygroscopic tendencies and UV stability must be considered. Most coatings are intended for internal use, especially those that are water soluble. **Duration** Understanding the required duration of the tie down option is critical. To achieve maximum effect even in static weather conditions, tie down should be done at the very earliest opportunity to prevent secondary contamination. Types of products and relative durations of use include: Hours – Water spray, glycerol. Days – Gels and rheological modifying agents. Months – Latex and polymer solutions. Years – Consider use of tie-down coatings of a semi-permanent nature, for example paint systems, poly urea coatings, resins. A number of strippable coatings have been tested and assessed for nominal disposability within the wider UK civil nuclear industry. **Safety** High volume fine mist sprayers have the potential to quickly blind the filters on a respirator, resulting in asphyxiation.
Target	Any dry robust surface such as building surfaces, paved surfaces, hard surfaces, metal surfaces in buildings and parts of machinery, hand tools and other equipment. Contamination should be loose, removable particulates or loose contaminant-harbouring debris. Any critical area where access is necessary for critical safety or enabling function.
Targeted radionuclides	All long-lived radionuclides. Should not be used for short-lived radionuclides alone due to the cost of the coatings in application, removal, and disposal.
Scale of application	Generally applicable to small scale events, although there is industrial experience for application on 1,000’s m^2. May be used for

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	parts of houses and paved areas though resources required may become a problem as area to be treated increases. Alongside commercial products that could be used, Argonne National Laboratory have developed strippable coatings for larger scale applications. Although, these are not currently cost effective.
Timing of application to optimise effectiveness	Maximum benefit if carried out soon after deposition when maximum contamination is still on the surface before any wetting or weathering.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Generally, coatings cannot be applied in wet or severe cold weather. There are limited number of examples of coating items in wet or submerged environments. However, the long-term leaching of constituent chemicals has not been assessed. Optimum temperature range 4 to 32°C (5).
Effectiveness	
Reduction in contamination on the surface	Decontamination factors (DFs) vary, typically in the range of 1.5 to 100 (30% to 99% reduction), depending on the nature of the contaminated surface, with the lower end of the range more applicable for porous materials such as bricks and tiles (3). This

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	action is likely to be more effective if this removal option is implemented within a few weeks of deposition, depending on intervening weather. The application of the coating is particularly useful to manage alpha emitting contaminants.
Reduction in surface dose rates	External gamma and beta dose rates dose rates from external walls and roofs will be reduced by approximately the value of the DF.
Reduction in resuspended activity in air	While the strippable coating is in place, resuspended activity in air from the covered surface will be reduced by almost 100%.
Technical factors influencing effectiveness of protective action	Ambient humidity and temperature will affect curing time on outdoor surfaces such that curing may not be possible. Type, evenness, shape and condition of surface. With increasing surface roughness or complexity, strippable coatings become more difficult to remove if metal surfaces corrode after deposition or weathering, decontamination is reduced. Strippable coatings are temporary (ideally less than 12 months), primarily as their flexible physical characteristics reduce over time resulting in cracking, embrittlement or degradation (for example, by UV light). Time of operation: the longer the time between deposition and implementation of the option the less effective it will be due to fixing of the contamination to the surface or transfer of contamination to other surfaces (such as by weathering). Care of operation: careful removal is required to be effective. Removal should be done by hand. Consistent application of strippable coating over the contaminated area. Viscosity of applied liquids (noting that dilution to reduce viscosity is not recommended). Number of buildings and paved surfaces in the area (that is, the proportion of the contaminated surface area that it is possible to treat).
Resourcing	
Specific equipment	Coating solution and suitable containers or applicators (for example, brushes, weedkiller backpack or pumped sprayers). Transport vehicles for equipment and waste.
Ancillary equipment	Protective clothing, including respiratory protection.

42. Strippable coatings	
	High volume fine mist sprayers have a strong potential to blind the filters on a respirator in quick time. Result is effective asphyxiation or by removal of RPE, an inhalation dose. Ladders, scaffolding and other equipment required if working at height.
Utilities and infrastructure	Roads for transport of equipment, materials and waste.
Consumables	Currently, the most commercialised materials used for decontamination and decommissioning are by spray-on, or roll-on or brush-on techniques. Choice of coating: for example, biodegradable and water soluble strippable coatings include solutions based on polyvinyl alcohol (PVA) mixed with glycerine (6). Water soluble coatings should only be used for internal, dry only conditions. Sprayers, brushes, rollers and so on.
Skills	Semi-skilled personnel essential to apply (and remove) coating. Personnel can be readily trained if they have prior hazardous environment working experience. Removal of coatings is less demanding of skilled resource, but requires greater numbers of personnel, after a brief training period. Industrial cleaning companies may have some of the required skills, but not in a radiological context.
Work rates and operator time	0.5 to 1 litre of coating per m^2. Work rate spraying approximately 10 m^2/h. Work rate recovery or stripping: highly variable based on the complexity of the geometry.
Waste	
Type	Around 1 kg/m^2 (range 0.2 to 1.8 kg/m^2) solid, rubber like material (7).
Transport	Suitable for transport via road.
Treatment	Contain in Isofreight container or suitable bag or drum. No specific treatment required for permitted incinerator or landfill. Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).

42. Strippable coatings	
Storage	Suitable wastebin, approved container or Isofreight stored and managed near point of generation. To minimise the spread of contamination, attempt to store waste directly in the container that will go to landfill or incinerator. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Preferred solution is disposal to permitted incinerator. Alternative route – disposal to permitted landfill. Disposal to permitted landfill or nuclear disposal site may not be possible if the waste is classified as hazardous as well as radioactive. Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special nuclear materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the ground and other surfaces • inadvertent ingestion of dust (can be avoided by correct use of RPE or PPE) Those transporting and managing waste may also be subject to external exposure. Members of the public: none.
Impact of protective action	
Environmental impact	Some commercial solutions are based on rubber latexes (polyacrylates, polyisobutylene, polyisoprene or polyvinyl esters), detergents and solvents which are relatively toxic and not biodegradable (6).
Practical experience	
	Use of strippable coatings in the civil nuclear industry is widespread, on small, medium and large-scale requirements with a wide range of DFs, nominally 5 to 1,000. A number of products have been tested against a range of substrates alongside their

42. Strippable coatings	
	nominal disposability. However, the data are commercially sensitive. The use of polymer pastes on metal surfaces was tested on a small-scale in Gomel province of Belarus after the Chornobyl accident (2). Use of peeling gels on residential houses at test sites following the Fukushima accident (1). A coating release agent was trialled on roof tiles in areas contaminated after the Fukushima accident but due to the length of time required by the process it was found not to be a practical option (4). New generation strippable coatings have shown DFs greater than 20 (that is a greater than 95% reduction) for ^{137}Cs on all surfaces, DFs greater than 10 (greater than 90% reduction) for ^{60}Co, and DFs more than 3.5 (greater than 72% reduction) for ^{241}Am on all surfaces except galvanized metal, where lower DFs were found (approximately 40% for ^{60}Co and ^{241}Am (6). Use of a clay paste in Pripyat in 1993 (7 years after Chornobyl) gave rise to a DF of 1.6 (approximately 37% reduction) (7). Polymer-based coatings were also applied in tests on buildings in the Chornobyl-affected area (Gomel region) and these resulted in DFs from 1.5 to 4.5 (33% to 77% reduction) (2).
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42. Strippable coatings	
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Comments	
	Strippable coatings are a subset of the tie down options. The primary purpose of a coating is to contain and immobilise loose contamination on a surface on a temporary basis. The secondary purpose is to allow for the recovery of the coating (and contamination). Intended for short to intermediate term use. Can also use strippable coatings as a sacrificial coating to keep something clean, deploy in a contaminated environment. The coating can then be removed to reveal a clean item.

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43. Temporary relocation	
General	
Objective	To reduce external doses from material deposited on surfaces and inhalation doses from material resuspended from surfaces within contaminated inhabited areas.
Other benefits	Other protective actions are more easily implemented whilst the population are absent.
Protective action description	Temporary relocation is the planned (non-urgent) removal of people either from short-term reception centres following evacuation or directly from their homes to temporary accommodation that can meet all of their basic needs and where living conditions can be properly supported. Temporary relocation is carried out to enable remediation of properties and land. It can last for an extended, but limited period, that is, weeks, months or several years depending on the characteristics and extent of the contamination. If it is not possible to return home within one or 2 years (5 years maximum), relocation may be considered as permanent. Following relocation, the elderly, those with physical disabilities and poor mental health as well as children and pregnant women are likely to face physical, social and psychological challenges. Therefore, physical and psychosocial support is likely to be needed for many of those who have been relocated and this should be considered in preparedness and planning for relocation. Decisions on allowing those who have been temporarily relocated to return to their homes involve an extensive dialogue with the affected people and the authorities and professionals in their communities. It is important to provide inhabitants with full details about the living and working conditions, and the quality of the environment they will face if they choose to return to their homes. They are entitled to expect support and have access to appropriate medical services and education.
Target	People living in contaminated areas, where residual levels of contamination are deemed to be too high to allow continued habitation.
Targeted radionuclides	All radionuclides. Particularly useful for short-lived radionuclides, but also as an enabler for other decontamination options.
Scale of application	Easier and quicker to implement on a small scale (that is, a few hundred properties, rather than a few thousand) that requires a regional response.

