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# Public Health Protection in Radiation Emergencies

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# Public Health Protection in Radiation Emergencies

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## Abstract

PHE provides advice on public health protection in the event of radiation emergencies. This report brings together much of the advice previously published separately and it supersedes a number of earlier publications by the National Radiological Protection Board. International recommendations, lessons learned from nuclear accidents, and the identification of aspects not previously considered, have been additional drivers for reviewing, updating and consolidating PHE's advice in this area. The advice applies to the protection of public health in a wide range of radiation emergencies and is intended to be applied pragmatically and flexibly during preparedness, response and recovery phases, according to the scale and type of release; location specific factors; and the needs of the local community. The advice is primarily intended to inform those at national and local level who have responsibility for developing radiation emergency plans to protect the public.

The advice sets out the principles of radiation protection and the framework for managing a radiation emergency. It discusses emergency planning in the context of likelihood and severity of exposures and describes a range of protective actions to mitigate exposures above and below the thresholds for deterministic effects. The latter, and most extensive category includes urgent protective actions and longer-term protective actions.

Advice is given on two types of dose criteria: emergency planning thresholds of dose for guiding decisions on actions to avoid deterministic effects; and sets of other dose criteria (Emergency Reference Levels (ERLs), Reference Levels (RLs), Maximum Permitted Levels (MPLs) and Action Levels (ALs)) to optimise protection against lower levels of exposures from the early phase of an emergency through to the long-term. PHE advises that response plans, based on the separate optimisation of urgent protective actions using the framework of ERLs and RLs; longer-term protective actions using the framework of RLs; and food/water restrictions using the framework of MPLs/ALs will result in an overall protection strategy that is optimised. Over time, as response transitions to recovery, non-radiological criteria play an increasingly important role in optimising protection by taking into account the prevailing circumstances and opinion from a wide range of stakeholders, including representatives from the affected communities.

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# Executive Summary

## Introduction

PHE provides advice on public health protection in the event of radiation emergencies. This report brings together much of the advice previously published separately and it supersedes a number of earlier publications by the National Radiological Protection Board (NRPB, 1990a; NRPB, 1990b; NRPB, 1997a; NRPB 1997b). International recommendations, lessons learned from nuclear accidents, and the identification of aspects not previously considered, have been additional drivers for reviewing, updating and consolidating PHE's advice in this area. The advice applies to the protection of public health in a wide range of radiation emergencies and is intended to be applied pragmatically and flexibly during preparedness, response and recovery phases, according to the scale and type of release; location specific factors; and the needs of the local community.

The advice is primarily intended to inform those at national and local level who have responsibility for developing radiation emergency plans to protect the public. The intended audience includes, but is not limited to, public health professionals, local authorities, site operators, regulators, environment agencies and food standards agencies, that is, those organisations who might be represented on any of the following groups: Scientific Advisory Group in Emergencies (SAGE), Scientific and Technical Advisory Cell (STAC) and Recovery Working Group (RWG) and Recovery Co-ordination Group (RCG).

## Principles of radiation protection

There are two key categories of exposure relevant to radiation emergencies: exposures that are sufficiently high to lead directly to tissue damage, resulting in deterministic effects to individuals; and exposures below those capable of causing deterministic effects but which may lead to an increased risk of health problems, such as cancer incidence, in the future. PHE recommends three principles of radiological protection for response to radiation emergencies:

**a** *all protection strategies should aim to do more good than harm (justification)*

**b** *protection strategies should aim to avoid the occurrence of deterministic effects (avoid deterministic effects)*

**c** *protection strategies for exposures below the thresholds for deterministic effects should aim to maximise the benefit achieved (optimisation)*

The first principle of justification applies to all protection strategies, and for all levels of potential exposure. In determining whether a strategy is justified, that is, it does more good than harm, account should be taken of all the expected consequences, both beneficial and undesirable, including: radiation health risks; wider health risks (including psychological impact); consequential injuries; economic consequences; social and environmental factors. The second principle is to plan for avoidance of deterministic effects. PHE recommends that priority in both planning and response should always be given to consideration of protection strategies to avoid exposures that could lead to deterministic effects. The third principle of optimisation applies to protection from exposures that are expected to be below the thresholds for deterministic effects. In this region of dose, protection strategies require a balance to be struck between the expected harms and benefits (in the widest sense) of introducing particular protective actions, so that the margin of benefit over harm is maximised.

### Timeline of an emergency and application of the radiological protection framework

In describing the framework for managing a radiation emergency it is helpful to use different time phases, namely: early; intermediate; and long-term. The early and intermediate phases correspond to the emergency response, which according to the radiological protection framework is managed as an emergency exposure situation. The long-term phase, corresponding to recovery is managed as an existing exposure situation.

The early phase of an emergency is characterised as the period during which releases of radioactive material to the environment take place. It is especially during the early phase that doses can be high and various protective actions need to be taken promptly according to pre-established plans, to avoid or reduce radiation exposures. The intermediate phase of the response starts when the source of release has been stabilised and further significant releases are unlikely. The focus here is on characterising the radiological situation to decide upon the best course of actions to take to protect people and the environment. The long-term 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.

### Emergency planning

A comprehensive understanding of the risk from radiation emergencies and potential consequences is necessary for appropriate emergency planning. Of particular relevance is the need to consider both likelihood and severity of any exposures. Assessments based on a range of potential site events, including those of very low probability but severe impact, inform detailed and outline planning requirements, including the relevant distances. Detailed emergency plans describe arrangements for immediate implementation of sheltering-in-place, evacuation and administration of stable iodine by having capabilities in place. In contrast, outline plans only contain high level provision for how capabilities could be extended or where they could be obtained from in the short-term following a release. The responsible authority/body decides on what is appropriate and proportionate, based on the consequence assessment, the technical distances recommended, and a range of geographic and demographic factors.

### Protective actions

For most emergencies, radiation emergency planning focuses on protective actions (urgent protective actions, and longer-term protective actions) to reduce or avoid exposures below the thresholds for deterministic effects.

*Urgent protective actions* are those that are required to be implemented quickly for periods of hours or days, in order to protect against exposures received over relatively short-timescales. Urgent protective actions include sheltering-in-place, evacuation; the administration of stable iodine; and initial restrictions on food and water supplies.  Evacuation is very effective for protecting small communities, provided it is implemented before a release occurs and has been well planned. For large numbers of people or without prior planning, evacuation can lead to serious physical and psychological health risks, including fatalities. Sheltering-in-place is a less disruptive option, although health and wellbeing can be affected by restricted access to medical care or assistance.  The administration of stable iodine also has few side-effects and is most effective when accompanied by either sheltering-in-place or evacuation, and if administered less than 24 hours prior to, or up to 2 hours after, inhalation of radioiodine released to atmosphere.

In situations where there is a protracted threat of a release, an intermittent release or a release that continues over an extended period, it may be necessary to modify the implementation of some urgent protective actions for example by temporary lifting of sheltering-in-place, supervised re-entry into an evacuated area; or the issuing of second doses of stable iodine.

Restrictions on food and water may be implemented on a precautionary basis (that is within 24 hours) following an airborne release, advising people not to eat unwashed fresh fruit and vegetables that have been outside or not to drink rain water. On the basis of radiological measurement data, statutory food restrictions on marketed foods may follow in a matter of days to prevent contaminated foodstuffs entering the foodchain; this can generate large volumes of waste requiring disposal. Similar restrictions will apply to potentially contaminated drinking water supplies or to marketed food from contaminated aquatic habitats.

*Longer-term protective actions* provide protection from longer-term exposures due to contamination of the environment and food supplies. These may include temporary or permanent relocation as well as actions to restrict access to contaminated areas, remediation of land and buildings including decontamination, and further restrictions on food and water supplies.  These actions are not urgent, so there is time to plan their implementation to maximise benefit over harm. Nevertheless, there can still be wider health risks associated with some of these protective actions, for example, psychological impact following relocation; or waste management challenges following wide-scale decontamination of land.

## Radiological criteria for emergency planning, response and recovery

There are two types of dose criteria: emergency planning thresholds of dose for guiding decisions on actions to avoid deterministic effects; and sets of other dose criteria (Emergency Reference Levels (ERLs), Reference Levels (RLs), Maximum Permitted Levels (MPLs) and Action Levels (ALs)) to optimise protection against lower levels of exposures from the early phase of an emergency through to the long-term. For most emergencies, it is the latter criteria that are applicable.

*Emergency planning thresholds of dose* are specified for planning actions to protect people from receiving exposures that would lead to deterministic effects; they are lower than biological thresholds.  The relevant threshold exposures for emergency planning purposes are acute doses of 1 Gy whole body (to avoid direct injury to the bone marrow) and 2-3 Gy to the other most radiosensitive organs for low Linear Energy Transfer (LET) radiation, and 0.5 Gy whole body for acute exposure to neutrons. PHE recommends the prudent adoption of an emergency planning threshold of 1 Gy lung dose, integrated to 1 year, from an acute inhalation of alpha-emitting radionuclides.

*Emergency Reference Levels* are dose criteria that apply to the justification and optimisation of sheltering-in-place, evacuation and administration of stable iodine.  They are most appropriately expressed in terms of averted dose (mSv effective dose or mSv equivalent dose to the thyroid), over a period of up to 7 days following a release.  ERLs are provided in pairs. The upper and lower ERLs are indicative, rather than precise values.  The lower ERL indicates the likely balance of averted dose against all the other consequences of implementing the protective action in situations that are favourable for its implementation. The upper ERL indicates the likely balance in unfavourable circumstances, for example, where there is only outline planning, weather conditions are extreme or larger numbers of people are involved. ERLs recommended by PHE for the planning of sheltering-in-place, evacuation and administration of stable iodine are given in the table. These values for the ERLs are unchanged from those recommended previously, with one exception, a reduction in the upper ERL for administration of stable iodine. This reflects a better understanding of the increased risk of thyroid cancer in young children and of the lower risks of adverse health effects from administration of stable iodine.

**Recommended ERLs for the planning of sheltering-in-place, evacuation and administration of stable iodine**

| Protective action | Effective dose or organ dose | Averted dose (mSv)[a] | |
|---|---|---|---|
| | | Lower | Upper |
| Sheltering | Effective | 3 | 30 |
| Evacuation | Effective | 30 | 300 |
| Stable iodine | Thyroid[b] | 30 | 100 |

[a] In recognition of their higher cancer risk, the doses are those potentially averted in young children

[b] mSv equivalent dose to the thyroid

The use of ERLs in response can be challenging, partly as the future evolution of the release is not known and partly because the calculation of averted dose is made difficult by limited ability to gather measurements and other data. Nevertheless, as data do become available, it is possible to estimate the doses averted by these urgent protective actions, for comparison with the ERLs to provide a perspective on the level of protection achieved, and whether further actions are necessary.

*Reference Levels (RLs)* are constraints on overall dose (that is, a level of ambition to keep below) for timeframes from the early phase of a release through to the long-term. RLs are most appropriately expressed in terms of individual annual effective residual dose (mSv $y^{-1}$), that is the dose expected to be received following implementation of the protection strategy. RLs, like ERLs, are useful as a planning tool but additionally apply in response to, and recovery from, a radiation emergency. The concept of a RL, as defined by the International Commission on Radiological Protection (ICRP, 2007) and subsequently Euratom (2013), is the level of dose above which it is judged inappropriate to plan to allow exposures to occur. RLs are tools for supporting the practical implementation of the optimisation principle by maintaining doses as low as reasonably achievable (ALARA – also referred to in the UK as low as reasonably practicable (ALARP)) and are applicable to all areas/planning zones affected by contamination following the radiation emergency.

For the early and intermediate phases (constituting an emergency exposure situation) it is appropriate in planning to select a national RL of below 100 mSv for a short period (that is, short duration, low impact release) or up to a year (longer duration, high impact release). This level of exposure is well below the level at which deterministic effects would be expected to occur. Lower, site specific RL can also be used for planning. For the longer-term recovery phase (constituting an existing exposure situation), PHE considers it appropriate in planning to select a RL of 20 mSv $y^{-1}$ or less. The chosen value of the RL in response and recovery will depend on the prevailing circumstances, and could change over time, as more information becomes available and as residual doses decrease due to natural processes and the implementation of remediation and other protective actions.

*Maximum Permitted Levels* of radionuclides in marketed foods and animal feed are set in European Union regulations (Euratom 2016) for application in the immediate aftermath of a radiation emergency. Foods and feedstuffs exceeding the relevant MPL cannot enter the foodchain. In the UK, the Food Standards Agency and Food Standards Scotland are responsible for implementing these regulations. MPLs are expressed in terms of activity concentrations (Bq $kg^{-1}$ and Bq $l^{-1}$) and are divided into four groups of radionuclides (radiostrontium, radioiodine, alpha-emitting radionuclides, and other radionuclides with relatively long half-lives) and five food categories (baby foods, dairy foods, other major foods, minor foods and liquid foods). The MPLs represent a judgement on the optimum balance between the beneficial and harmful consequences of introducing food restrictions across the European Union; they do not represent a boundary between safe and unsafe levels.

*Action Levels* of radionuclides in drinking water supplies have been recommended by PHE for application following a radiation emergency. They should be used to indicate whether any protective actions are required to protect public health, such as provision of alternative water supplies or additional water treatments.

### Radiological impact assessments

In responding to a radiation emergency, it is important to assess doses to those in the affected area as this will inform decisions on protective actions. Radiological impact assessments should be carried out for planning purposes as well as for response. These impact assessments may involve computer modelling based on a combination of estimated data (planning and response) and actual measurements (response). Early in the emergency, when few measurements are available, reliance will be placed mainly on data from previous studies or expert judgement. As increasing numbers of measurements become available (such as dose rates, concentrations of radionuclides in air, and levels of deposition) these can be used to improve the earlier assessments. However, modelling and estimated data will always be required to some extent, because they allow estimation of health effects/risks, endpoints which are not directly measurable, and they provide for interpolation and extrapolation of endpoints across time and space.

### Withdrawal of sheltering-in-place and evacuation advice

There are no predetermined radiological criteria for initiating withdrawal of sheltering and evacuation advice. In general terms, this advice should only be issued when these urgent protective actions have achieved their desired effect by averting doses, or when their continued application will cause more harm than good in the broadest sense. When making decisions on withdrawal of sheltering-in-place and evacuation advice, a large number of radiological and non-radiological factors need to be taken in to account, necessitating a pragmatic and flexible approach. Radiological factors include: official confirmation that the release has stopped; monitoring data on ambient dose rates, ground deposition and surface contamination; and estimates of effective doses integrated over a range of time periods. Non-radiological factors include: wider health and social needs; caring for livestock; provision of resources for environmental monitoring, decontamination, medical services; and stakeholder opinion. Withdrawal of sheltering-in-place and evacuation advice does not necessarily signify a return to normality. Evidence from previous radiation emergencies suggests that further protective actions may be required ranging from some simple decontamination techniques to temporary or even permanent relocation.

## Transition from response to recovery

The boundary between the intermediate phase and the long-term recovery 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. It is likely that initial planning for recovery will run in parallel with the intermediate phase, although, broadly speaking, the recovery phase is likely to officially start once there is no threat of further release and the radiological situation is well characterised. Furthermore, the fundamental decision to allow inhabitants to remain in the affected areas, generally would have been made. There is also a change in management, from processes and procedures planned in advance, driven by the need to implement urgent protective actions, to more longer-term operational strategies led by the responsible authority in close collaboration with the local community. These latter actions aim to improve living conditions and reduce chronic exposures in the affected areas. The transition from response to recovery requires agreement on establishing a new RL appropriate for existing exposure situations and on which to optimise protection.

## Recovery

Planning for recovery needs to be risk-based; proportionate; flexible, scalable and non-prescriptive; open to lessons learned from previous events; inclusive; and co-ordinated. Developing frameworks and processes for recovery that are reviewed, updated and tested regularly will facilitate the delivery of an appropriate response when required.

Whilst reinstatement of pre-emergency conditions may not be practicable, much can be done when managing recovery to find a reasonable balance between maximising dose reduction and minimising the adverse consequences of remediation to enable affected communities to thrive again by the restoration of infrastructure, businesses, employment and public services. The recovery process itself involves a series of well-defined steps requiring the active participation of the local community in: defining the situation; assessing impacts; identifying goals; evaluating options; making decisions; implementing the strategy; and monitoring for success. Over time, the recovery goals will be met and a strategy for withdrawing any remaining actions will be discussed and agreed with the local community.

## References

Euratom (2013). Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Official Journal of the European Union, L13/1

Euratom (2016) Council Regulation 2016/52 of 15 January 2016 laying down maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency, and repealing Regulation (Euratom) No 3954/87 and Commission Regulations (Euratom) No 944/89 and (Euratom) No 770/90

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# Contents

# 1 Introduction

Authoritative advice for public health protection in the event of radiation emergencies has been published by the National Radiological Protection Board (NRPB)[*] and Health Protection Agency (HPA)[†] since 1990 and has more recently been adopted by Public Health England (PHE). Much of that advice remains applicable. However, international recommendations and requirements (ICRP, 2007; Euratom, 2013; IAEA, 2014), lessons learned from previous nuclear accidents and the identification of aspects not previously covered, but where advice is now required, have been drivers for reviewing, updating and consolidating PHE's advice in this area. In particular, the advice published here aims to bring together much of the advice previously published separately and supersedes a number of earlier publications (NRPB, 1990a; NRPB, 1990b; NRPB, 1997a; NRPB 1997b). The advice covers preparedness, response, and recovery.

This advice is primarily intended to inform those at UK national and local level who have responsibility for developing radiation emergency plans to protect the public and to complement other guidance and regulations on emergency preparedness, response and recovery. The intended audience includes, but is not limited to, public health professionals, local authorities, site operators, regulators, environment agencies and food standards agencies, that is those organisations who might be represented on any of the following groups, set up in response to an emergency: Scientific Advisory Group in Emergencies (SAGE), Scientific and Technical Advisory Cell (STAC) and Recovery Working Group (RWG) and Recovery Co-ordination Group (RCG).

This advice applies to the protection of public health in a wide range of radiation emergencies, including but not limited to: accidental releases of radionuclides from nuclear installations (including defence facilities) in the UK and overseas; transport accidents involving potential radiation exposure of members of the public; fires and other events causing damage to sites holding radioactive materials; accidents involving radioactive materials in premises to which the public have access; satellite accidents involving radioactive material impacting on the UK; and malicious use of radioactive materials where there is potential exposure of members of the public. The advice is also applicable to the impact on UK nationals of events arising overseas. Radiation emergencies may range from small events requiring localised action, to potentially very large events requiring decisions covering a wide area with possible national and international consequences. The advice here is appropriate for use across the entire spectrum of radiation emergencies where there is a possibility of unplanned or unauthorised radiation exposure of members of the public, from the relatively minor to the most severe; it does not however specifically include detonation of nuclear weapons. The advice is intended to be applied pragmatically and flexibly during preparedness, response and recovery phases, according to the scale and type of release; location specific factors; and the needs of the local community. It does not however, provide operational details, which are covered in supporting documents published elsewhere.

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[*] NRPB became part of HPA on 1 April 2005

[†] HPA became part of PHE on 1 April 2013

# 2 Principles of radiation protection for radiation emergencies

There are two key categories of exposure relevant to radiation emergencies:

**a** exposures that are sufficiently high to lead directly to tissue damage, resulting in deterministic effects[*] to individuals (for example radiation burns, radiation sickness, cataracts, hair loss, sterility and the potential for fatalities)

**b** exposures below those capable of causing deterministic effects but which may lead to an increased risk of health problems, such as cancer incidence, in the future

PHE recommends three principles of radiological protection for response to radiation emergencies. These take into account recommendations from the International Commission on Radiological Protection (ICRP, 2007) and interpret them for application in the UK. These principles are shown below.

**Principles of radiological protection**

**a** All protection strategies should aim to do more good than harm (*justification*)

**b** Protection strategies should aim to avoid the occurrence of deterministic effects (*avoid deterministic effects*)

**c** Protection strategies for exposures below the thresholds for deterministic effects should aim to maximise the benefit achieved (*optimisation)*

The first principle of justification applies to all protection strategies, and for all levels of potential exposure. In determining whether a strategy is justified, that is it does more good than harm, account should be taken of all the expected consequences, both beneficial and undesirable, including: radiation health risks; wider health risks (including psychological impact); consequential injuries; economic consequences; social and environmental factors. Significantly higher weight should be afforded to the prevention of deterministic effects than to other consequences such as cost and disruption when determining whether a strategy is justified.

The second principle is to plan for avoidance of deterministic effects. PHE recommends that priority in both planning and response should always be given to consideration of protection strategies to avoid exposures that could lead to deterministic effects. This implies a general presumption that all potentially effective protective actions with the ability to keep exposures below the relevant thresholds are justified, unless a specific case can be developed that clearly demonstrates they are not. It may not always be possible to prevent individuals from receiving radiation exposure above the thresholds for deterministic effects. The second principle requires additional protective actions to be included in emergency plans aimed at ensuring that individuals who have received doses in excess of the thresholds are identified promptly and treated where possible. PHE recommends that equipment and procedures are maintained for promptly identifying individuals who have been highly exposed and require

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[*] Deterministic effects are also referred to as ‘tissue reactions’ and ‘serious direct injury’ in some publications

urgent medical attention.  Such planning is particularly important for those members of the public potentially exposed in a malicious attack.

The third principle of optimisation applies to protection from exposures that are expected to be below the thresholds for deterministic effects.  Optimisation should only be applied to strategies that have been justified. For low exposures, it is generally assumed for the purposes of radiological protection that the increase in radiation health risk is directly proportional to the increase in dose*, and that there is no threshold dose below which there is no risk (ICRP, 2007; HPA, 2009; Little et al, 2018). This means that there is no safe/unsafe boundary of dose on which to base protection decisions. In this region of dose, protection strategies require a balance to be struck between the expected harms and benefits (in the widest sense) of introducing particular protective actions. It is particularly important to ensure that, when deciding on strategies to protect against small increases in potential future health risk from radiation, all possible adverse consequences of the protective actions are thoroughly evaluated, including wider health risks (including psychological impact); consequential injuries; economic consequences; social and environmental factors, to ensure that unintended harmful consequences including potential injuries and fatalities, do not outweigh the intended benefits. More information on how to balance the likely harms and benefits of implementing a range of urgent protective actions is given in Appendix A and Appendix B.

# 3 Timeline of an emergency

In describing the framework for managing a radiation emergency it is helpful to use different time phases, namely: early; intermediate; and long-term, acknowledging that there may be no hard boundary between the different time phases.

*Early phase.* The early phase of an emergency is characterised as the period during which releases of radioactive material to the environment take place. Depending upon the type of emergency, there may also be a period of time (the so-called threat phase) between the start of an emergency and the emission of radioactive material. It is especially 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 has to 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 of release 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 to decide upon the best course of actions to take to protect people and the environment in the intermediate and long-term.

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* Throughout the remainder of the text, the term dose, unless otherwise qualified, is used to signify the effective dose, comprising both external exposure and the committed dose from intakes of radionuclides to age 70 years.

*Long-term (recovery) phase.* The transition between the intermediate and the long-term phase (also known as the recovery 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. The 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.

## 3.1 Radiological protection framework for managing an emergency

ICRP has characterised its recommendations on radiological protection in the context of existing, planned and emergency exposure situations (ICRP, 2007). For managing radiation emergencies, emergency and existing exposure situations are the most relevant. Depending on the progression of the situation, the early and intermediate phases correspond to the emergency response, which according to the radiological protection framework is managed as an emergency exposure situation. The long-term phase, corresponding to recovery is managed as an existing exposure situation.  The relationship between phases and exposure situations is illustrated in Figure 1. The change from managing the situation as an emergency exposure situation to an existing exposure situation may take place at some point during the intermediate phase but not necessarily for all affected areas at the same time.

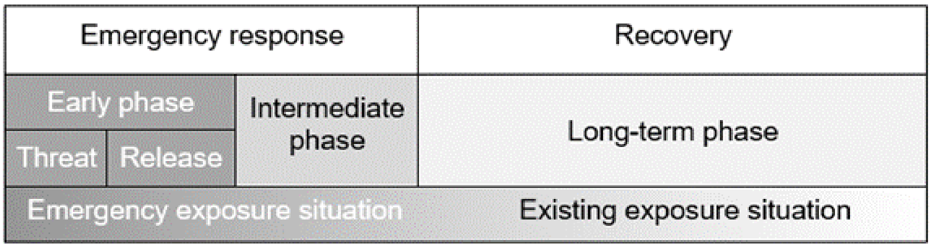

**Figure 1 Timeline of a radiation emergency**

# 4 Emergency planning

A comprehensive understanding of the risk from radiation emergencies and potential consequences is necessary for appropriate emergency planning. Of particular relevance is the need to consider both likelihood and severity of any exposures. The assessment that is carried out by site operators (a nuclear site, hospital, industrial premises) is based on a suitable and sufficient range of source terms representing a full range of potential radiation emergencies, including those of very low probability but severe impact. When evaluating hazards, the potential for events that could affect several facilities or activities concurrently, should be considered, as well as non-radiation related hazards that may impair the effectiveness of, or change, the protective action to be taken. This may include the potential for hazards associated with explosion, fire, chemical releases, severe weather, and self-evacuation. For airborne releases, a range of weather conditions are also considered. The outcome of the assessments provides the responsible authority/body with recommendations on the technical minimum distances required for detailed emergency planning and outline planning. The responsible authority/body then decides on what is appropriate and proportionate, based on local geographic, demographic and practical implementation factors (for example, avoidance of bisecting local communities, and inclusion of immediately adjacent vulnerable groups[*] such as schools, care homes, retirement homes and hospitals).

The detailed emergency planning zone (DEPZ) is the area around a site/facility/mobile site where the responsible authority/body is required to prepare a detailed off-site emergency plan with the purpose of restricting public exposure in the event of a radiation emergency. The DEPZ should provide an effective response to a range of radiation emergencies. It should reflect the benefits and harms of protective actions such as sheltering-in-place, evacuation and the administration of stable iodine (if appropriate), by considering an appropriate balance between dose aversion and the consequences of implementing these protective actions across too wide an area, thereby diverting important resource from the affected areas which require the most attention. In defining the boundary of a DEPZ, the use of practical geographic or physical features such as roads, rivers, railways or footpaths should be considered as well as parish or postcode boundaries, particularly where these features and concepts correspond with other local emergency planning arrangements.