43. Temporary relocation	
Timing of application to optimise effectiveness	Early phase to intermediate phase. Maximum benefit is achieved if people are moved out soon after deposition or are evacuated during the emergency phase and then moved into temporary accommodation. However, provided the receiving area has lower levels of contamination, temporary relocation will still reduce doses, even if not carried out immediately. In this situation, caution should be exercised regarding cross-contamination of people and possessions, including clothing.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • preventing or controlling access to the affected areas, or to impose restrictions on living conditions in these areas
Physical environment	The physical risks associated with temporary relocation are relatively small compared with those for evacuation, as the action can be implemented without haste and with enough time to interact with those involved. Some weather conditions may make relocation more difficult for example, if carried out during periods of heavy snow, frost, or flooding. The relocation should capture all the physical needs of the infirm and able bodied alike. Physical and psychological burdens can lead to a deterioration in daily life activities, causing significant health impacts (9).
Effectiveness	
Reduction in contamination on the surface	None. This option will not reduce surface contamination in the area subject to relocation. However, early return or late relocation can lead to cross contamination of lesser contaminated or unaffected areas.
Reduction in surface dose rates	None. This option will not reduce surface dose rates in the area subject to relocation. However, the dose rate would be expected to fall either naturally due to weathering and radiological decay, or due to the implementation of other protective actions that remove contamination from the area.
Reduction in resuspended activity in air	Some reduction is activity concentrations in air may occur due to reduction in road traffic and other mechanisms for physically disturbing deposited radionuclides, but also weathering of external environments.

43. Temporary relocation	
Technical factors influencing effectiveness of protective action	Timing of displacement, ideally starting with most contaminated areas first. Level of exposure at new location. Cross contamination from vehicles, individuals, and their possessions or clothing during the evacuation will require some checks and mitigations for items leaving the affected areas.
Resourcing	
Specific equipment	Transport for moving people and essential possessions.
Ancillary equipment	Monitoring equipment to provide measurements of ambient dose rates and environmental and foodstuff contamination in the area subject to relocation. Monitoring equipment to check contamination of vehicles used in the relocation.
Utilities and infrastructure	Good communication channels. Transport routes. Alternative accommodation or housing with water and power supplies Infrastructure to support relocated populations: schools, doctors, social services and so on. Security services for area that has been relocated.
Consumables	Fuel.
Skills	Drivers. Security personnel to secure the area. Expertise in dose and risk assessment (allowing people to return home and to live there permanently requires an assessment of their future exposures and the associated risks). Environmental and food monitoring data coupled with realistic modelling can be used to predict future exposure (2). Resourcing may be impacted if workforce has been displaced. Additional workforce may have to be brought in.
Work rates and operator time	Influenced by types of vehicles used, their seating capacity, the number of belongings people are permitted to take with them, the location and type of temporary accommodation and hence distances that people have to be moved.
Waste	
Type	None.
Transport	n/a
Treatment	n/a

43. Temporary relocation	
Storage	n/a
Disposal	n/a
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers: • external exposure to drivers • potential for inhalation of resuspended material from vehicles used for relocation Members of the public: • cross contamination from people and items • external exposure if travelling through more highly contaminated areas en route to temporary accommodation
Impact of protective action	
Environmental impact	Increasing the size of the population in the area where people are temporarily relocated to may impact on the environment, for example, amount of general waste generated, increased traffic.
Agricultural impact	Temporary relocation can raise serious issues for farmers who may have to abandon their animals or crops.
Psychosocial impact	Changes of lifestyle, following temporary relocation can have a significant impact on physical and mental health, with strong links between the 2. Careful monitoring of both psychological and physical health of displaced populations is recommended (4). Mental health and psychosocial well-being were adversely affected by the relocations carried out after the Chornobyl accident in 1986 and after the 2011 Great East Japan Earthquake, Tsunami and subsequent nuclear accident at Fukushima (1, 5). The impacts were felt by relocated populations as well as the hosting communities. Several studies carried out after the Fukushima accident showed significant increases in the incidence of depression and Post Traumatic Stress Disorder (PTSD) among relocated residents of Fukushima prefecture (7, 8), that were disproportionate to the radiation risk. Studies following the English floods of 2013 and 2014 provided evidence that there was a higher incidence of depression and PTSD in those who were relocated compared to those who remained at home, even when the primary stressor (flooding) was removed (6, 10).

43. Temporary relocation	
Practical experience	
	In the UK, there is experience of temporary relocation after flooding in 2013 and 2014 (6, 10). Relocation after the accident at Chornobyl (1). Relocation after Great East Japan Earthquake, Tsunami and Fukushima (5, 7, 8). Relocation after the incident in Goiânia (3). Civil nuclear experience of managing minor incidents within a facility, adopting the practice of denied access to the affected area.
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Comments	
	The maximum period of time that temporary relocation could be tolerated would depend on a range of social and economic factors. For example, there might be increasing discontent with temporary accommodation if inferior or simply the desire to re-establish settled social patterns at the home location. Conversely, there may be concerns about returning home, such as the lack of employment opportunities, loss of local village or town bonds or cohesion, the need to repair or reconstruct abandoned houses; insufficient infrastructure such as schools, hospitals, and shops; and persistent concerns about radiation. Furthermore, there would be anxiety for the security of homes left unoccupied. For businesses in the area, there would be disruption and loss of economic activity and also anxiety for the security of premises left empty. Temporary relocation can be used in conjunction with other protective actions, making use of the time when residents are absent (such as various physical removal techniques).

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44. Tie-down	
General	
Objective	To prevent mobilisation of contamination for example by resuspension or transfer by humans or objects, that might lead to enhanced inhalation doses. To contain localised contamination hotspots. To prevent secondary contamination from wind-blow of resuspended activity from human activity, including clean-up operations that generate dust. To contain contamination where a structure is identified for demolition.
Other benefits	Some options remove secondary contamination risk. Some coatings bind contamination into matrix with option to remove (strippable coatings, datasheet 42). Durability varies from temporary to permanent (hours to years). Many of the coatings are also suited to managing asbestos or other surfaces that are chemically contaminated.
Protective action description	All tie-down techniques involve putting a liquid or solid material onto a surface to provide a barrier to direct contact or resuspension of contamination from a surface. Some materials such as water mist will provide only a temporary barrier which may need to be renewed, other materials such as bitumen are much more permanent. Various tie-down materials have been used in the literature, coupled with other unreported industrial experience, the choice depends on the surface, the aim (that is, short- or long-term tie-down) and other constraints (environmental considerations, availability). Covering of localised areas with sheeting materials such as PVC, tarpaulin and so on. can also be effective. These work by either creating a quick setting barrier with no or little binding onto the substrates or wetting of the surface to entrain some or all of the contamination into the matrix. Tie down coatings can be deployed in a number of ways, but mostly spraying or mechanical spreading of a viscous fluid or solid over the substrate. Factors to consider for spraying include, the degree of atomisation required and hence spray pressure, the range of unintended application due to draughts; any heating or mixing requirements. Spraying systems of low viscosity fluids (such as, water) is readily achieved with hand or weedkiller spray packs, or for wide areas, crop spraying systems. More viscous fluids may