Outline planning builds on the arrangements and capabilities within detailed emergency plans to provide commensurate planning for low probability events up to and including unforeseen events. Outline planning is about identifying the high-level provision for how capabilities in place for the DEPZ could be extended to the outline planning zone including the logistics for obtaining regional or national support and the location of vulnerable groups. It does not aim to implement protective actions immediately, although there still should be a timely response, and is proportionately less detailed and less onerous than detailed planning. PHE advises that when adopting a proportionate approach to planning, focus should be on methods for quickly identifying the need to extend protective actions beyond those given in the detailed off-site emergency plan, and for efficient coordination of information and resources between neighbouring local authorities and between local and national levels. In some situations, a DEPZ may be required but without an outline planning zone. This could occur, for example, where the impact of a severe accident is close to the site and the nature of the event means that it does not warrant emergency arrangements being extended (for example criticality).

Outline planning will generally happen within the outline planning zone and detailed planning will generally happen within the DEPZ. Nevertheless, there may be pockets of detailed planning inside the outline planning zone where local circumstances make it proportionate to put these in place (presence of schools or hospitals within that area).

# 5 Protective actions

## 5.1 Protective actions for exposures above the threshold for deterministic effects

It is very unlikely that radiation emergencies at nuclear facilities in the UK would lead to deterministic effects for members of the public, but a few sites and scenarios do have the

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[*] Vulnerable groups include those that are less able to help themselves in the circumstances of an emergency

potential (albeit at very low probabilities) for releases that could result in exposures on-site and off-site at very high levels. Such emergencies include uncontrolled criticality, large airborne releases of radioactive material, and failure of shielding around high activity sources with high dose rates. Operations at these sites or facilities are particularly closely regulated, and specific plans are required to reduce the likelihood of such accidents occurring and to protect individuals in the event that they do occur. Emergency plans are required to include a range of protective actions, aimed at ensuring there is prompt alerting for such an emergency and that people are protected from any consequent high exposures. Prompt identification of those who may have been highly exposed is also needed so that they can be prioritised for urgent medical attention. Furthermore, it is important to regularly review protective actions for any members of the public who might be at risk of receiving deterministic effects in an emergency.

## 5.2 Protective actions for exposures below the thresholds for deterministic effects

For most sites and scenarios, radiation emergency planning focuses on protective actions to reduce or avoid potential exposures at exposures below the thresholds for deterministic effects. This means that radiation emergency planning is very different from most other forms of emergency planning, in that its focus is generally the reduction of (relatively low) long-term health risks, rather than the prevention of serious acute risks. Given this, detailed off-site radiation emergency planning is generally based on the first and third principles of radiation protection, that is, justification and optimisation. Protective actions for exposures below the thresholds for deterministic effects may be classified as either urgent protective actions and longer-term protective actions.

*Urgent protective actions* – a subset of protective actions directly aimed at reducing exposure to people prior to and during the early phase of a radiation emergency (emergency exposure situation). These include: sheltering-in-place; administration of stable iodine; evacuation; and restrictions on food and water supplies. Some of these actions may be taken on a precautionary basis (that is, prior to exposures/ contamination occurring). In addition, other urgent protective actions such as personal decontamination and medical intervention may be required at an individual level and on a case-by-case basis, according to the prevailing circumstances.

*Longer-term protective actions* – a subset of protective actions aimed at reducing exposure to people during the intermediate and long-term recovery phase resulting from a radiation emergency. These encompass continuing restrictions on food and water supplies; temporary and permanent relocation; and recovery actions. Recovery actions provide protection from exposures due to contamination of the environment and food supplies. Some longer-term actions, such as follow-up health surveillance may be taken on a precautionary basis.

### 5.2.1 Urgent protective actions

#### *5.2.1.1 Sheltering-in-place*

Sheltering-in-place involves individuals going inside buildings, closing doors and windows, and turning off ventilation fans and air conditioning. The best protection is provided by solidly constructed and reasonably airtight buildings. As a stand-alone action, sheltering-in-place can be used to provide protection against external radiation from airborne gases and particles which have been deposited on the ground in inhabited areas.  The dose reduction factors (DRF)[*] for external gamma dose (derived solely on the basis of a literature review) are 0.15 for typical residential brick-built homes and 0.05 for multi-storey buildings (Bedwell et al, in preparation). Buildings can also slow down the rate of ingress of radioactive material that could be inhaled[†]. A DRF of 0.6 (derived on the basis of a combination of modelling and literature review) should be assumed for inhalation dose to an individual sheltering during the entire passage of the plume, until both the indoor and outdoor air concentrations fall back down to (or close to) zero, with no opening of windows and doors to the external environment (and under such circumstances the DRF remains constant irrespective of the release duration). These generic, typical values can be applied to prospective assessments or retrospective assessments where scenario specific information is limited. Key factors affecting the effectiveness of sheltering-in-place include: the air permeability of a building used for shelter; the meteorological conditions; the particle size distribution; the effectiveness/timing of opening windows and doors; and the release duration, all of which could vary significantly from one scenario to another (or even within a single scenario). Some of these factors such as meteorological conditions are time dependent, and therefore the DRF may vary as a function of time.

The health and wellbeing of sheltered populations may be affected by restricted access to medical care or assistance. In such situations, consideration should be given to supervised entry into the sheltered area by medical professionals and carers, or planned evacuation of these vulnerable groups. Residents of hospitals and nursing homes can face additional challenges, for example, sheltering-in-place without electrical power can be fatal for those dependent on modern technology such as ventilators. Therefore, if electrical power is lost, evacuation of the vulnerable groups is likely to be essential in such situations.  Similarly, specific support and advice should be provided to farmers needing to tend livestock and those managing key infrastructure. Sheltering-in-place is not a long-term option and whilst it is potentially straightforward to implement, its use should ideally only be planned to last hours, and, at most, 1 or 2 days.  In order to minimise the anxiety and stress created by advice to shelter, it is important to ensure communication with those sheltering is continuously maintained through appropriate communication channels.  In particular, those sheltering-in-place for prolonged periods require reassurance that the advice has not changed and that those from whom they may be separated (for example, children at school, partners at work) are being properly cared for.

Sheltering-in-place can also be implemented as a transition measure to provide interim protection against radionuclides with longer half-lives, whilst arrangements are made for other protective actions, for example, transfer to a more solidly constructed building or for evacuation.

#### *5.2.1.2  Evacuation*

Evacuation is the temporary removal of people from an area to avoid or reduce short term radiation exposure in an emergency. The primary purpose of evacuation is to protect the population against inhalation of radionuclides and external exposures from radionuclides in

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[*] A DRF of 0.15 means that the external dose will be reduced by 85% compared to that outdoors

[†] Sheltering-in-place to reduce inhalation of airborne material is not unique to radiation emergencies since major chemical sites also have a similar approach

the air and deposited on the ground. It is the only urgent protective action which has the potential to prevent virtually all exposure to a release. To achieve this, evacuation must be implemented before a release occurs. If evacuation prior to the release is not possible then careful consideration needs to be given to the timing of the evacuation and whether it would be better to shelter the population until exposure levels outside the shelter have reduced; evacuation through a dispersing plume may expose people to higher doses than sheltering-in-place and should only be considered where sheltering is not adequate or the situation is likely to get worse. If the evacuation still goes ahead, then duration of exposure in the plume should be kept to a minimum. In practice, road layouts and physical constraints (such as rivers or mountains) will mean that moving away from the plume is not always achievable, leading to enhanced exposure during the evacuation. Poor road conditions and constrained traffic flows can also increase the time required to evacuate and, hence, can increase exposure duration while evacuating. Furthermore, the number of people involved and size of the affected area will influence the efficiency of evacuation; urban areas contain more people but the supporting infrastructure is likely to be greater and could result in speedier evacuations than rural areas. The longer the time spent travelling in the plume, the greater the exposure period. While people are in transit in vehicles such as cars and buses, their protection against exposure is likely to be significantly less than the protection they would receive from sheltering inside typical UK buildings, although this would depend on the radionuclides involved. In such situations, there would be no protection from inhalation of radioactive contaminants.

Evacuation can be effective and relatively straightforward for protecting small communities (of perhaps tens to a few hundred people), but it is a very disruptive protective action and also difficult to implement if a large number of people (more than a few hundred) are involved and/or it has not been planned. Without planning, evacuation can lead to major physical and psychological health risks. The evacuation of vulnerable groups, such as residents of hospitals or care homes, is more difficult than the evacuation of healthy adults and may seriously affect their overall health and wellbeing and in extreme circumstances lead to fatalities (Tanigawa et al, 2012). In a review of ten studies on evacuation from nursing homes after the Fukushima accident in 2011, only one study reported no deaths from the evacuation (Willoughby et al, 2017). It is clear that careful, transparent, evidence-based emergency planning is required so that the needs of evacuees can be met during and after an evacuation; continuous specialist care and equipment may be required, as well as transport and supplies of medication.

In addition to vulnerable populations described above, there are other special groups such as pregnant women, school children, farmers, tourists and those working in high risk industrial premises that have special needs, which if not considered, can cause delays in completing evacuation. Therefore, circumstances may require prioritisation on the day for these special groups. It is also important to prepare plans for maintaining critical national infrastructure, such as power stations and Control of Major Accident Hazards (COMAH) sites, during an evacuation event. Furthermore, farmers will need guidance on the welfare of their animals.

There can be practical problems associated with feeding and housing the evacuated population in reception centres and ensuring security of property in the evacuation zone. The evacuation of residents from their homes for periods of days or even weeks can cause high levels of stress, especially if the accommodation provided is not suited to their needs. Evacuation implemented with little prior warning is necessarily urgent and therefore affords little time for those affected to plan what to take with them, placing challenges on the management of pets and livestock. Evacuation carried out following a period of several hours of sheltering-in-place, will permit some preparations to be made.

#### *5.2.1.3 Administration of stable iodine*

The administration of stable iodine in tablet form is carried out to reduce or prevent uptake of radioactive iodine (radioiodine) by the thyroid, by saturating the thyroid with iodine which is not radioactive. Exposure to radioactive iodine which occurs either through inhalation or ingestion may increase the risk of thyroid cancer, particularly in children. The optimal period of administration of stable iodine is less than 24 hours prior to, and up to 2 hours after, the expected onset of exposure. It would still be reasonable to administer stable iodine up to 8 hours after the estimated onset of exposure. Commencing treatment later than 24 hours following exposure may do more harm than good by prolonging the biological half-life of radioactive iodine that has already accumulated in the thyroid (WHO, 2017). A number of factors, in addition to the time of administration, can affect the effectiveness of stable iodine tablets, including the duration of the exposure to radioactive iodine, how much food is in an individual’s stomach and the individual’s metabolic characteristics. It is therefore recommended that, if an emergency plan includes the administration of stable iodine, then it should aim to deliver the stable iodine as quickly as reasonably practicable in order to maximise the dose saving achieved.

The administration of stable iodine is primarily recommended for reducing doses from inhalation of radioiodine and should be accompanied by either sheltering-in-place or evacuation. Food restrictions are the preferred option for reducing transfer via the ingestion pathway. Planning for the administration of stable iodine as a stand-alone protective action is not recommended, since a release containing radioiodine will also result in exposure from external irradiation, and will, in most circumstances, contain other radionuclides (exceptions being where radioiodine dominates releases (for example, certain faults at nuclear installations, or research establishments and hospitals where radioiodine is the predominant radionuclide). Individuals most likely to benefit from the administration of stable iodine include children, adolescents, pregnant and breast feeding women. Nevertheless, in the UK no distinction is made on the basis of age when distributing stable iodine.

A single dosage of stable iodine would generally be sufficient, as it gives adequate protection for 24 hours (Table 1); these dosages are consistent with those recommended by World Health Organisation (WHO, 2017). There is a Patient Information Leaflet available on the UK Medicines and Healthcare products Regulatory Agency (MHRA) website containing information on the safe use of stable iodine, especially in pregnancy, whilst breast feeding and for newborn babies. In the rare circumstances where additional dosages of stable iodine are required, for example, prolonged or repeat exposure or unavoidable ingestion of contaminated food or water, PHE advises that any repeat administration should be given at the same dosage as the initial administration, although in pregnant or breastfeeding women and newborn babies (aged up to 1 month) repeat dosing should be avoided.

**TABLE 1 Dosages of stable iodine**

| Age group | Equivalent mass of iodine (mg) |
|---|---|
| Adults including the elderly and children over 12 years | 100 |
| Children aged 3-12 years | 50 |
| Children aged 1 month – 3 years | 25 |
| Newborn babies aged up to 1 month | 12.5 |

#### *5.2.1.4 Adaptations to some urgent protective actions for longer duration releases and exposures*

The urgent protective actions of sheltering-in-place, evacuation and administration of stable iodine are most straightforward to implement for discrete releases of relatively short duration. In situations where there is a protracted threat of a release, an intermittent release or a release that continues over an extended period, it may be necessary to modify their implementation. For example, if a sustained cessation in the release is predictable, temporary lifting of sheltering-in-place or supervised re-entry into an evacuated area may reduce the negative social consequences of these protective actions. Alternatively, advantage may be taken of a period prior to the initial release when the risk of a release is known to be high but delayed, or an extended safe period during an intermittent release, to organise precautionary evacuation, movement of people to a better shelter location or the issuing of second dosages of stable iodine. It is prudent to consider in outline planning how such variations to the detailed response plans could be implemented and communicated as part of the overall planning process, as improvised implementation ‘on the day’ may result in unintended harmful consequences.

#### *5.2.1.5 Decontamination of people*

First responders and members of the public may be externally contaminated with radioactive materials on skin or hair during and after the release. Dry decontamination is the default decontamination method in the UK for non-caustic substances (PHE, 2018). Disrobing is the first and critical step in the decontamination process, removing much of the external contamination. Wet wipes may also be used on exposed skin before re-robing with clean clothing. Implementation is subject to careful pre-planning, taking into account resource availability; the management of associated wastes; and subsequent reassurance monitoring by suitably qualified persons. Further details about decontamination of people are out of scope of this document.

#### *5.2.1.6 Medical interventions*

Medical interventions are treatments administered, following exposure, under the supervision of a clinician. They are generally only relevant for individuals who are thought to have received high exposures to radiation, approaching or in excess of the thresholds for direct injury (Section 6.1, Table 2). Medical interventions include appropriate use of treatments used more widely for supporting patients with compromised immune systems, and other treatments more specific to removing radionuclides from the body (Gerber and Thomas, 1992; Rojas-Palma et al, 2009). Advice on Prussian Blue (ferric hexacyanoferrate), which is 1 type of medical intervention has been published and remains applicable (HPA, 2010). Prussian Blue is used to assist in reducing internal contamination by radiocaesium. Further details about medical interventions are out of scope of this document.

#### *5.2.1.7 Initial restrictions on food and drinking water supplies*

The urgency of implementing restrictions on food and water supplies will depend on the circumstances of the emergency. For an airborne release, it is essential to issue prompt (that is within 24 hours) precautionary advice, particularly advising people not to eat unwashed fresh fruit and vegetables that have been outside or to drink rain water. The need for prompt restrictions on other food pathways, such as fresh milk, will depend on the levels of contamination in the food consumed by animals and the uptake and retention of radioactive materials in their bodies: for an airborne release occurring when dairy cows are grazing outdoors the concentrations of iodine and caesium will normally peak in milk after 1-2 days. On the basis of measurement data, statutory food restrictions on marketed foods may follow to prevent contaminated foodstuffs entering the foodchain (any such food would require disposal). Similar restrictions will apply to potentially contaminated drinking water supplies or to marketed food from contaminated aquatic habitats.

There is no simple relationship between the size and composition of a release of radioactivity and the individual doses that result from ingestion of contaminated foods. The rates at which radionuclide levels build up and decline in plants and animals depend on a complex interaction of the chemical and physical properties of the radionuclides, the amount available for uptake and the size and state of development of the animal or plant and its metabolism. Furthermore, people may obtain their food from a variety of sources: marketed foods; home produced foods; and foods sourced from the wild, so-called ‘foraged foods’. Marketed foods will be controlled through statutory food restrictions. Guidance will be required to assist individuals in managing their consumption of foods from other sources that may be contaminated and some form of monitoring resource may be provided locally.

Considerable volumes of contaminated waste can be generated as a result of the placing of restrictions on the marketing of crops, milk and meat. As these restrictions are based on statutory requirements it is important that appropriate sampling, monitoring and storage arrangements and routes of disposal be identified in advance of future emergencies. Waste disposal options range from relatively simple in-situ methods (for example, ploughing in, composting and landspreading) to offsite commercial treatment facilities (for example, landfill and incineration).

Contamination of drinking water supplies to levels that would pose a risk to public health is extremely unlikely for accidental releases. Levels of radioactivity in drinking water are expected to be considerably lower than those in contaminated water sources due to environmental processes, which dilute and delay the transport of contamination, and processes used to treat mains water supplies. Individuals, who are reliant on untreated rainwater as their primary source of drinking water, should be considered as the most likely to be at risk from contamination in the absence of any protective actions, so prompt advice is required for these consumers. It is important that health protection advice following a radiation emergency takes account of these consumers and their circumstances, which may vary between areas and individual supplies.

### 5.2.2 Longer-term protective actions

Following the end of a release of radionuclides to the environment, it is important to determine whether the magnitude of the residual doses[*] warrant further protective actions to be implemented in the long-term as part of the recovery strategy, when urgent protective actions are withdrawn. These longer-term protective actions may include temporary or permanent relocation as well as actions to aid recovery in the affected areas. Recovery actions, as their name suggests, are implemented to assist the affected population, as much as possible, to return to a way of living in which the emergency is no longer dominant in their thinking. Recovery actions include restricting access to contaminated areas, remediation of land and buildings, and further restrictions on food and water supplies.

#### *5.2.2.1 Temporary relocation*

Temporary relocation is the planned removal of people for an extended but limited period of time (weeks, months or several years depending on the characteristics and extent of the contamination) to avoid doses from radioactive material deposited on the ground or resuspended. The dose rate would be expected to fall either naturally due to weathering or physical decay or due to decontamination procedures that remove contamination from the area. Temporary relocation involves the movement of people either from short-term reception centres or directly from their homes to temporary accommodation that would meet all their basic needs and where longer-term living can be properly supported. 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 unoccupied.

The physical risks associated with temporary relocation are relatively small compared with those for evacuation, since the action can be carried out in a controlled manner, with more time to prepare and implement. Nevertheless, temporary relocation is associated with psychological effects. 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 (Oe et al, 2017; Ohto et al, 2017). A UK based study on the impact of temporary relocation after flooding also provided supporting evidence for a higher incidence of depression and PTSD in those who were relocated compared to those who remained at home (Munro et al, 2017; Waite et al, 2017).

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 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, the need to repair or reconstruct abandoned houses; insufficient infrastructure such as schools, hospitals and shops; and persistent concerns about radiation.

#### *5.2.2.2 Permanent relocation*

Permanent relocation is the complete removal of people from an area with no expectation of their return. The decision to permanently relocate people will be based on radiological, social and economic considerations with due recognition of the gravity and irreversibility of such a

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[*] Residual dose in this context is the dose expected to be received following implementation of the urgent protective actions

difficult decision. The decision on permanent relocation must be taken on a case by case basis taking into account the prevailing circumstances including, the current level of exposure and the level foreseen following the implementation of recovery actions (for example, decontamination), and the conditions and means to maintain sustainable societal and economic living conditions. It is a non-urgent protective action and therefore, as with temporary relocation, time is available to allow those being relocated to take action to address personal needs. Depending on the scale and severity of the radiation emergency, construction of new housing and infrastructure may be required for those subject to permanent relocation.

#### *5.2.2.3 Further restrictions on food and water*

In general, consumption of small amounts of contaminated food and water over a few days is unlikely to pose significant risks to public health. The purpose of restrictions on food and water supplies is to provide protection from the cumulative health risk that would result from consumption over protracted periods. Owing to the potentially long timescales over which foods can remain contaminated, and, for all but the most extreme events, the relative ease with which food supplies can be replaced in the modern international market, it is likely that food and water restrictions will be enforced over very much larger areas, and imply lower dose criteria, than will sheltering-in-place, evacuation or administration of stable iodine. The latter urgent protective actions are necessary to avoid relatively high, short-term doses from inhalation and external exposure to the plume, following a large airborne release. This rather complex situation will require careful explanation to affected populations and needs to be considered as part of a wider communication strategy.

As with contamination in food, in general, consumption of water contaminated with radioactivity over periods of a few days, or even weeks, is unlikely to pose a significant health risk. However, if activity concentrations are such that protective actions are required, then additional techniques to reduce levels in drinking water by physical or chemical treatment, may be applied or alternative drinking water provided. For public supplies, water utilities have well developed plans for blending water from different sources and for providing alternative supplies by tanker if required. It is not expected that there would be a requirement to replace mains water supplies for non-culinary uses, such as flushing toilets, watering the garden and other domestic uses.

#### *5.2.2.4 Recovery actions*

The aim of a recovery action is to reduce doses either from exposure to contaminated surfaces in an inhabited area via external irradiation and inhalation of resuspended material, or from the consumption of contaminated foodstuffs and water via the ingestion pathway. A full set of recovery actions is provided in the UK Recovery Handbooks for Radiation Incidents v4 (Nisbet et al, 2015). There is also significant information on decontamination guidelines and the efficiency of the different decontamination techniques published by the Japanese Ministry of Environment, relating to the Fukushima accident (Ministry of Environment (Japan), 2015).

##### *Food supplies and drinking water*

The radiological quality of foodstuffs can be managed by various recovery actions taken to reduce the transfer of radionuclides in the foodchain either through the soil-to-plant pathway or intervention in animal production systems and drinking water supplies. The recovery actions selected will depend on the physical and chemical properties of the radionuclides released, season of the year and the types of land use affected.

Intervention along the soil-to-plant pathway includes options that remove contamination by removing topsoil, or reduce soil-to-plant transfer of radionuclides by ploughing and/or application of fertilisers and lime. In animal production systems, the ingestion of contaminated feed by livestock can be managed by the provision of uncontaminated feed or the movement of animals to less contaminated pasture for a period of time before slaughter. Livestock can also be given chemicals to reduce the uptake of radionuclides by the gut, for example, administration of Prussian Blue in feed for incidents involving radiocaesium. For emergencies involving drinking water, recovery options include the provision of an alternative supply in the short term and exploitation of the various treatment processes (for example, ion exchange, reverse osmosis) that are available for removing contamination on longer timescales.

### *Inhabited areas*

Recovery actions limit exposure by restricting access to, or by remediation of, contaminated areas. Restricted access reduces exposures by removing people from areas of contamination, or by controlling the time spent in such areas. Restricted access measures may range from preventing or limiting access to localised contaminated areas (that is, the location of the release, key infrastructure that has become highly contaminated, or known areas of more intense contamination), to relocation of the resident population from, and prohibition of all access to, an area for weeks, months or even years.

Remediation can be achieved by either providing protection from exposure to the contamination (shielding) or by removing contamination (decontamination). Shielding can be used to reduce external exposure and the inhalation of contaminated material. It can also restrict or prevent mobility of the contamination. The use of shielding materials is potentially a very effective option for radionuclides emitting alpha or beta radiation, particularly for radionuclides with short half-lives. Some more permanent shielding options, such as burial of contamination to reduce external exposure by covering with clean topsoil or ploughing, are also effective for long-lived radionuclides and gamma emitting radionuclides. Fixing contamination to a surface, through so-called tie-down options, will reduce the resuspension hazard.

Decontamination involves the removal of contamination from surfaces and objects. Whilst decontamination can be very effective, it has the potential to lead to the production of contaminated waste, often in large quantities and for which appropriate characterisation, segregation, temporary storage (potentially long-term) and disposal routes must be found; this can present a significant challenge. For example, it is estimated that the final amount of low level radioactive waste produced by decontamination of land following the Fukushima accident will be around 22,000,000 $m^3$ (Sato and Lyamzina, 2018). Over 800 temporary storage sites have been created in local communities to hold millions of bags of waste until they can be removed off site. The construction of interim storage facilities has been slower than the rate of waste accumulation and very little progress has been made in identifying a site for final disposal (Sato and Lyamzina, 2018). In contrast, the redistribution of contamination (for example, shielding through ploughing) avoids such waste disposal problems, but leaves the contamination in situ, as a quantifiable long-term risk.

Clearly, the recovery actions available in the long-term are many and varied; they may be used in isolation or in combination as part of a broader strategy. Some options will only be applicable for 1 radionuclide or 1 type of land use. Other options may generate unacceptable amounts of waste or may only be effective at certain times of the year or under particular environmental conditions. Consequently, the development of a recovery strategy will involve evaluating and selecting and combining recovery actions based on input from a wide range of stakeholders, including those with local knowledge.

# 6 Radiological criteria for emergency planning, response and recovery

## 6.1 Overview of radiological criteria

PHE provides authoritative advice on dose criteria used to inform the development of emergency plans and guide decisions on response and recovery. Two types of criteria are provided: emergency planning thresholds of dose for guiding decisions on protective actions to avoid deterministic effects; and sets of other dose criteria (Emergency Reference Levels (ERLs), Reference Levels (RLs), Maximum Permitted Levels (MPLs) and Action Levels) to optimise protection against lower exposures from the early phase of a release through to the long-term (Table 2). ERLs have been implemented in UK emergency plans for nuclear sites since the 1990s. MPLs have been set in European Union Regulations (Euratom, 2016) and are implemented in the UK by the Food Standards Agency and Food Standards Scotland. RLs are a concept introduced by ICRP in 2007 (ICRP, 2007) and subsequently adopted in a European Union Directive in 2013 (Euratom, 2013) and UK legislation. Despite having similar names, ERLs and RLs have different, yet complementary applications.

**TABLE 2 Radiological criteria for optimising protection below the thresholds for deterministic effects**

| Dose criteria | Units | Pathway | Timeframe |
|---|---|---|---|
| Emergency Reference Levels | Averted dose (mSv) | Inhalation, external irradiation | Early phase |
| Maximum Permitted Levels | Activity concentrations in food and animal feedstuffs (Bq kg$^{-1}$) | Ingestion | All |
| Action Levels | Activity concentrations in drinking water (Bq l$^{-1}$) | Ingestion | All |
| Reference Levels | Residual effective dose (mSv y$^{-1}$) | All | All |

ERLs are criteria that apply to the justification and optimisation of sheltering-in-place, evacuation and stable iodine administration. ERLs are most appropriately expressed in terms of averted dose (mSv effective dose or mSv equivalent dose to the thyroid), over a period of up to 7 days[*] following a release. ERLs consider the balance between the benefit from reducing the dose against the other consequences of implementing these urgent protective actions (that is, wider health risks (including psychological impact); consequential injuries and fatalities; economic consequences; social and environmental factors). In contrast, RLs are constraints on overall dose for timeframes from the early phase of a release through to the long-term; they are a level of ambition to keep below). RLs are most appropriately expressed in terms of individual annual residual effective dose (mSv $y^{-1}$), that is, the dose expected to be received following implementation of the protection strategy, which may include urgent protective actions and longer-term protective actions.