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	require heat and positive displacement pumps operating up to 200 bar. Selection of tie down coatings varies according to the required duration and durability. For example, if the coating is required to last for 1 to 2 years, will it withstand weathering? Will the coating be subject to footfall or light equipment movements, such as fork-lift trucks? Some products are hygroscopic while others can be redissolved, some are UV stable, however many are not. **Duration** Understanding the required duration of the tie down option is critical. To achieve maximum effect even in static weather conditions, tie down should be done at the very earliest opportunity to prevent secondary contamination. Types of products and relative durations of use include: • hours – water spray, glycerol • days – gels and rheological modifying agents • months – latex and polymer solutions • years – robust paint systems, poly urea coatings, resins, bitumen **Roads and paved areas** Water can be used as a temporary tie-down measure on roads or paved areas. Spraying water on to the surface, from a sprinkler boom mounted on a vehicle, forms a meniscus between the radioactive particles and the paved surface, preventing resuspension. Sand can also be used as a temporary tie-down measure on roads or paved areas. For small areas, sand is shovelled by hand from a lorry on to the paved surface. For large areas, about 10 to 15 mm of sand is sprinkled on to the paved surface using a lorry fitted with a rotary motorised sprinkler. Note that sand even if damp can readily dry out and blow away in the wind, unless covered with a tarpaulin or top coat of cement or grout. Lignin is the generic name for products whose main ingredient is a by-product of wood pulp processing and are often used as dust suppressants on unmade roads. They are non-toxic and biodegradable and last about one year. The lignin is diluted with water and applied by spraying with a tractor and boom. Harvesting or cutting can be problematic as lignin can be sticky and clog equipment. Bitumen can be used to give permanent tie-down on hard outdoor surfaces such as roads or paved areas. For small areas, bitumen is

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	sprayed on to the surface. A tank with a capacity of about 2,000 to 3,000 litres is required which can be moved by a 4-wheel drive vehicle. The coating is permanent. For large areas, bitumen is sprayed on to the surface via a bulk surface-dressing machine. In both cases, if the surface is damp, a bitumen emulsion should be applied. When spraying bitumen, drain covers and so on should be covered to protect them from the spray. **Soil and grass** Water can also be used on soil or grass areas, though this technique should not be used if the aim is to tie contamination to grass prior to grass cutting, as the water will wash the contamination into the soil and root mat. If treating small areas of grass or soil, the area is sprayed with water using a hose connected to a hydrant. For large areas, standard movable hose-reel irrigation equipment can be used. Hose-reel irrigation systems come in a variety of sizes, the equipment is laid out by tractor and when connected to a pump or water supply the travelling sprinkler is slowly pulled towards the reel usually by the hydraulic power of the water. Clean soil or sand can be used to tie down contaminated soil in order to prevent against resuspension hazard.
Target	External walls and roofs of buildings, hard outdoor surfaces (roads, pavements, paths, playgrounds and so on), semi-enclosed surfaces (such as within train stations) and soil or grass surfaces in gardens, parks, playing fields and other open spaces. Tie-down coatings may be particularly useful to prevent mobilisation of contamination in inaccessible areas, for example roof area, building external surfaces above a predetermined height and so on, to reduce the amount of effort required to clean up surfaces and also internal environments to reduce the risk to decontamination teams, where demolition is expected.
Targeted radionuclides	All radionuclides where the inhalation dose from resuspended material is likely to be of concern or where there is a need to prevent secondary contamination or immobilise the material during clean-up to operators and or the public.
Scale of application	Any size, although there may be difficulties scaling up application with equipment availability and supply of coatings.
Timing of application to optimise effectiveness	Very generally, the concentration of resuspended material in air is expected to be at its highest immediately after initial deposition but to drop off rapidly over days and weeks. Subsequently it continues to reduce but at a slower rate over months and years. However, on

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	top of this general trend, resuspension is dependent on many other factors, including weather conditions (dampness and wind speed) and human activity. Therefore, the maximum benefit, in terms of (a) dose reduction and (b) prevention of secondary contamination, can be achieved if tie-down is applied at the earliest opportunity. If an area can be fully controlled, that is, access restricted, actions may be delayed, for example within retail structures, offices with the HVAC switched off early or when prevailing conditions promote resuspension. Conversely, it may be unnecessary or can be delayed when conditions do not promote resuspension.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Wet or cold weather. Uneven surfaces and areas which are difficult to physically access. High temperatures and high humidity. Tie-down cannot be applied to a surface covered in snow or standing water, Initially, may not be an issue, as resuspension only becomes a potential problem when the surface dries out.

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	Not well suited for fabrics in domestic environments, trains, buses and so on. unless they are ultimately destined for disposal.
Effectiveness	
Reduction in contamination on the surface	**Tie-down material left in place** Where coatings are applied permanently, very high decontamination factors (DFs) can be attained with respect to loose contamination. It should be noted that the contamination remains in-situ, albeit 'unavailable' for mobilisation. **Coating subsequently removed** Where coatings are removed (strippable), not only are high DFs attained for loose contamination, but upon removal DFs of up to 100 (99% reduction) are credible. Removal can be as a result of a solid coating being disposed of or a soluble coating being washed off carrying activity with it.
Reduction in surface dose rates	**Tie-down material left in place** Tie down is not effective at reducing gamma dose rates. While the tie-down material is in place, external beta dose rates adjacent to the surface will be reduced by a factor depending on the tie-down material, its thickness and the energy of the beta emissions – low energy beta emissions being more effectively reduced. When considering tie-down of contamination on a hard surface such as a road, sand (2 mm) would be the most effective at reducing beta dose rates. For example, for ^{90}Sr and its daughter ^{90}Y, a reduction of 90% for sand (RF 10), 70% for bitumen (RF approximately 3.5) and 45% for water (RF approximately 2) could be expected. **Coating subsequently removed** Removal of the coating material can give DFs of up to 100 (99% reduction), with associated dose reduction. However, strippable coatings would not be the primary method for decontaminating surfaces, as more aggressive actions may be more applicable.
Reduction in resuspended activity in air	While the tie-down material is in place, resuspended activity in air adjacent to the surface will be reduced by close to 100%. Use of water or glycerol are effective only in the short term (hours to days), subsequently they can lead to elevated and prolonged airborne contamination levels and hence inhalation doses. If treating soil or grass areas, applying water will aid the bonding of activity to soil particles and can wash contamination below the surface, both of which will reduce resuspension in the longer term.

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	However, if plants, shrubs and trees are not removed, these will still contribute to radiation doses when in leaf and inhalation doses from decayed material.
Technical factors influencing effectiveness of protective action	Tie-down is most effective when weather conditions are conducive to resuspension, for example dry and windy conditions. Although, the variability and range of UK weather generally means, some form of coating is required to prevent mobilisation. For demolition of a contaminated structure, use of a coating is essential. Type, evenness, condition, and slope of surface. Timing – unless in a controlled and enclosed internal environment, application at the very earliest opportunity is essential. Weathering – will the coating be subject to natural weathering or high or low temperatures, high humidity and so on. Duration of requirement: water or mist systems have useful durations of hours. Durability of coating whilst in place. Run-off from vertical surfaces (or excessive use horizontally) can lead to product entering surface drains and so on. Particular care is required for the use of any water-based systems on porous surfaces to prevent the ingress of contamination into the substrate. Thicker coatings are usually required to facilitate the removal. Avoid high energy spray systems (that is, compressed air) for atomisation that can disperse the loose contamination. Consequences of wetting a surface or washing down for future decontamination.
Resourcing	
Specific equipment	The equipment required depends on the surface, tie-down material, and size of area being treated. **For external building surfaces** Coatings, airless spray pump and compressor, access by scaffolding or fire-tender with hydraulic platform, protection of surface drains. **For roads or paved areas** Water: a motorised water filtered system should be used not a standard municipal sweeper, sand: a lorry, sprinkler attachment and excavator or loader are required, bitumen: a hot bitumen sprayer or cold emulsion sprayer are required. **For soil grass areas** Water: on small surface areas, a hydrant and hose are required. For large areas, a winding hose-reel system including tractor or crop sprayer.

44. Tie-down	
Ancillary equipment	Transport vehicles for equipment and waste disposal.
Utilities and infrastructure	Roads for transport of equipment, materials and waste. Water supply may be required.
Consumables	Tie-down material (for example, coatings, water, sand, hot bitumen, bitumen emulsion, or lignin). Fuel and parts for transport vehicles and equipment.
Skills	Skilled personnel essential to operate equipment. Personnel applying coatings will need to understand how the coatings will react with the application surface and also how the coatings will stand up to wear and tear and weathering.
Work rates and operator time	Operator times are subject to many variables including the environment, weather conditions, the skills and equipment available **External building surfaces: coatings** Work rate m^2/h: 150 to 200 (excludes setting up of scaffolding). Team size: 3 to 6 (depending on area, equipment, and access). **Roads with water** Work rate m^2/h: 30,000. Team size: 1. **Roads with bitumen** Work rate m^2/h: 500 to 1,000. Team size: 2. **Soil or grass with clean soil or sand or water** Work rate m^2/h: 200 to 3,000 (depending on material and equipment used). Team size: 2.
Waste	
Type	The amount of waste depends on the treatment used and whether the tie down actions are permanent. Political and social pressures will dictate removal of contamination and the tie down material at some stage. On that basis, such protective actions usually create significant waste volumes (Defra, personal communication). **For external building surfaces** Using acrylic paint if subsequently removed: Paint: 0.4 kg/m^2 paint and dust. **For roads or paved areas** Water: 0.33 l/m^2 water and dust. Sand: 1 to 2 kg/m^2 sand and dust. Bitumen: no waste because this is a permanent tie-down option (If bitumen layer is removed in the future, typical quantities of waste from the applied layer would be 1 to 2 kg/m^2).