MPLs are the maximum permitted levels of radionuclides in marketed foods and animal feed that might arise following a radiation emergency. Foods and feedstuffs exceeding the relevant MPL will not enter the foodchain. MPLs are expressed in terms of activity concentrations (Bq $kg^{-1}$ and Bq $l^{-1}$).

The dose criteria provided by ERLs (for sheltering-in-place, evacuation and administration of stable iodine, RLs (for all protective actions), MPLs (for food and animal feedstuffs) and ALs (for drinking water) provide a complementary framework for optimising protection following a radiation emergency.

## 6.2 Criteria to avoid deterministic effects

Deterministic effects may be avoided entirely by preventing doses from exceeding the relevant thresholds for these injuries. Due to uncertainties and variability of exposures immediately following a severe radiation emergency, it is important to develop plans with a degree of inherent caution, so that there can be confidence that all individuals who have the potential to be highly exposed are sufficiently protected. PHE therefore specifies ‘emergency planning’ thresholds of dose, which are lower than biological thresholds, as the basis for planning actions to protect people from receiving exposures that would lead to deterministic effects.

PHE advises that the relevant threshold exposures for emergency planning purposes are acute doses of 1 Gy whole body (which may result in direct injury to the bone marrow) and 2-3 Gy to the other most radiosensitive organs for low Linear Energy Transfer (LET) radiation (mostly beta and gamma radiation), and 0.5 Gy whole body for acute exposure to neutrons. In the context of the emergency dose thresholds cited, acute doses are those delivered over a period of up to a few days. Specifying an appropriate threshold for an acute inhalation of alpha emitting radionuclides is difficult, as there is a large uncertainty associated with the models for deterministic effects resulting from acute intakes of alpha-emitting radionuclides. For the purposes of developing emergency plans, PHE recommends the prudent adoption of an emergency planning threshold of 1 Gy lung dose, integrated to 1 year, from an acute inhalation of alpha-emitting radionuclides. These values are summarised in Table 3.

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[*] The integration time of 7 days is assumed as typical of the longest period for which evacuation would be considered. The choice of 7 days in this particular application of the ERLs is partially arbitrary and does not constitute advice on the appropriate integration time for doses to be compared with ERLs when emergency plans are developed: the appropriate time will vary between sites and different proposed implementations of protective actions.

**TABLE 3 Emergency planning threshold doses for deterministic effects**

| Type of radiation | Dose (Gy)[a] | Integration period |
|---|---|---|
| Low LET[b] | 1 Gy whole body / red bone marrow<br>2-3 Gy other radiosensitive organs | Up to a few days |
| Neutron[c] | 0.5 Gy whole body | Up to a few days |
| Alpha | 1 Gy lung | Up to 1 year from acute inhalation |

[a] A Gray (Gy) is a derived unit of radiation dose. It is defined as the absorption of 1 joule of radiation energy per kilogram of matter

[b] If significant beta contamination of skin is considered likely, a separate assessment of doses to skin should be made in order to determine whether these could result in serious skin burns. (ICRP, 2012)

[c] These whole-body thresholds should be reduced by up to a factor of 5 for foetal exposure during the first 21 weeks of development (NRPB, 1993)

## 6.3 Emergency Reference Levels

### 6.3.1 Application of ERLs during planning

Detailed plans that can be implemented quickly are required to avoid or reduce the risk of cancer and other health effects. This requires an evaluation of the benefits and likely consequences of sheltering-in-place, evacuation and the administration of stable iodine. To assist in ensuring that this process of optimisation is carried out on a consistent basis across the UK, and for all types of emergency situation, PHE and its predecessor bodies have specified Emergency Reference Levels (ERLs) of averted dose for use in the planning of these urgent protective actions (NRPB, 1997). Since the combination of circumstances at the time of implementing a protective action will determine the benefit achieved in terms of reduced radiation risk, it is not meaningful to provide advice in terms of total potential dose received – it is dose averted or avoided by the protective action that determines its benefit. PHE therefore continues to recommend ERLs in terms of averted dose.

ERLs are not intended to be limits on dose or indicators of doses which may be ‘safely’ received by an individual, but indicate the range of levels of dose (expected to be averted by the protective action) within which the overall benefit of taking that action would be maximised, taking into account the risks and disruption which arise from it.

The principles of justification and optimisation mean that a balance needs to be struck between averting radiation doses and incurring other harmful consequences. During planning, the ERLs provide guidance on where this balance lies for sheltering-in-place, evacuation and the administration of stable iodine. The balance changes depending on the scale, nature and location of the release. Since the exact consequences of these protective actions depend very much upon the circumstances prevailing at the time and location of an emergency, and because many of the consequences cannot be directly quantified, PHE specifies a range of averted doses, bounded by an upper and a lower ERL for each of these protective actions.

ERLs are provided in pairs. The upper and lower ERLs are indicative, rather than precise values. The lower ERL indicates the likely balance of averted dose against all the other consequences of implementing the protective action in situations that are favourable for its implementation. In other words, this is likely to be the smallest quantity of expected averted dose for which it would be justified to implement the action. ‘Favourable’ circumstances usually include the availability of detailed plans and the involvement of small numbers of people for whom the action is implemented. The upper ERL indicates the likely balance in unfavourable circumstances, for example, where there is only outline planning, weather conditions are extreme or larger numbers of people are involved. The ERLs are only indicative levels: plans may involve implementation of a protective action for lower or higher levels of averted dose, owing to local factors such as population density, weather conditions.

There could be circumstances where it would be inappropriate to implement evacuation, even at the upper ERL due to the potential for harm to outweigh the benefits of dose reduction. This is particularly the case for very large, extremely unlikely or unpredictable releases with the potential to expose major population centres. In such situations, the best protection may be afforded by initially advising everyone in affected areas, beyond the DEPZ, to shelter-in-place (preferably with administration of stable iodine where appropriate) and then identifying particularly vulnerable groups (residents of hospitals and care homes, the elderly, school children) for the selective, planned evacuation of these groups together with their families/carers.

Table 4 lists PHE recommended ERLs for the planning of sheltering-in-place, evacuation and the administration of stable iodine. These values for the ERLs are unchanged from those recommended previously, with 1 exception, a reduction in the upper ERL for administration of stable iodine. This reflects a better understanding of the increased risk of thyroid cancer in young children (AGIR, 2011) and of the lower risks of adverse health effects from administration of stable iodine (Spallek et al, 2012) since publication of previous advice (this is further explored in Appendix B). As most emergency planning is done on the basis of the lower ERLs, the impact of a reduction in the upper ERL for administration of stable iodine is likely to be minimal.

**TABLE 4 Recommended ERLs for the planning of sheltering-in-place, evacuation and the administration of stable iodine**

| Protective action | Effective dose or organ dose | Averted dose (mSv)[a] | |
|---|---|---|---|
| | | Lower | Upper |
| Sheltering | Effective | 3 | 30 |
| Evacuation | Effective | 30 | 300 |
| Stable iodine | Thyroid[b] | 30 | 100 |

[a] In recognition of their higher cancer risk, the doses are those potentially averted in young children

[b] mSv equivalent dose to the thyroid

In developing the plan for sheltering-in-place, evacuation and the administration of stable iodine, the potential dose savings from the implementation of each protective action should be compared with the appropriate ERLs for each scenario. In general, if the potential dose saving at a particular location is expected to be less than the lower ERL for a protective action, the emergency plan should not include that action for that location. Similarly, if the expected dose saving is above the relevant upper ERL, then in general PHE would recommend that provision should be made either for that action or, if appropriate, for a more protective one.

Once a generally appropriate response for a range of emergencies has been identified, it is important that the circumstances which should trigger this response are clearly identified. PHE supports the role of appropriate observable criteria to trigger the emergency response (see section 6.3.2). Other valid approaches are used. For example, the International Atomic Energy Agency (IAEA, 2015, IAEA, 2017) recommends the use of Operational Intervention Levels (OILs) for prompt decision making, based on directly measurable quantities. However, waiting for any measurements to be taken (for comparison with OILs) may introduce delays and the assumptions made to link environmental activity concentrations with public exposure, are necessarily very generic.

### 6.3.2 Observable criteria (triggers)

Whatever the type of emergency, there is a need for highly competent trained and adaptable staff who can respond appropriately to novel and unforeseen circumstances and utilise their knowledge and experience to trigger the emergency response. The appropriate observable criteria used to trigger the response include: symptom-based criteria such as instrument readings or the more subjective event-based criteria such as an earthquake or fire. These observable triggers are not directly related to the ERLs. The ERLs are used to determine the broad response contained in the plan. The purpose of observable criteria is to trigger the implementation of part or all, of the emergency plan. The triggers are defined by those responsible for the emergency plan and can be specified in terms of a wide range of direct observations according to what is impacted by the emergency (nuclear site, transport of nuclear material, fires and other events causing damage to sites holding radioactive materials, malicious events), as well as gross activity concentrations in air. Expert knowledge of the source term and potential scale of the emergency can also provide additional triggers. Some triggers cannot be used in isolation. In setting appropriate observable criteria and defining the precautionary set of urgent protective actions they will trigger, it is important that the plan takes into account practical factors, such as numbers of people, demographic boundaries, transport networks, and the impacts that different types of weather or time of day would have on the safety and effectiveness of the protective action.  Where there is potential for ‘on the day’ circumstances to indicate that a particular response would be inappropriate, the plan should state this and provide an alternative.

Although precautionary, the urgent protective actions will have been well thought through in advance, taking account of the types of emergencies that could occur. Therefore, there can be confidence that implementing them in advance of detailed assessments of the actual impact of the emergency, will provide a net benefit. It may be that further protective actions are triggered after initial implementation of the emergency plan, by for example, a change in wind direction, rate of release, or subsequent measurement data.  Whatever the type of emergency, there is a need for highly competent trained and adaptable staff who can respond appropriately to novel and unforeseen circumstances.

### 6.3.3 Application of ERLs during response

The use of ERLs in response can be challenging, partly as the future evolution of the release is not known and partly because the calculation of averted dose is made difficult by the absence or limited ability to gather measurements and other data on which to base the estimates of averted dose. Nevertheless, the concept of averted dose is an important one and needs to be retained because of its practical benefit in weighing up benefits and detriments of urgent protective actions.

#### *6.3.3.1 Detailed emergency planning zone*

If an accident occurs at a location for which a detailed emergency plan has been developed, one or more of sheltering-in-place, evacuation or the administration of stable iodine will initially be activated by observable criteria (triggers). Once the most urgent actions have been carried out or, at least, initiated, and as more information becomes available, it is reasonable for the responsible authority/response body to reappraise the response defined in the emergency plan and consider whether it should be modified. Such reappraisal will not delay the implementation of sheltering-in-place, evacuation or administration of stable iodine which need to be taken urgently but, as detailed information becomes available, it will enable better estimates of the impact of the emergency and the need for possible further protective actions, to be made. The doses estimated to have been averted by the urgent protective actions taken can be compared with the ERLs to provide a perspective on the level of protection achieved. Similarly, the averted doses anticipated for additional urgent protective actions can be compared with the ERLs, to form 1 input to decisions on whether further actions are appropriate (another input for decision making on further protective actions is a comparison of projected dose for the first year with RLs (see Section 6.4.2)).

Generally, decisions to modify the emergency plan during the course of an emergency should only be taken if the planned response proves significantly inappropriate (for example, if doses are an order of magnitude higher or lower than planned). Again, the generic nature of the ERLs is emphasised; modifications to the response based on small (that is, factors of 2 or 3) deviations from the numerical guidance (ERLs) would be most unlikely to be warranted (provided, of course, there was no likelihood of individuals suffering deterministic effects). In particular, reducing the scale of the response, because it is subsequently thought to be an overreaction, is not advised, unless those responsible are certain that there is no further threat of escalation of the release. Such a reduction could cause confusion and would certainly undermine the confidence of the public in the ability of the authorities to manage the situation. Moreover, while a release is continuing or further releases are threatened, it is prudent to maintain in force all urgent protective actions already implemented, in case the situation worsens. This demonstrates consistent and conservative decision making. Once there is no further threat of an uncontrolled release, it is important to consider withdrawing advice to shelter-in-place since prolonged sheltering-in-place unnecessarily will reduce the overall benefit achieved (see Section 8).

#### *6.3.3.2 Outline planning zone*

If, in considering the impact of an emergency, a comparison of possible dose savings with the ERLs indicates that more widespread urgent protective actions should be taken than those indicated in the plans, then it is entirely appropriate that the planned response should be extended, or even altered altogether. For outline planning, PHE recommends that the comparison of potential dose savings should be made towards the upper end of the range indicated by the ERLs (that is, it is most unlikely that extended implementation of an urgent protective action would be justified at the lower ERL).

PHE also recognises that ERLs were primarily developed for application to situations where detailed prior planning is possible. Consequently, the balance of harms and benefits represented by the ERLs for evacuation is not necessarily appropriate for very large populations or for responses that have not been planned in detail, for example, for very low likelihood, more severe emergencies. In general, the larger the area over which urgent protective actions are thought to be required, the less likely it is that very disruptive actions, such as evacuation, will offer a net benefit. In these situations, sheltering-in-place could provide strong benefits and only limited harmful consequences. For accidents involving operating and recently operated nuclear reactors, outline planning should address the practical challenges associated with distribution of stable iodine in the area under extended sheltering.

## 6.4 Reference Levels

RLs, like ERLs, are useful as a planning tool but additionally apply in response to and recovery from a radiation emergency. The concept of a RL, as defined by ICRP (2007) and subsequently Euratom (2013) is the level of dose above which it is judged inappropriate to plan to allow exposures to occur. The RL can be taken as an indicator of the level of exposure considered as tolerable, given the prevailing circumstances. RLs are different from dose limits, which are also restrictions on individual doses but only used for planned exposure situations, that is, situations for which authorities permit an operator to introduce a radioactive source. A dose limit is a value not to be exceeded. In contrast, RLs are values to inform decisions on: urgent protective actions and longer-term protective actions. RLs are applicable to areas affected by contamination following the radiation emergency (that is, the DEPZ and outline planning zone).

### 6.4.1 Optimisation and the use of RLs

RLs are tools for supporting the practical implementation of the optimisation principle by maintaining doses ALARA/ALARP. RLs, expressed in terms of individual effective dose (mSv), are selected taking into account the distribution of individual doses as well as economic, social and environmental considerations, which will vary according to the prevailing circumstances. The objective is to ensure that when implementing protective actions the dose distribution moves towards lower levels of dose, reducing (preferably eliminating) individuals who would be receiving an exposure greater than the selected RL. Optimisation is an iterative process that will, over time, reduce inequities in the overall dose distribution. The involvement of relevant stakeholders will help to drive the optimisation process.

The use of RLs in emergency and existing exposure situations is illustrated in Figure 2. The figure shows the evolution of the distribution of individual doses with time as a result of natural processes and the implementation of protective actions. When the optimisation process starts, a proportion of the exposures are likely to be above the RL – the exact proportion depends on the value of the RL set and the severity of the emergency. The priority is to identify the most exposed people and to reduce their exposure. Over time, the number of people receiving doses above the RL will decrease and only a few people with atypical behaviours are likely to receive exposures exceeding the RL. Eventually, the dose distribution is likely to become narrow, with the mean exposure well below the RL. Exposures below the RL should also be assessed to decide whether protection is optimised or if further actions are still required. Furthermore, as the circumstances evolve, and the dose distribution changes, it may be appropriate to re-evaluate the RL and to set a lower value, to accompany the progressive improvement of the situation.

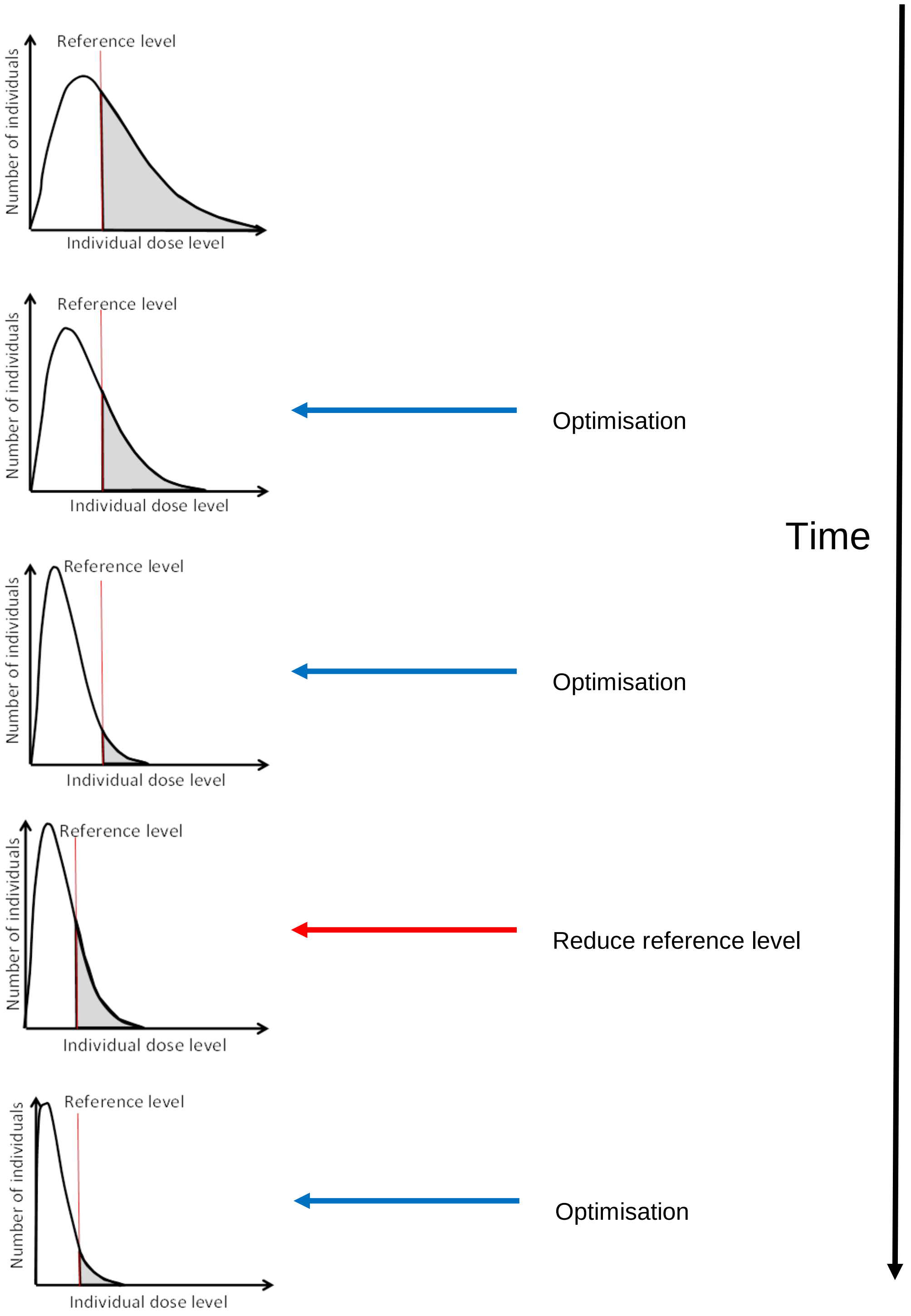

**Figure 2. Use of RLs to optimise protection. The graphs show the evolution of doses with time as a result of the step by step implementation of protection strategies and introduction of a new RL**

### 6.4.2 Application of RLs during planning

RLs should be considered during planning to ensure that protective actions keep doses to members of the public from all exposure pathways below an upper level; this may be the selected national RL or a site specific RL, if one has been set. For the early and intermediate phases (constituting an emergency exposure situation), it is appropriate to select a RL of below 100 mSv for a short period (that is, short duration, low impact releases) or up to a year (longer duration, high impact releases). This level of exposure is well below the level at which deterministic effects would be expected to occur. There may be situations where it might not be possible to keep all doses below 100 mSv, for example, low probability, high consequence accidents and for these situations proportionate actions should be taken (if they are not already) to reduce the probability or severity of these exposures. For such events, it is important to focus on the doses that can be controlled or influenced and to plan for protective actions to be implemented to reduce doses ALARA/ALARP through the optimisation of protection.

For planning purposes, residual doses in the first year are assessed for a spectrum of emergency scenarios taking into account any urgent protective actions that have been planned based on the ERLs, and any restrictions placed on marketed foodstuffs or drinking water based on MPLs and ALs. It is these residual doses that are compared to the RL. An understanding of the evolution of residual dose over time and the contribution of different exposure pathways help in assessing whether there are reasonable additional protective actions that could be applied to keep doses: (a) below the reference level and; (b) ALARA/ALARP. It also highlights the areas where prior planning by the responsible authority/body might assist transition to, and subsequent management of recovery.

For the longer-term recovery phase (constituting an existing exposure situation), RLs relate to the total residual dose estimated to be received in a year, once the emergency exposure situation is declared over. PHE considers it appropriate in planning to select a RL of 20 mSv $y^{-1}$ or below, noting that in some situations an existing exposure situation can begin during the first year following the emergency, if the release was of short duration and low impact. Furthermore, and depending on the duration of the recovery phase, it may be appropriate over time to re-evaluate and lower the RL to accompany any improvement in the radiological situation.

### 6.4.3 Application of RLs during response

Once urgent protective actions have been initiated, and as more information becomes available, it is reasonable for the responsible authority (or local response body) to reappraise the response defined in the emergency plan and consider whether it should be modified. In addition to comparing averted doses with ERLs, projected doses in the first year can be compared with RLs to give an additional perspective on the level of protection achieved. This information can be used to indicate whether urgent protective actions need to be extended beyond the DEPZ, whether evacuation of sheltered populations may be required and subsequently whether any further protective actions are necessary (including decontamination, further food restrictions, temporary relocation).

The chosen value of the RL during response will depend on the prevailing circumstances. The significance of this point is that the RL set during planning should be reassessed or even modified, if, for example, the prevailing circumstances are significantly different from those assumed for planning purposes. Early in an emergency, where the prevailing circumstances are unknown and may be changing rapidly, it is appropriate to use the RL selected during planning. However, as more information becomes available, it will be necessary to reassess the situation to determine whether a new RL should be selected. It should be noted that 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 RL.

### 6.4.4 Application of RLs during recovery

During the recovery phase, the responsible authority (or local response body) will select a RL in the range of 20 mSv $y^{-1}$or below, with a long-term objective of 1 mSv $y^{-1}$. Annual doses will decrease progressively over time due to natural processes as well as remediation and other protective actions that are taken. Eventually, the objective of a recovery strategy would be to reduce exposures to levels that are considered close or similar to situations considered as normal (ICRP, 2007). Depending on the circumstances (for example, the presence of long-lived radionuclides) this could take years or decades, during which authorities may use intermediate RLs to achieve this objective. The ability to reasonably judge the appropriateness of changing a RL will depend strongly on the quality of the understanding of the situation including contamination levels and realistic estimates of individual internal and external exposures. The evolution of a RL is a matter of choice and stakeholder views should be taken into account. A time variable RL may help to improve the situation progressively. Because individual doses of people living in contaminated areas are not strictly controllable due to their behaviour and habits, it is not possible to guarantee that in the long-term all individual doses will be kept below 1 mSv $y^{-1}$, as is the case with planned exposure situations. A small fraction of the population may receive higher exposures of the order of a few mSv $y^{-1}$, in circumstances where behaviours are not adapted due to personal choice or other factors.

## 6.5 Maximum Permitted Levels in food

At the time of publication, European Union Regulations govern the maximum permitted levels of radionuclides in marketed foods and animal feed (MPLs) that might arise following a radiation emergency that has the potential to contaminate foods in Europe above the specified levels (Council Regulation (Euratom), 2016). 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 across the EU; they do not represent a boundary between safe and unsafe levels. The MPLs are divided into four groups of radionuclides (radiostrontium, radioiodine, alpha-emitting radionuclides, and other radionuclides with relatively long half-lives) and five food categories (baby foods, dairy foods, other major foods, minor foods and liquid foods). The regulations also specify MPLs for radiocaesium in animal feed intended as a guide to the exceedance of MPLs in food obtained from these animals (although does not lessen the requirements for monitoring contamination levels in these animal products for human consumption). The MPLs that would initially apply, pending review by EU Member States in the aftermath of a radiation emergency, are set out in Table 5 for foodstuffs and Table 6 for animal feeds (radiocaesium only). Under current government policy, these MPLs will continue to apply following the withdrawal of the UK from the European Union.

As discussed in Section 5.2.5, the relationship between activity concentration of radionuclides in foods and doses to people is complex and depends particularly on the percentage of contaminated foodstuffs in the diet. PHE 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. 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 1 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. However, PHE advises that, following a very severe release, it could be justified in terms of radiological risk to relax the MPLs by up to a factor of ten, in order to avoid food shortages. The detailed advice published by NRPB (1994) on the dose implications of the MPLs and their application in the UK following a radiation emergency continues to be relevant.

**TABLE 5 Maximum Permitted Levels of radionuclides in food marketed in the EU**[a]

| | **Maximum permitted levels (Bq kg$^{-1}$)**[b] | | | | |
|---|---|---|---|---|---|
| **Radionuclide** | **Baby foods** | **Dairy produce** | **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 trans-plutonium 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[c] | 400 | 1,000 | 12,500 | 1,250 | 1,000 |

Note:

[a] COUNCIL REGULATION (Euratom) 2016/52 of 15 January 2016

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

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

**TABLE 6 Maximum Permitted Levels of $^{134}$Cs and $^{137}$Cs in contaminated feed**[a]

| **Feed for:** | **Maximum permitted levels (Bq kg$^{-1}$)** [b] |
|---|---|
| Pigs | 1,250 |
| Poultry, lambs, calves | 2,500 |
| Other | 5,000 |

Note:

[a] COUNCIL REGULATION (Euratom) 2016/52 of 15 January 2016

[b] These levels apply to feed as ready for consumption

## 6.6 Action Levels in drinking water

The EU Regulations on MPLs do not explicitly 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 in order to manage the use of water intended for human consumption. Based on this, PHE has recommended UK action levels (ALs) for radionuclide activity concentrations in drinking water, following an emergency, as set out in Table 7. PHE 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. Consumption of drinking water at the AL would result in exposures of at most a few mSv effective dose committed over 1 year. It should be noted that these ALs are more conservative than the screening OILs for drinking water published by IAEA (2011).

**TABLE 7 Recommended UK Action Levels for drinking water supplies**[a,b]

| Radionuclide | Action Levels (Bq $l^{-1}$) |
|---|---|
| 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 $^{137}Cs$[c] | 1,000 |

Notes:

[a] NRPB, 1994

[b] These Action Levels refer to all water supplies which are intended, at least in part, for drinking and food preparation purposes. See text for advice on the urgency with which contaminated drinking water supplies should be replaced.

[c] This category does not include $^{14}C$, $^{3}H$ or $^{40}K$.