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	For soil or grass areas Water or lignin: putrescible waste. Potential for contaminated equipment (see 'Specific equipment', listed under 'Resourcing', above).
Transport	NDA has a specialist group Nuclear Transport Solutions (rail and shipping) and access to road transport options via NDA or Sellafield. Other licenced road hauliers could be used. Likely to require IP2 containers or other approved packages.
Treatment	For Incineration – drainage of any leachates will be required. VLLW and LLW – drainage of leachates, characterisation, and compaction prior to storing in approved packages (half or full height Isofreight containers). ILW and special nuclear materials require specific measures for handling, transport, transport for storage, storage, and disposal via NDA, Sellafield or AWE. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	NDA has a specialist group Nuclear Waste Services with access to storage and disposal options. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	NDA has a specialist group Nuclear Waste Services for VLLW and LLW depending upon contamination levels and chemical composition, including incineration. In extremis, ILW and Special Nuclear Materials are possible via the NDA, Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers • external doses from radionuclides • inhalation doses (without necessary PPE or RPE) Some methods of application, particularly those involving vehicles, could temporarily enhance resuspension for implementors and public (unless travelling at very low speeds).

44. Tie-down	
Impact of protective action	
Environmental impact	Some treatment options may give rise to contaminated waste – for example, if paint is used on external building surfaces and later removed, or future maintenance of road surfaces treated with bitumen. The use of water may wash some of the contamination on to other surfaces and potentially into drainage or wastewater systems. Run-off issues need to be addressed, otherwise abstraction of water from watercourses may have to be restricted. Chemical contamination from coatings migrating into soil may be an issue. Bitumen spraying of roads may provide a positive impact if road surfaces are poor.
Practical experience	
	There is extensive experience of coatings use within the UK civil nuclear sector for both removable or strippable and permanent coatings in both normal operations and incident exercises mindful of the radiological disposal criteria. Use of lignin on soil has been tested on a small scale (only a few m^2) in Denmark in conjunction with removal. Full scale tests on the use of lignin for dust suppression have been carried out in the USA and Sweden, where it is routinely used. However, disposal of contaminated putrescible wastes may be an issue. It appears tie-down was not used following the Goiânia incident, however secondary contamination was observed after a very hot and dry episode, with windblown contamination onto roofs being of concern. It appears the tie-down was not used as a primary technique following the Fukushima accident, however the MOE guidelines stress the importance of dust suppression during clean-up operations, primarily to protect the implementors, and suggests using “curing materials”,” solidification agents” or “sprinkling in advance” for this purpose (2). Various chemicals including latex were used for dust suppression to prevent wind driven secondary contamination within the 30 km zone around Chornobyl in the period 1986 to 1988. Experiments in dust suppression in inhabited areas by spraying water suspended polymers following soil removal were carried out on soils contaminated following the Chornobyl accident (1), but

44. Tie-down	
	since these occurred sometime after deposition there was little resuspension, and no conclusions could be drawn.
Key references	
	1. Hubert P, Annisomova L, Antsipov G, Ramsaev V and Sobotovich V (1996). 'Strategies of decontamination. Experimental collaboration project number 4: final report' European Commission, EUR 16530 EN 2. Ministry of Environment (2013). 'Decontamination guidelines' (second edition)
Comments	
	Tie-down may also be referred to as dust suppression', 'fixatives', 'fixation', 'fix in place', 'contamination stabilisation' and 'particle containment'. If treatment gives long-term tie-down on hard outdoor surfaces, account should be taken of the need for surface repair and access to underlying services (for example, gas or water pipes, cables). Permanent tie-down may hamper future 'gentle' decontamination and require more destructive techniques to be used.

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Return to index of protective actions for inhabited areas in Annexe A3

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
General	
Objective	To remove loose particulate contamination from indoor and outdoor surfaces and objects in inhabited areas and to reduce doses from external irradiation and inhalation of resuspended material. This is not a self-help option.
Other benefits	Implementing this action outdoors provides reassurance to the public that contamination 'pick up' from items has been reduced. An enabler for other options.
Protective action description	A variety of vacuum cleaning machines are available - specialist advice should be sought for individual applications. **Indoor or vehicle interiors** **a) Dry vacuum cleaning and wet wiping** Any domestic or industrial vacuum cleaner can be used to clean surfaces and objects, such as furniture provided it has been fitted with high efficiency particulate (HEPA) filters of greater than 99% efficiency to remove dust and loose particles from building and equipment surfaces. The HEPA filters trap dust and debris to protect against bulk airborne contamination and prevent resuspension or recontamination of surfaces that have been vacuumed. The filters remove a minimum of 99.97% of particulates larger than 0.3 μm (6). Where domestic vacuum cleaners are used, the resuspension hazard should be addressed by equipping implementers with suitable PPE and/or using long hoses with the vacuum located outside the work area. Use of brush heads and other tools can reach more complex geometry items, but care is required to prevent spread of contamination by the brush head or contact with the substrate. Decontaminated areas may be wet wiped after dry vacuuming. The introduction of a moist wipe helps overcome electrostatic or absorption forces holding the contamination in place. Depending upon the brand or type of wet wipe, there may be surfactants to assist in breaking down thin films of grease. **b) Steam vacuum cleaning** More ideally suited to items with grease or heavy organics, steam vacuum cleaning uses a jet of steam to soften media that can be mechanically dislodged carrying any associated contaminant. It is usually prudent to follow up with an absorbent wipe to capture the softened material.

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	Domestic steam cleaners operate at lower temperatures and pressures resulting in early condensation of the steam. Industrial units are more effective due to the high temperatures (dry steam) and pressure (performance) coupled with a shroud to contain debris. The hood is attached to a vacuum system and solids collection trap. The waste stream passes through a vacuum recovery subsystem that discharges clean air to atmosphere. A detergent may be added to the pressurised water stream to improve washing effectiveness. The above measures to mitigate the resuspension hazard (using high-efficiency filters and suitable PPE) still apply. **Outdoor** Standard municipal vacuum sweepers must not be used on account of their very poor filtration and resuspension of fine particles via their discharge point as they do not contain HEPA filters. There are specialist road sweepers that use a water filtration system that have been proven for the cleaning of Carbon Black fine powders (A38 near Bristol, UK,1995/6) akin to photocopier toner, without a particulate discharge. Additional mitigations can and should include a water spray that acts as a carrier for the contamination. Water consumption will be lower in wet weather. **Semi-enclosed areas** Depending on the scenario, such as train stations, large retail outlets and subways with smooth flooring, existing ride-on floor cleaners can be employed subject to the use of HEPA filters. However, some surfaces in semi-enclosed areas may need smaller vacuum cleaners, around complex features such as structural beams, typically found in indoor environments. **Stopping re-contamination** Re-contamination can be minimised if cleaning processes are treated in the same manner as radiological areas in nuclear facilities, where strict measures are implemented between clean and dirty areas and associated change areas, to minimise the spread of contamination. Such controls may need to be factored into the operation, working from a clean area incrementally decontaminating dirty areas as the clean-up progresses. This deliberate and measured approach would impact time and resources and should be factored into the planning cycle.
Target	Ideal for loose contamination (not effective against fixed contamination).