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 (of up to a few weeks), this need not pose a significant radiological hazard. Thus, the immediate withdrawal of drinking water supplies is unlikely to be essential. 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 in order to maximise the dose reduction achieved. In circumstances where replacement of supplies is extremely difficult, relaxation of the ALs over the longer-term by factors of 2 or 3 may be justified but would need specific consideration of the harms and benefits according to the prevailing circumstances.

### 6.7 Optimisation of protection strategies

This section has described the various sets of radiological criteria that can be used to assist in the optimisation of protection strategies. PHE has analysed a number of postulated releases of radioactivity from a range of fixed nuclear sites and calculated the resulting potential doses to people from different exposure pathways and over various time frames. Based on this work, PHE advises that response plans, based on the separate optimisation of urgent protective actions (using the framework of ERLs and RL); longer-term recovery actions (using the framework of RLs); and food/water restrictions (using the framework of MPLs/ALs), will result in an overall protection strategy that is optimised.

## 7 Radiological impact assessments

In responding to a radiation emergency, it is important to assess doses to those in the affected area as this will inform decisions on protective actions. Initially, there will be considerable uncertainty about the situation. In order to better understand the likely health impacts, information is required on the quantity and types of radionuclides released, duration of the release, atmospheric dispersion and subsequent fate of the deposited radionuclides in the environment. Guidance from PHE, environment agencies and food standard agencies will be required to ensure appropriate radiological measurements are made. PHE advises that it is extremely important that adequate planning is undertaken for the timely acquisition and sharing of radiological measurements and for the appropriate interpretation of these measurements for the protection of public health.

Radiological impact assessments should be carried out for planning purposes as well as for response. These impact assessments may involve computer modelling based on a combination of estimated data (planning and response) and actual measurements (response). Early in the emergency, when few measurements are available, reliance will be placed mainly on data from previous studies or expert judgement. As increasing numbers of measurements become available (dose rates, activity concentrations in air and levels of deposition) these can be used to improve the earlier assessments. However, modelling and estimated data will always be required to some extent, because they allow estimation of health effects/risks, endpoints which are not directly measurable, and they provide for interpolation and extrapolation of endpoints across time and space. Since contamination can vary markedly in space, time and between people, individual measurements can only be used to inform decisions when interpreted through modelling to provide an overall understanding of the likely past, current and future impacts of exposures on people living in the affected area. The magnitude of the doses will affect decisions on temporary or permanent relocation and the implementation of decontamination strategies, once the urgent protective actions are withdrawn.

# 8 Withdrawal of sheltering-in-place and evacuation advice

In the early, uncertain phase of an emergency, the objective of the protection strategy should be to avoid deterministic effects and to keep the risk of other health consequences as low as reasonably achievable. To accomplish this there is a need to act very quickly and without much specific knowledge of releases or exposures. Consequently, sheltering-in-place and evacuation will of necessity follow procedures and processes planned in advance, and tend to be considered together. However, as their characteristics in terms of harms and benefits are very different, sheltering-in-place and evacuation may need to be considered independently of each other in any decisions on their withdrawal, as a large number of radiological and non-radiological factors need to be taken into account. There are no pre-determined criteria for initiating withdrawal which is likely to require a flexible and pragmatic approach. Key factors for consideration are listed in Table 8; they are intended to be illustrative, rather than exhaustive. The relative importance placed by decision makers on these and other factors will depend on the prevailing circumstances. In general terms, this advice should only be issued either when these protective actions have achieved their desired effect by averting doses or when their continued application will cause more harm than good in the broadest sense.

It is important to recognise that the withdrawal of urgent protective actions rarely signifies a return to normality; the exception being where evacuation and sheltering-in-place have been carried out on a precautionary basis and exposure didn’t happen, or for a transient hazard such as direct irradiation, criticality or noble gas releases. Evidence from past emergencies suggests that withdrawal of sheltering-in-place may be followed by the implementation of further protective actions: evacuation (where there is still a threat of further release); temporary relocation (to avoid doses from identified exposure pathways such as external irradiation from the deposited radionuclides and to allow some decontamination to be carried out); permanent relocation (where external doses are so high as to preclude sustainable living conditions in a reasonable time period). Similarly, withdrawal of evacuation advice may also be followed by temporary or permanent relocation depending on the levels of contamination and the longevity and availability of radionuclides in the environment.

**Table 8 Factors to consider in decisions on withdrawal of sheltering and evacuation advice**

| **Radiological Factors** |
|---|
| Official confirmation that the release has stopped and unlikely to recur |
| Monitoring data on, for example, ambient dose rates, ground deposition levels and surface contamination |
| Estimates of effective doses to adults and children living in the affected area, integrated to a range of times |
| **Non-Radiological Factors** |
| Wider health and social needs |
| The need to look after livestock |
| Availability of resources for monitoring, communication, medical services and decontamination |
| Stakeholder dialogue and opinion |
| Business activities |

## 8.1 Withdrawal of sheltering-in-place advice

The withdrawal of sheltering-in-place advice in its simplest form would be a return to normality, whereby people were able to ventilate their properties and to go outside to undertake their day to day activities without any restrictions. However, before this can happen, monitoring information is required to determine whether doses from external irradiation or inhalation of resuspended material from ground deposits are likely to be of radiological concern once sheltering is lifted. The time required to mobilise and deploy sampling and measurement teams during and after the release influences the availability of data on, for example, ambient dose rates, ground deposition levels, and surface contamination. It will be important to focus monitoring where it is likely to bring most benefit and a timeframe may need to be defined to establish priorities for monitoring. If it is not possible to be confident that the radiological situation supports the lifting of sheltering, consideration should be given to phased evacuation and temporary relocation of any groups for whom continuing sheltering-in-place may pose unacceptable or inadequately defined risks.

## 8.2 Withdrawal of evacuation advice

Advising people who have been evacuated that they are allowed to return home requires an assessment of their future doses and risks, based on measurements of environmental contamination in the evacuation zone, as well as predictions on the evolution of the radiological situation and capability to improve it. The composition of the release, the complexity of the contamination pattern and the size of the area affected will determine how rapidly assessments can be made of the future public health risks. In particular, where the major components of the contamination are alpha-emitting radionuclides, it may require some time to obtain measurement results. Monitoring data will need to be gathered from the evacuation zone, initially characterising areas where contamination is expected to be low, with a view to an early return of evacuees from these areas. The decision to return should also be informed by any other significant risks present at the time, for example, chemicals or flooding. In the longer-term (days and weeks) a much more comprehensive radiological characterisation of the whole area affected by deposition would be carried out to identify areas of higher contamination (for example where it may have rained) and to help prioritise areas that might require decontamination before any remaining evacuees are returned. Measurements should be taken for a variety of environments focussing on places where people spend their time and an assessment made of projected doses to those who would be living in the affected area.

## 8.3 Non-radiological criteria

When considering decisions on withdrawal of sheltering-in-place and evacuation, non-radiological criteria play an important role that encompass: wider health and social needs; resources for monitoring (including personal monitoring); communication strategies; medical services; stakeholder dialogue and opinion; and public reassurance. Sheltering-in-place for periods of more than a few hours can cause stress which can affect the health and wellbeing of the sheltered population. Issues such as the need to obtain medical supplies and to receive medical attention, the legitimate desire for families to be together and the need for farmers to look after livestock need to be addressed. Section 5.2.2 proposes some adaptations to overcome some of the non-radiological issues associated with sheltering-in-place for longer duration releases.

Pressure to lift the evacuation order may be alleviated by supervised re-entry into the evacuation zone for limited periods to collect essential belongings, to check the security of property or to attend to the needs of animals. However, this will require careful consideration of health and safety issues for all those involved. Living in short-term reception centres is not an ideal location and for a variety of understandable reasons, many people will wish to return home as soon as it is appropriate to do so.

Withdrawal of sheltering-in-place and evacuation is resource intensive and requires co-ordination and sourcing of monitoring and sampling teams (for timely provision of monitoring data); effective communication mechanisms; provision of temporary accommodation (if relocation of sheltered populations is required); provision of bespoke medical services; and access to decontamination technology and teams. Due to the relatively short timescales involved, the lifting of sheltering-in-place is likely to be carried out without significant involvement of stakeholders, although a mechanism for communicating with those who are sheltered is essential. Stakeholders representing local people may have been involved in the development of the emergency plan and may have had some input on selecting the key criteria for lifting of sheltering-in-place. Decisions on allowing evacuees, and those who have been temporarily relocated, home will involve a more extensive dialogue with the local community. It is important to not only provide information about the incident and its radiological impact but also to give reassurance that inhabitants would be returning to decent and sustainable living conditions, and will be given the expert support, from radiological protection experts and medical services, to address their concerns. Individuals have a basic right to decide whether to return or not. All decisions about whether to remain in or leave an affected area must be respected and supported wherever possible by the authorities, resources permitting, and strategies developed for resettlement of those who either don’t want to, or are not permitted to move back to their homes. It will be difficult to solve the dilemma as radiological protection is not the only consideration.

# 9 Transition from response to recovery

The boundary between the intermediate phase and the long-term recovery 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. It is likely that initial planning for recovery will run in parallel with the intermediate phase, although, broadly speaking, the recovery phase is likely to officially start once there is no threat of further release and the radiological situation is well characterised. Furthermore, the fundamental decision to allow inhabitants to remain in the affected areas, generally would have been made. There is also a change in management, from processes and procedures planned in advance, driven by the need to implement urgent protective actions, to more longer-term operational strategies led by the responsible authority in close collaboration with the local community. These latter actions aim to improve living conditions and reduce chronic exposures in the affected areas.

The transition to recovery requires agreement on establishing a new RL appropriate for existing exposure situations and on which to optimise protection. In general, a RL of the magnitude used in the early and intermediate phases would not be acceptable, as these exposure levels are unsustainable from social, ethical and political standpoints. The setting of a RL and decisions on recovery actions and long-term rehabilitation of living conditions in the affected areas necessitates the establishment of appropriate mechanisms for involving a wide range of stakeholders including representatives from the affected communities.

# 10 Recovery

Recovery is the process of rebuilding, restoring and rehabilitating the community following an emergency (DECC, 2015). For a radiation emergency, the focus of recovery is to develop and implement an agreed strategy for returning areas affected by the emergency to a state as close as possible to that existing before the release of radioactivity, and to return the population to a lifestyle where the event is no longer a dominant influence.

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 such as that resulting from a severe airborne release of fission products, 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. Furthermore, practical problems are likely to arise associated with the characterisation, segregation, storage (temporary and interim) and final disposal of potentially large volumes of contaminated waste for which the involvement of stakeholders will be essential.

Whilst reinstatement of pre-emergency conditions may not be practicable, much can be done when managing recovery to find a reasonable balance between maximising dose reduction and minimising the adverse consequences of intervention to enable affected communities to thrive again by the restoration of infrastructure, businesses, employment and public services. Setting priorities for recovery will inevitably involve trade-offs. Optimisation is a multi-faceted approach for balancing radiological and non-radiological risks. It has played an increasingly important role in radiation protection by taking into account the prevailing circumstances and maximising the margin of potential benefit over harm. Recovery is focussed on restoring the functionality of communities, therefore requiring an optimisation approach that is necessarily incident- and site-specific and involving the active participation of stakeholders.

Recovery is an iterative process involving a series of well-defined steps. These and some of the key elements underpinning the recovery process are presented in Figure 3. The steps start with defining the situation before moving through a series of actions to assess the impact of the incident and to identify goals and evaluate options for recovery. An optimised recovery strategy is then agreed and implemented. The process concludes with the demonstration of the successful implementation of the recovery strategy by monitoring and evaluation. Experience from the Chernobyl and Fukushima accidents has demonstrated that the involvement of local professionals and inhabitants in the development and implementation of the recovery programme is important for its acceptability and sustainability. Open channels of communication also need to be established between all interested parties so that comprehensive, coherent and easily understandable information on the recovery process can be made available from sources which people are familiar with and have easy access to.

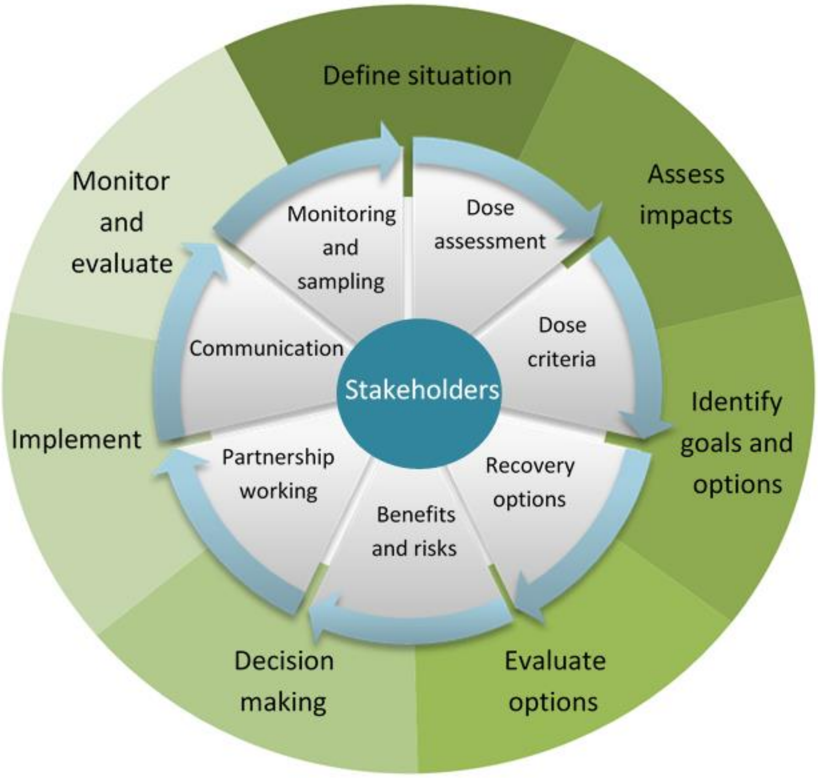

**Figure 3: The recovery process**

## 10.1 Planning for recovery

Radiation emergencies in the UK are rare, so it is important to ensure that the time, resources and effort spent on planning is effective and will make a significant difference should an emergency occur. Therefore, planning for radiation recovery needs to be: risk-based; proportionate; flexible, scalable and non-prescriptive; open to lessons learned from previous events; inclusive; and co-ordinated.