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	Dry vacuum cleaning suitable for internal surfaces (particularly floors, but also other surfaces including walls, ceilings and other irregularly shaped objects and objects in buildings and semi-enclosed areas, paved surfaces (roads, pavements, paths, yards, and so on) and vehicles. Steam vacuum cleaning is not suited to irregularly shaped objects. Vacuuming is clean and does not damage materials, so may be suitable where a gentle cleaning method is required. However, the high temperatures of a steam vacuum can damage certain surfaces. The thermal stability of the surface may therefore be important. Steam cleaning is not appropriate for porous materials due to tendency to push or soak debris further into matrix. Industrial experience has shown the contamination can then release over time to be mobilised or resuspended. Use of either a coating or covering can prevent either further spread of contamination or recontamination of vacuumed items.
Targeted radionuclides	All radionuclides, including short-lived radionuclides in particulate form if implemented quickly. Not suited to gaseous or liquid or aerosol releases.
Scale of application	Small to large. Suitable for indoor surfaces in all types of building or vehicle, or any size road or paved area. Suitable outdoor water-filtered vacuum sweepers are difficult to find due to their specific filtration method. Not a self-help option.
Timing of application to optimise effectiveness	Short-term. Maximum benefit if implemented when maximum contamination on surfaces. In external environments it is extremely important to stop contamination blowing around, so vacuuming should be carried out within hours of deposition to reduce inhalation doses from resuspension. A slightly longer timescale is applicable to contamination deposited indoors, that is, within the first week or two.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system [note 1] Notes [note 1] Expert advice should be sought as most fissile materials are dense and would drop out of solution in drains and catch-pots. If there is no approved waste route, none of the wet vacuuming options should be used.
Physical environment	**Indoor vacuuming** Different machines or fittings may be more suitable for certain materials, surfaces or indoor environments. **Outdoor vacuuming** Significantly affected by weather at the time of implementation. Severe cold weather could result in contamination becoming trapped under a layer of ice. Wet conditions create additional contaminated wastewater which would also need to be collected. Without collection, this action should not be considered.
Effectiveness	
Reduction in contamination on the surface	**Indoor vacuuming** Vacuum cleaning of carpets will generally have an insignificant effect on activity concentrations of contaminated particles in the region of size 1 µm (as observed with the initial caesium contamination after the Chornobyl accident). However, a fraction of the contamination will rapidly become attached to larger house dust particles (greater than 5 µm), for which vacuum cleaning is effective (and preferable to washing treatments, because ^{137}Cs attached to house dust is likely to be insoluble (7)). Soil particles brought into the buildings on shoes or by the wind will be relatively large and therefore easy to remove by vacuuming (2).

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	Decontamination factors (DF) of 5 (reduction of 80%) and above can be achieved, although there is likely to be large variation in this value (2). This assumes that this option is implemented within a few weeks of deposition and no previous cleaning has taken place. Repeated application is unlikely to give any significant increase in DF if implemented thoroughly the first time. However, over longer periods, contamination may be brought into buildings, for example, on the soles of shoes, and so repeated application regularly may be beneficial until any surrounding soil or grass areas are cleaned (1). Dry vacuuming removes only loose particles, and no fixed or subsurface contamination is removed. Thus, dry vacuuming may be used as an initial treatment method, possibly followed by another technology for further treatment to reach desired protection levels. For carpets and certain drapery, a good vacuum with a carpet cleaner followed by a wet vacuum is going to give the best DF. **Outdoor vacuuming** Decontamination factor (DF) of 2 (50% reduction) can be achieved if this option is implemented within one week of deposition and before rain (2). The factor is likely to be lower if deposition occurred during rainfall. The effectiveness of outdoor vacuuming is very susceptible to the weather, where even a light breeze can redistribute material very quickly. Therefore, during response, misting of the contaminated area then fixing of contamination with coatings or sheeting is recommended at the earliest opportunity. Reductions in external and resuspension doses received by a member of public living in the area will depend on the amount of the area covered by outdoor hard surfaces and the time spent by individuals on or close to these surfaces. Since the contamination will be removed rapidly from these surfaces through weathering, the effectiveness of the method will decrease with time and after a few months is unlikely to remove significant contamination. Repeated application is unlikely to provide any significant increase in DF. In the short term, the quoted DF can be considered to be same for all radionuclides, with the exception of elemental iodine and tritium, for which thorough cleaning of impermeable surfaces will lead to virtually full removal.
Reduction in surface dose rates	External gamma and beta dose rates immediately above the cleaned surface will be reduced by a value similar to the DF.

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	However, the vacuum, collection or interceptor will become a radiation source with dose implications to workers.
Reduction in resuspended activity in air	The resuspension potential will be markedly reduced.
Technical factors influencing effectiveness of protective action	Effectiveness will vary depending on the vacuum cleaning technique used, size and scale of contamination. Specific factors that should be considered include: Type, evenness or roughness, and porosity of surface. Degree of footfall or vehicle movements that can entrain contamination. Time of implementation. Thoroughness, for example, ensuring edges and corners are cleaned. Amount of dust on surfaces at the time of deposition. Whether any cleaning has already been undertaken. Particle size of dust and efficiency of equipment. Factors specifically affecting indoor vacuuming: Weather at time of deposition; less material is deposited indoors during wet deposition. Amount of furniture and furnishings in the buildings. Building ventilation rates. Factors specifically affecting outdoor vacuuming: Careful cleaning of road gutters – contamination tends to accumulate here. Use of water spraying (may increase the effectiveness slightly). Amount of hard outdoor surfaces in the area. Whether decontamination is carried out on adjacent surfaces. Run-off of contamination on to other outdoor surfaces.
Resourcing	
Specific equipment	**Indoor vacuuming** Vacuum cleaner with brush attachment and upholstery cleaning attachment (must be HEPA filtered or an industrial vacuum cleaner). Steam vacuum cleaning system (if required). **Outdoor vacuuming** Pavement cleaner or specialist road sweeper (not municipal type). Spate pumps. Storage tanks.

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
Ancillary equipment	Transport vehicles for equipment and waste.
Utilities and infrastructure	Electricity supply. Water supply if using wet or steam vacuuming. Public sewer system for outdoor road or paved area cleaning. Roads for transport of equipment and waste.
Consumables	Fuel and parts for transport vehicles. HEPA filters. Collection bags. Water (if used).
Skills	Whilst training people to vacuum clean is straightforward, the considerations relating to minimisation of contamination spread will arguably need a more radiologically aware workforce. **Indoor vacuuming** Only a little instruction is likely to be required. Dry vacuuming method could be implemented by the population, after instruction from authorities and the provision of suitable safety equipment (PPE). Steam vacuuming is ergonomically challenging for workers using the equipment. There are hot parts that potentially increase the risk of skin burns. **Outdoor vacuuming** Can be implemented by already skilled operators such as municipal workers, provided they are familiar with specialist road sweepers; additional operators could be instructed within a day.
Work rates and operator time	**Indoor vacuuming** Rates range from 20 m^2/h (3) to 120 m^2/h per person (2). **Outdoor vacuuming** 3,000 to 4,000 m^2/h per person (2). Depends on the type of industrial equipment used. Depending on the PPE used, individuals may need to work restricted shifts.
Waste	
Type	Indoor vacuuming: 50 g/m^2 contaminated filters (3) which may have high contamination levels but relatively low volume. Outdoor vacuuming: 100 to 200 g/m^2 of dust and sludge (2). The amount depends on dustiness of surface. If cleaning done under wet conditions and water disposed of directly to drains, then the quantities of waste will be higher.

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	A safe mechanism for changing vacuum capture bags or pots and also HEPA filters will be required. Compared to the working environment, they will have very high contamination levels or dose rates.
Transport	Filters are suitable for transport via road. If items have high levels of activity present, may need to consider separating into multiple consignments or smaller transport volumes. Dust and sludges must be contained during transport using leak-proof approved containers.
Treatment	Extreme care is required when changing vacuum collection bags and packaging into bags and drums (or similar). There is a high potential for a dropped bag to resuspend contamination at very harmful levels in close proximity. Waste should be characterised to inform disposal route. Wastes should be sorted and segregated based on radioactive and chemical properties. Filters should be bagged and placed in drums although the immobilisation of the collected dusts is strongly recommended. Items may be suitable for super compaction which will reduce the waste volume. The compactability of treatment wastes depends on their form. Disposal is possible with or without super compaction. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).
Storage	Collection bags and filters must be bagged and packaged into approved containers to account for PVC or cellulose collection bag degradation. Filter wastes can be managed near point of generation. To minimise the spread of contamination, attempt to store waste directly in the container that will go to landfill or incinerator. Dust and sludges should be stored in dedicated specialist containers which prevent escape of liquids. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Preferred solution permitted incinerator for certain VLLW materials. Alternative routes may include disposal to landfill. Disposal to landfill may not be possible if the waste is classified as hazardous as well as radioactive.

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	Nuclear Waste Services can advise on viability of disposal routes if information is provided on waste characteristics and volume. Special Nuclear Materials or materials with significant alpha content may need ongoing storage at Sellafield or AWE. Advice from the relevant environment agency should be sought as disposal options for waste could require a permit (if considered to be an activity involving radioactive substances).
Pathways of exposure to implementers and the public	
Exposure pathways	Implementers performing cleaning: • external exposure from radionuclides in the environment and contaminated equipment • inhalation of radioactive material resuspended from the floor and other surfaces (may be enhanced over normal levels) • inadvertent ingestion of dust from workers' hands (can be avoided by correct use of PPE) Those transporting and managing waste may also be subject to external exposure. Members of the public: none.
Impact of protective action	
Environmental impact	Outdoor vacuum cleaning in wet conditions will create contaminated wastewater which may need management. Direct disposal to drains should be avoided where possible.
Practical experience	
	Indoor vacuuming Applied in houses following the incident in Goiânia (4). Several small-scale tests have been reported after the Chornobyl accident and in Japan after the Fukushima accident (2, 8). In an industrial setting in the UK, significant benefits were gained from vacuuming alone and incorporation of coating to contain any residual contamination. On a plant wide scale, battery powered backpack vacuums were very effective for clean-up and controlled entries, reducing the ‘normal’ PPE or RPE requirements. **Outdoor vacuuming** Applied in the former Soviet Union after the Chornobyl accident and in Japan after the Fukushima accident (in the form of vacuum blasting) (2, 5). Small-scale tests conducted in Denmark and USA under varying conditions to examine the influence of, for example, street dust loading (2).

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
	UK civil nuclear has very successful experience of vacuuming, including use for housekeeping of potentially contaminated dusts in work areas, but also on large scale. DFs of 10,000 (99.9% reduction) have been achieved for dry loose particulates. Other experience of steam decontamination shows some effectiveness for greases and so on, but access to industrial and certified equipment (such as, pressure system registration), detracts from its value.
Key references	
	1. Allott RW, Kelly M and Hewitt CN (1994). 'A model of environmental behaviour of contaminated dust and its application to determining dust fluxes and residence times' Atmospheric Environment: volume 28, issue 4, pages 679 to 687 2. Andersson KG, Roed J, Eged K, Kis Z, Voigt G, Meckbach R, Oughton DH, Hunt J, Lee R, Beresford NA and Sandalls FJ (2003). 'Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas' Risø-R-1396(EN), Risø National Laboratory, Roskilde, Denmark 3. Flaws L (1995). 'Review of decontamination and cleanup methodologies – urban areas' Waste Management Operations, Rolls-Royce Nuclear Engineering Services Ltd. RRNESL reference number WMO 095/233 4. IAEA (1988). 'The radiological accident in Goiânia' STI/PUB/815 ISBN 92-0-129088-8 5. Ministry of the Environment, Japan (2015). 'Ministry of the Environment, FY2014 decontamination report' (accessed 21 December 2023) 6. NCRP (2014). 'Decision-making for late-phase recovery from major nuclear or radiological incidents' NCRP report 175 7. Shinohara N and Yoshida-Ohuch H (2018). 'Radiocesium contamination in house dust within evacuation areas close to the Fukushima Daiichi nuclear power plant' Environment International: volume 114, pages 107 to 114 8. Shinohara N and Yoshida-Ohuchi H (2019). 'Radiocesium concentration in indoor air during residential house cleaning in Fukushima Dai-ichi nuclear power plant evacuation areas' Journal of Environmental Radioactivity: volumes 205 to 206, issues 127 to 134

45. Vacuum cleaning: dry and steam (indoor and outdoor)	
Comments	
	Works well with other physical decontamination technologies. When implementing vacuuming outdoors in highly contaminated areas, the tank containing the dust must be water-filled. It may even be recommended to apply a metal shielding between the operator and the waste vessel.

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46. Water-based cleaning	
General	
Objective	To remove contamination from internal surfaces of buildings including personal items and precious objects, semi-enclosed areas, vehicles, and indoor and outdoor objects within inhabited areas, thereby reducing doses from the inhalation of resuspended dusts or external irradiation from those contaminants.
Other benefits	Will remove contamination from surfaces and objects, especially loose contamination, which will reduce the potential for further spread of the contamination. The removal of contamination from buildings or items may increase acceptance of using those buildings or items into the future.
Protective action description	A variety of cleaning methods are available according to the material, fragility, and functionality of the target surface or object (these include, scrubbing, wet wipes, ultrasonic bath). The method chosen and equipment required will depend on what the target surface is made from (such as, fabric, plasterboard, wood, brick, glass, jewellery and so on), the state of any covering material (whether fixed or flaky paint or wallpaper), the size of the physical area needing to be cleaned, and the overall accessibility of the surface. Cleaning should be done in a structured way to prevent less contaminated areas becoming contaminated (for example, by the mismanagement of wastewater). Furthermore, careful attention should be made to identify if the surface is porous, has broken surfaces and so on where contamination can be absorbed and leach contamination in the future. All cleaning has the potential to disturb contaminated surfaces and create airborne contamination and so on. Ideally when cleaning, areas should be tackled deliberately, in manageable sections under controlled conditions (as far as reasonably possible – based on risk assessments) covering areas prior to cleaning with contamination control tools, that is, tents fitted with air extraction and filters should be considered. Methods for marking clean and dirty areas and carefully monitoring progress should be considered, particularly for whole building or larger events. **Hard surfaces** Wash using warm or hot water and mild detergent followed by rinsing to remove any residual contamination or detergent. When wiping, all sides of folded paper towels, dust cloths and so on shall be used, using a new side of cloth for each wipe to prevent contamination from re-adhering (3). An alternative method could use proprietary

<table>
<tr><th colspan="2">46. Water-based cleaning</th></tr>
<tr><td></td><td>Tack cloth (‘tak’ rags; tac cloth) which typically a cotton gauze textile impregnated with a sticky resinous material. It is designed to remove loose particles of dust and dirt on surfaces. Wipes or scrubbing brushes may also be used. A systematic way of working is essential. This includes frequent changes of absorbent materials. It is very important absorbent materials are not reused or used to wipe over large areas. Use of an ‘absorb and throw’ approach is essential.

Care should be taken when the surface is porous, such as wood, or contains joints that are not waterproof such as laminated boards, so that contaminated water is prevented from being forced into the material or into cracks that could result in underlying surfaces becoming contaminated. Brushing and scrubbing also have the potential to entrain contamination, notably into porous surfaces.

If cleaning internal walls and ceilings, if possible, work should start in high places and work down to lower levels to prevent re-contamination via dripping. In addition, sheeting should be used to prevent contamination of the floor with wastewater.

Upholstered surfaces or fabrics

There is a risk that wet cleaning of upholstered surfaces, carpets, tapestries and so on will take contamination deeper into the material. Therefore, water-based cleaning is not recommended for these surfaces. If wet cleaning is attempted, it must be done with great care so only the surface becomes wet. Possible options are spraying with detergent solution and vacuuming off or using wet or tacky wipes. Wet and dry ‘carpet’ cleaning style units may also be suitable.

Precious objects

Specialist, gentle cleaning techniques (such as ultrasonic bath cleaning) could be carried out on some objects such as jewellery. Gentle, water-based cleaning or use of wipes may also be suitable for some objects if carried out with care. This can be followed by a period of storage to allow for radioactive decay (see datasheet 41: ‘Store and cover personal and precious objects’)</td></tr>
<tr><td>Target</td><td>Indoor surfaces of buildings, surfaces within semi-enclosed areas, vehicles, indoor hard surfaces, particularly floors and objects, and those that are robust enough to be cleaned with water. Precious objects, such as museum artefacts, tapestries, jewellery, paintings and so on, and personal objects such as toys, keepsakes and so on.

Some exterior metal and wooden surfaces such as fences, benches, playground equipment may also be suitable.</td></tr>
</table>

46. Water-based cleaning	
Targeted radionuclides	Long-lived radionuclides. Unlikely to be worthwhile for very short-lived radionuclides unless implemented quickly, and then, only for critical items.
Scale of application	Scalable subject to access and supplies. Careful cleaning is labour intensive and may require skilled practitioners, therefore it may be difficult to scale up to include objects from a large area. For low levels of contamination, personnel could be trained in basic RPE or PPE alongside a brief demonstration on the decontamination approach, subject to oversight and assurance measures.
Timing of application to optimise effectiveness	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. Aging may also reduce the effectiveness of cleaning approaches as loose contamination can become fixed and/or migrate deeper into the material over time.
Constraints	
Legal	See Annexe B for relevant legislation applicable to the following activities: • allowing access by authorised persons to enter area and investigate • undertaking or commissioning various remediation actions such as: remediate or remove topsoil; remediate buildings, street furniture, fixtures and fittings, and other structures; replace road surfaces and remove or destroy or decontaminate vehicles; remove grass after cutting, remove leaves and branches after pruning shrubs • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition) • providing the leading authority, the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage • management of radioactive waste and management of radioactive water to the public sewer system
Physical environment	Difficult to reach surfaces may require additional actions to ensure areas can be considered as decontaminated, for example, some structures may need to be dismantled and destroyed or replaced

46. Water-based cleaning	
	with like for like – such factors should be considered during the recovery planning (time and resources being especially impacted).
Effectiveness	
Reduction in contamination on the surface	A wide range of DFs can be achieved, usually with the highest single pass DF on the first cycle. Multiple cycles may be applied, although there will be an ever-diminishing benefit. Higher DFs will be seen with loose particulate contamination. The skill of the operator will be key to maximising benefit and knowing when to stop. An indication of the range of DFs encountered in the literature for different surfaces are given below, but are variable. **External surfaces** A decontamination factor (DF) of up to 4 (75% reduction) can be achieved. **Hard internal surfaces** A DF of up to 5 (80% reduction) can be achieved. (1). DF of 2 (50% reduction) for water-based cleaning (all internal surfaces) in houses affected by Goiânia incident (2). **Fabric or upholstered surfaces** A DF of up to 5 (80% reduction) can be achieved (1). Decontamination factors are likely to be much lower for cleaning rough surfaces such as concrete, stone and brick surfaces and for carpets, rugs, tapestries, upholstery, bedding and soft furnishings.
Reduction in surface dose rates	External gamma and beta dose rates from decontaminated surfaces will be reduced by a factor similar to the DF.
Reduction in re-suspended activity in air	Resuspended activity in air following decontamination will be reduced by the value of the DF.
Technical factors influencing effectiveness of protective action	The effectiveness is very dependent on the physio-chemical form of the contamination, material or surface involved, the accessibility of the surface, its condition, the cleaning method used and operator skill, vigour, and consistency (for example, in their ability to ensure the contamination is removed, including from edges and corners, rather than just moved around the surface or on to another surface). Amount of dust or dirt on surfaces at the time of deposition may affect the rate at which contamination adheres to the surface, altering the fraction amenable to being removed with washing. Longer durations of exposure risks ingress of contamination into the material. This can effectively be irreversible. Solubility of contaminating radionuclides.

46. Water-based cleaning	
	Weather (less material is deposited indoors during wet deposition, but wet weather may increase contamination of carpets or flooring via carry-in on shoes). Removal of contamination deposited via wet deposition and allowed to dry, is likely to be much more difficult to remove than dried (dust) contamination. Especially by simple cleaning methods alone. Steam cleaners, which use very hot water, are not suitable for all surfaces.
Resourcing	
Specific equipment	Depending on the technique used, the following may be required: Detergent and detergent sprayer. Scrubbing machines with solution dispenser. Steam cleaners. Rotating brush for indoor surfaces or objects. Specialist cleaning equipment for gentle cleaning (such as, ultrasonic baths) within a lab using techniques for fine art restoration and the jewellery trades. HEPA filtered carpet cleaning style vacuum systems. Wastewater collecting devices if not already part of equipment.
Ancillary equipment	PVC sheeting. Ladders. Monitoring equipment to determine efficacy of cleaning process.
Utilities and infrastructure	Access to buildings. Water supply. Power supply may be required depending on equipment used. Temporary relocation of building occupants may need to occur during cleaning.
Consumables	Water, detergent, wash cloths, wipes. Gloves, overalls and other PPE, such as, masks. Waterproof clothing may be required.
Skills	In general, only a little instruction is likely to be required. The method could, at least partially, be carried out by the population as a self-help measure, after instruction by authorities and provision of safety and other required equipment. However, it is important that specific objectives and potential problems associated with techniques are fully explained, and access to monitoring results is given.

46. Water-based cleaning	
	For precious objects, specialist cleaning and handling skills are required. Also see datasheet 41 (‘Store and cover personal and precious objects’) for more information.
Work rates and operator time	Work rates will vary considerably depending on the surface type (soft furnishings generally require more time per unit area to clean than hard surfaces); the accessibility of a surface (for example, gaining access to an internal wall may require moving furniture); the intricateness of the surface (small, detailed items will require more time to clean than large flat surfaces); the equipment used; worker expertise and care, and so on. It is therefore not possible to provide nominal work rates for different surfaces or locations. Intricate surfaces will markedly decrease work rate.
Waste	
Type	Wastes will generally be liquid in nature and include wastewater with dissolved detergents as well as particulates formed from household dust. Other waste generated will include material associated with cleaning such as wash cloths and wipes, protective coverings (such as, PVC sheeting), as well as used PPE such as gloves and overalls. 1.3 million kg/km^2 (dust, detergent and water) from cleaning internal surfaces (1).
Transport	Possible use of sump pumps to collection vessels for example, IBCs, or a tanker to remove wastewater. Typical articulated tanker has a maximum volume of 30,000 litres. PPE, wipes, textiles, cloths can be transported via road in Isofreight container or suitable bag or drum.
Treatment	**Wastewater** Consider using settling agents which can be added to remove suspended particles and other impurities from the water. This would separate some of the radioactive particles from the water leaving a solid or sludge waste which would need disposal. For very large volumes of highly contaminated liquids, filtration or ion-exchange systems may be used to separate radioactive material from liquid. The concentrate and contain principle should be applied. **PPE, wipes, textiles, cloths and so on** Contain in Isofreight container or suitable bag or drum. Treatment may be required for disposal to permitted VLLW incinerator or landfill. Suitable for super compaction which will reduce volume. If nuclides are short-lived, storage to allow for radioactive decay should be considered. Advice from the relevant environment agency should be sought as treatment options for waste could require a permit (if considered to be an activity involving radioactive substances).

46. Water-based cleaning	
Storage	**Wastewater** Should be stored in IBCs or tankers in bunded areas. **PPE, wipes, textiles, cloths and so on** Should be stored in a suitable waste bin or Isofreight container, stored and managed near to the point of generation. To minimise the spread of contamination, attempt to store waste directly in the container that will go to landfill or incinerator. Advice from the relevant environment agency should be sought as storage options for waste could require a permit (if considered to be an activity involving radioactive substances).
Disposal	Wastewater can potentially be suitable for disposal via a radioactive substance activity permitted discharge route for aqueous waste or disposal to a STW. Advice must be sought from the relevant environment agency. The preferred solution for PPE, wipes, textiles, cloths and so on is to a permitted incinerator. Alternatively, disposal to landfill or other VLLW disposal options.
Pathways of exposure to implementers and the public	
Exposure pathways	Implementors, including members of the public: • external irradiation from contamination in situ (gamma irradiation at distance and beta irradiation of skin when handling surfaces or items) • inhalation or ingestion of radioactive material resuspended from surfaces, if some form of light respiratory protection is not used
Impact of protective action	
Environmental impact	Care should be taken to prevent the spread of contamination from the area being cleaned, for example, by preventing resuspension of dust or dispersal of contaminated water. The disposal or storage of waste arising from the implementation of this option may have an environmental impact which should be minimised through the control of any disposal route and relevant permitting or authorisations.
Agricultural impact	None.
Practical experience	
	Several small-scale tests have been reported before or after the Chornobyl accident in 1986. Experience in Japan after the Fukushima accident in 2011 (4).

46. Water-based cleaning	
	Removal of non-fixed contamination at various locations following the death of Alexander Litvinenko in 2006 (5). Following the Goiânia incident, the importance of precious objects and objects of sentimental value was recognised, and decontamination was preferred even when it would be cheaper to dispose and replace. The distressing effect on both residents and implementors of seeing toys and other objects of sentimental value, carelessly heaped prior to disposal, was observed (2). Water based cleaning is widely used in the UK Civil Nuclear industry as part of normal activities, for example, housekeeping.
Key references	
	1. Brown J and Jones AL (2000). 'Review of decontamination and remediation techniques for plutonium and application for CONDO version 1.0' National Radiological Protection Board, Chilton (UK), NRPB-R315 2. IAEA (1988). 'The radiological Accident in Goiânia' STI/PUB/815, ISBN 92-0-129088-8 3. Ministry of the Environment, Japan (2013). 'Decontamination guidelines, second edition' 4. UNSCEAR (2015). 'The Fukushima Daiichi Accident: technical volume 5 – post-accident recovery' 5. Westminster City Council (2007). 'Framework strategy for dealing with radioactive contamination arising from the circumstances surrounding the death of Alexander Litvinenko'
Comments	
	Washing and wiping or scrubbing of building surfaces has been found to produce similar levels of decontamination as achieved using high-pressure washing, for smaller areas where water jetting would be impractical to apply. This option should be considered in conjunction with • restrict access • vacuum cleaning • strippable and peelable coatings • high-pressure hosing

Return to index of protective actions in section 4
Return to decision-aiding look-up tables for inhabited areas in section 6.3
Return to index of protective actions for inhabited areas in Annexe A3

Annexe B. Legislative framework for remediation of inhabited areas

The Department for Energy Security and Net Zero (DESNZ), formerly the Department for Business, Energy and Industrial Strategy (BEIS) recently reviewed the existing legislation that might be applied during the recovery phase following a radiation emergency (1).

The review indicated that the current legislation is adequate for food and drinking water supplies. So, where relevant the key pieces of legislation have been incorporated into each of the protective action datasheets for food production systems and drinking water supplies. In contrast, the review highlighted that there is no single piece of legislation that can be used to cover the whole remediation process in non-food, non-drinking water situations. Instead, regulators and local authorities would be expected to make use of a patchwork of existing legislation (1).

Table B1 gives an indication of relevant legislation, according to the actions that need to be taken, which may start at different times and involve different parties, have different cost-recovery mechanisms, and require clean-up to different end points. It should be noted that some pieces of legislation are only applicable to England and Wales (devolved equivalents will be applicable in Scotland and Northern Ireland). Furthermore, legislation for non-radioactive waste has not been reviewed or included in Table B1 but could be relevant where waste is managed under General Binding Rules and exemptions. In this situation, the non-radioactive properties may take primacy. DESNZ recommend that for small scale events, some changes to existing regulations are made, in particular Radioactive Contaminated Land Regime and the Environmental Permitting Regulations (England and Wales) 2016. More extensive amendments are required for a large-scale radiation emergency, either by amending existing legislation or by developing new, overarching legislation for the recovery process, analogous to Radiation (Emergency Preparedness and Public Information) Regulations (REPPIR).

Reference

1. Defra and DESNZ (2024). 'The legislative framework for recovery from a radiological incident', in preparation, for further information contact: CBRNRecovery@defra.gov.uk

Table B1. Overview of existing legislation relating to remedial protective actions for inhabited areas

Activity	Most suitable legislation identified	Alternative legislation	Relevant protective actions, including datasheet number in parentheses
Protection of workers engaged in all remediation and decontamination.	• Health and Safety at Work Act 1974 • The Ionising Radiations Regulations 2017, Part 1, Regulation 2		All
Preventing or controlling access to the affected areas, or to impose restrictions on living conditions in these areas.	Public Health (Control of Disease) Act 1984 including: • The Health Protection (Local Authority Powers) Regulations 2010 (LA Powers Regs) • The Health Protection (Part 2A Orders) Regulations 2010 (Part 2A Regs)	• Health and Safety at Work Act 1974 for work premises • Housing Act 2004 for residential properties • RCL in respect of land	Prohibit public access (D 34) Temporary relocation (D 43)
Allow access by authorised persons to enter and investigate.	Public Health (Control of Disease) Act 1984 including: • The Health Protection (Local Authority Powers) Regulations 2010 (LA Powers Regs) • The Health Protection (Part 2A Orders) Regulations 2010 (Part 2A Regs)	• limited powers under the Environment Act 1995 section 108 RCL gives local authorities limited powers of entry in respect of land • Health and Safety at Work Act 1974 for work premises • Buildings Act 1984 • Housing Act 2004 for residential properties	Cover contaminated soil and grass (D 30) High pressure washing including water jetting (D 31) Natural attenuation with monitoring (D 32) Ploughing and mechanical digging techniques (D 33) Reactive liquids: domestic chemicals (D 35) Remove and replace road and paved surfaces (D 36) Remove of building surfaces (D 37) Remove grass after cutting (D 38) Remove plant material (D 39) Remove topsoil (and turf) (D 40) Store and cover personal and precious objects (D 41) Strippable coatings (D 42) Tie-down (D 44) Vacuum cleaning (indoor and outdoor) (D 45) Water-based cleaning (D 46)
Undertake or commission various remediation actions such as: • remediate or remove topsoil • remediate buildings, street furniture, fixtures and fittings and other structures • replace road surfaces and remove or destroy or decontaminate vehicles • remove grass after cutting, remove leaves and branches after pruning shrubs	Public Health (Control of Disease) Act 1984 including: • The Health Protection (Local Authority Powers) Regulations 2010 (LA Powers Regs) • The Health Protection (Part 2A Orders) Regulations 2010 (Part 2A Regs)	• Buildings Act 1984 for buildings, street furniture, fixtures and structures only • RCL for land only • Housing Act 2004 for residential properties	Cover contaminated soil and grass (D 30) High pressure washing including water jetting (D 31) Ploughing and mechanical digging techniques (D 33) Reactive liquids: domestic chemicals (D 35) Remove and replace road and paved surfaces (D 36) Removal of building surfaces (D 37) Remove grass after cutting (D38) Remove plant material (D 39) Remove topsoil (and turf) (D 40) Store and cover personal and precious objects (D 41) Strippable coatings (D 42) Tie-down (D 44)

Activity	Most suitable legislation identified	Alternative legislation	Relevant protective actions, including datasheet number in parentheses
			Vacuum cleaning (indoor and outdoor) (D 45) Water-based cleaning (D 46)
Provide the leading authority the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict environmental damage – including on listed or historical sites, conservation areas and areas of cultural heritage.	Consent from Natural England, NatureScot or equivalent bodies in Wales and Northern Ireland will be required if a change in land use is to be carried out in an area designated a Site of Special Scientific Interest (SSSI). For conservation areas, permission may be required from the local authority. The appropriate legislation is the Planning (Listed Buildings and Conservation Areas) Act 1990.	NDA holds nuclear liabilities for NDA Group which includes damage to property during events or clean-up activities, where the event originated from NDA group of operational companies.	Cover contaminated soil or grass (D 30) High pressure washing including water jetting (D 31) Ploughing and mechanical digging techniques (P 33) Reactive liquids: domestic chemicals (D 35) Remove and replace road and paved surfaces (D 36) Removal of building surfaces (D 37) Remove grass after cutting (D 38) Remove plant material (D 39) Remove of topsoil (and turf) (D 40) Store and cover personal and precious objects (D 41) Strippable coatings (D 42) Tie-down (D 44) Vacuum cleaning(indoor and outdoor) (D 45) Water-based cleaning (D 46)
Provide the leading authority the power to carry out, or enable other parties to carry out on their behalf, remedial actions which may inflict damage to property (including partial or complete demolition).	Public Health (Control of Disease) Act 1984 including: • The Health Protection (Local Authority Powers) Regulations 2010 (LA Powers Regs) • The Health Protection (Part 2A Orders) Regulations 2010 (Part 2A Regs)	• Buildings Act 1984, subject to constraints • Housing Act 2004 for residential properties NDA holds nuclear liabilities for NDA Group which includes damage to property during events or clean-up activities, where the event originated from NDA group of operational companies.	Cover contaminated soil and grass (D 30) High pressure washing including water jetting (D 31) Reactive liquids: domestic chemicals (D 35) Remove and replace road and paved surfaces (D 36) Remove building surface (D 37) Remove grass after cutting (D 38) Remove plant material (D 39) Remove topsoil (and turf) (D 40) Store and cover personal and precious objects (D 41) Strippable coatings (D 42) Tie-down (D 44) Vacuum cleaning(indoor and outdoor) (D 45) Water-based cleaning (D 46)
Provide the leading authority with the power to seize, dispose of, destroy or damage possessions, including furniture and furnishings, clothing and vehicles, where these are shown or believed to be contaminated.	Public Health (Control of Disease) Act 1984 including: • The Health Protection (Local Authority Powers) Regulations 2010 (LA Powers Regs) • The Health Protection (Part 2A Orders) Regulations 2010 (Part 2A Regs)	Buildings Act 1984, if the item is a structure.	Remove building surfaces (D 37)

Activity	Most suitable legislation identified	Alternative legislation	Relevant protective actions, including datasheet number in parentheses
Handling of chemicals.	• Control of Substances Hazardous to Health (COSHH), 2002 and REACH, 2021 for registration, evaluation, authorisation and restriction of chemicals		Reactive liquids: domestic chemicals (D 35)
Management of radioactive waste and management of radioactive water to the public sewer system.	• The Environmental Permitting (England and Wales) Regulations 2016 • The Environmental Authorisations (Scotland) regs 2018 • The Radioactive Substances Act 1993, in Northern Ireland		High pressure washing including water jetting (D 31) Reactive liquids: domestic chemicals (D 35) Remove and replace road and paved surfaces (D 36) Removal of building surfaces (D 37) Remove grass after cutting (D 38) Remove plant material (D 39) Remove of topsoil (and turf) (D 40) Store and cover personal and precious objects (D 41) Strippable coatings (D 42) Tie-down (D 44) Vacuum cleaning (indoor and outdoor) (D 45) Water-based cleaning (D 46)

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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