When considering risks, it is important to plan for the aspects of recovery which if not addressed in advance will cause significant risks to health and the environment should an emergency occur. For example, to ensure that infrastructure such as roads, rail, communications and utilities are restored as soon as possible to support on-going recovery activities on the ground. Also, the placing of statutory food restrictions on the marketing of crops, milk and meat during response and recovery will generate large volumes of contaminated waste requiring disposal. Therefore, it is essential that appropriate routes of disposal be identified in advance, particularly for milk which is produced daily and poses a biological hazard if stored for long periods.

It is clear that a balance needs to be struck between the resources needed to establish and maintain recovery arrangements in advance and the benefits of delivering an appropriate response when required. This can be best achieved by developing frameworks and processes for recovery, which are reviewed, updated and tested regularly.

## 10.2 Exposure pathways

The main potential pathways of exposure during the recovery phase are external irradiation from deposited radionuclides and intakes of radionuclides from ingestion of contaminated food and/or inhalation of resuspended contaminated material. Once deposited in the environment, the risk posed by the radionuclides depends upon many factors including the amounts present, their radioactive half-lives, their mobility in the environment and the amount of time people spend in their proximity. In terms of individual risk, assuming food restrictions are effective, the primary concern for beta/gamma-emitting radionuclides would be external irradiation, whereas for alpha-emitting radionuclides (for example, $^{239}$Pu) it would be inhalation of resuspended radionuclides, although for young children inadvertent ingestion could also make a significant contribution to dose. Where activities are planned that are particularly prone to raising dust such as workers carrying out some decontamination measures or for farmers or others working on the land, it would be important to consider the resuspension pathway for all types of deposited radionuclides.

### 10.2.1 Characteristics of exposure

The exposure of people living in affected areas is mainly driven by their individual behaviour, which can result in a very heterogeneous distribution of exposures. The range of individual exposures is influenced by the time spent in the contaminated areas and habits of the population, particularly the diet for people who grow their own food or for whom gathering foods from the wild constitutes an important part of their diet. Establishment of a community-based monitoring system to enable inhabitants to access comprehensive data and information to address differences in individual lifestyles affecting radiation exposure should be considered. Fostering a radiation protection culture through active involvement of residents is important for the sustainability of long-term recovery strategies.

## 10.3 Protection of the population

Protection of the population in affected areas involves gathering of information about people’s surroundings and lifestyles so that strategies can be targeted at sensitive or vulnerable groups of individuals whose doses exceed the RL. The characterisation of the radiological situation at the local level enables individuals and communities to take action and make choices about their daily routine. Some protective actions can be implemented by the authorities (see Section 4.2.3.3) but it is also important that self-help protective actions can be taken by the inhabitants themselves to improve their situation, either under their own initiative or within a framework provided by the authorities. Typical self-help protective actions consist of dietary changes (for example, reduction in consumption of foodstuffs gathered from the wild) and adaptations in personal behaviour to avoid or limit the time spent in areas known to have elevated levels of contamination. For example, providing residents with dosimeters linked to GPS that can record the dose rate at minute intervals over the period of a week, can provide reassurance regarding the dose received and an understanding of the specific locations where the highest doses were received. Similarly, provision of a local service to monitor activity concentrations in home grown food or foods gathered from the wild can provide the residents of affected areas with information on whether the items are suitable to eat. Establishment of local forums with representatives of the affected population and relevant experts will allow gathering, sharing and interpretation of information and enable an assessment to be made of the effectiveness of strategies being implemented. The key message is that appropriate self-help measures should be developed with the local population taking into account the prevailing circumstances. The examples listed above may not be justified or proportionate in some situations.

## 10.4 Evolution and withdrawal of recovery actions

Throughout the recovery phase, various natural and man-made processes will reduce public exposure to deposited radionuclides, including weathering, radioactive decay, changes in bioavailability, and remediation. Consequently, over time, remediation goals will be met and the risks posed by any residual contamination will be in the range considered tolerable by most of the affected population. At this point, a strategy for withdrawing any remaining recovery actions will be discussed and agreed with the local community.

As there is a wide range of recovery actions that can be implemented over different timescales, it will not be necessary to withdraw all actions simultaneously; an action can be withdrawn when it has achieved its purpose or if continued application would cause more harm than good in the broadest sense. For example, options to decontaminate key infrastructure might be implemented rapidly and withdrawn in a matter of days or weeks, whereas intervention in certain food production systems might be introduced rapidly and then maintained for decades.

Reducing exposures below the RL may not automatically lead to termination of the recovery strategy provided there is still room for improvement and the strategy remains optimised; in such situations, a few protective actions (such as natural attenuation and monitoring, selective grazing, processing of domestic food) may continue until exposures are reduced to similar to those encountered before the emergency. Even then, it is unlikely that activity concentrations in the environment will return to pre-emergency levels.

Throughout the recovery phase, it will be important for the local community to be provided with maps showing the levels and extent of the contamination and given easily understandable information on the impacts of any residual contamination on health and what can be done to reduce exposures. Following recommendations on the withdrawal of recovery actions, periodic monitoring surveys should continue to provide the necessary reassurance to members of the public and enable actions to be taken if necessary.

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# Appendix A Derivation of Emergency Reference Levels for sheltering-in-place and evacuation

In this appendix, the factors which influence the determination of Emergency Reference Levels (ERLs) are discussed in detail. The text is based on the information presented in NRPB (1990). Using these factors, the upper and lower ERLs for sheltering-in-place and evacuation are determined.

## A1 Factors influencing decisions on sheltering-in-place and evacuation

Factors that could potentially influence decisions on sheltering-in-place and evacuation can be grouped under three categories of health, monetary costs and socio-psychological impact:

- Health
    - individual and collective risks from exposure to radiation
    - individual and collective physical risks associated with the protective actions
    - risks incurred by those implementing the protective actions
- Monetary costs
- Socio-psychological impact.
    - reassurance provide by the protective actions
    - anxiety caused by the need to introduce the protective actions
    - individual disruption
    - societal disruption

Some of these factors bring benefits and tend to reduce the ERL at which the protective action is introduced, whilst others bring harms and which would tend to increase the ERL. The appropriate ERL for a given protective action in a given situation is determined therefore by a comparison of balancing these factors. Benefits include averted individual and collective risks from exposure to radiation and reassurance provided by the protective action. Harms include individual and collective physical risk, monetary costs, individual and societal disruption, anxiety about the protective action and risks to those implementing the protective action. The relative importance of individual and collective risks is discussed below.

### A1.1 Individual and collective risks

The relative importance of individual and collective risk depends primarily on the level of individual harm or benefit incurred by introducing a protective action. Generally, at high levels of individual harm or benefit, it is the individual related factors which most strongly influence any decision on protective actions. Conversely, where individual levels of harm or benefit are very low, a decision on protective actions is likely to be dominated by consideration of the collective harms and benefits.

The magnitude of any collective harm or benefit is dependent on the population group considered. Many protective actions affect a larger number of people than those directly subject to the protective action. For example, a decision to evacuate has implications, not only for the evacuees, but also for all those required to manage the evacuation, for those providing food, accommodation and medical attention for the evacuees, and for all those who had planned to visit the area or make contact with individuals within it. If consideration were restricted to the collective harm experienced by the evacuated population only, then the total collective harm caused by the protective action could be significantly underestimated. Therefore, the value of an ERL determined by considering only the population group undergoing the protective action could be different in value from an ERL determined by considering the whole of society.

### A1.2 Health risks

The health risks resulting from exposure to radiation range from very debilitating injuries (including death in extreme circumstances) to treatable cancers, and also include damage to the developing foetus and hereditary effects. There is also a wide time variation in the incidence of these injuries, ranging from weeks to decades for the individual exposed, and occurring over generations in the case of hereditary defects. In principle, all these aspects should be taken into account when assessing health risk averted by taking the protective action, particularly when determining an ERL to optimise protection.

### A1.3 Physical risks

Generally, in the UK, the physical risks associated with protective actions are small. Nevertheless, it is possible to postulate scenarios where the individual risks might become a dominant factor in determining the ERL for which protection is optimised. For example, in very hot weather, prolonged sheltering-in-place of the young or elderly might pose health problems, while for nursing home residents or during extremely bad weather conditions, evacuation might endanger lives. Except for vulnerable groups, the individual physical risks involved in urgent protective actions are generally small, whilst the collective risks may not be. The magnitude of the collective risk is at least partly, dependent on the number of people affected by the protective action, while the magnitude of the individual risk is largely unaffected by this. This means that as the ERL for the protective action decreases (resulting in an increased number of people being involved), the collective physical risk increases proportionately. At some low level of individual risk, the collective physical risk may become a major factor in deciding on whether to implement sheltering-in-place or evacuation.

### A1.4 Individual disruption, reassurance and anxiety

The three factors of individual disruption, reassurance and anxiety are very difficult to quantify, and they may well be very different between individuals. The level of disruption experienced by individuals will be related to some extent to their lifestyle, health and intended activities during the period when the protective action is in place. For example, the advice to shelter for a few hours, given to a mother of several young children on a wet and cold winter evening my cause her negligible disruption. The same advice to that mother on a very hot summer’s day might cause her significant disruption, particularly if her home was small. Evacuation will always be disruptive.

The reassurance afforded to an individual by the introduction of either sheltering-in-place or evacuation depends on their perception of the risk to which they are exposed and the extent to which the protective action is seen as protective against the risk. An individual's perception of risk will be determined by a complex set of interacting factors, including the general nature of the risk (ionising radiation) and the degree to which the individual can quantify the risk and make a decision concerning the need for protective actions. In a situation involving potential accidental exposure to radiation, an individual has little chance for independently assessing the risk and generally perceives that risk to be relatively high. The individual is therefore unlikely to be reassured by advice that protective actions may not be required. However, if evacuation is advised, then the level of reassurance afforded to most individuals will be substantial (although personal disruption will also be high). A complicating factor here is that the reassurance afforded by implementing a protective action will also be strongly influenced by the level of control and competence the authorities are perceived to have in the management of the emergency.

Finally, anxiety will be experienced by individuals as a result of knowing that the protective action is considered necessary. It is likely that the anxiety will be strongly influenced by the level of risk that would exist in other circumstances where either sheltering-in-place or evacuation would be implemented. For example, evacuations are often carried out for severe flooding and less frequently for hurricanes and bomb scares. Sheltering-in-place is often recommended to avoid acute symptoms following a release of toxic chemicals. Generally, it is only for nuclear accidents that plans are made for sheltering-in-place and evacuation to be implemented to protect against stochastic health effects. Therefore, it is likely that if urgent protective actions are taken after a nuclear emergency, individuals will overestimate their personal health risk.

### A1.5 Monetary cost

Where the individual health risks are high, the monetary cost of introducing sheltering-in-place and evacuation will not be a major factor in decisions on ERLs. However, for many situations, monetary cost can form a significant contribution to the harm introduced by these protective actions. Moreover, this cost is rarely borne solely by those benefiting from the protective action, nor is it equitably shared throughout the population. Evacuation involves significant monetary cost irrespective of the number of people evacuated. This is because a decision to evacuate people requires organisation and mobilisation of a number of supporting services: additional police (both to organise the evacuation and to ensure security of property in the evacuated area), transport, accommodation, food supplies, monitoring services and general administration. The monetary cost is less significant for sheltering-in-place, although both will require the mobilisation of some support services. Therefore, at ERLs of dose which do not represent a significant health risk, it is reasonable that monetary cost has more weight in a decision on whether to implement sheltering-in-place and evacuation.

### A1.6 Societal disruption

Societal disruption is the collective disturbance to the normal or expected lifestyles of those affected by the protective action. As with monetary cost, it is likely to be experienced by a larger population group than those benefiting from the introduction of a protective action. It will also increase rapidly with decreasing ERLs, particularly for accident locations near major towns. As with monetary cost, societal disruption is likely to become a significant factor in determining the value of ERLs at lower levels of dose.

### A1.7 Risks incurred by those implementing the sheltering-in-place and evacuation

Risks incurred by those implementing sheltering-in-place and evacuation encompass individual and collective risks to workers as a result of exposure to radiation and also any physical risks involved during implementation. Whilst the individual dose received by implementers is unlikely to be a major consideration in the specification of ERLs, the collective dose may be. The ERLs used for implementing a protective action should clearly take account of the collective exposure expected in the workforce asked to implement it. For example, it would rarely be justified to ask emergency services personnel to experience a greater collective exposure in the course of introducing a protective action than the collective dose averted by it.

Risks to implementers include physical risks as well as radiation risks. Some emergency situations may be hazardous for workers, for example if weather conditions are bad. Therefore, it is important to take account of the magnitude of the physical risks faced by individuals implementing protective actions. Where this is significant, then the expected individual risk saving in the exposed population should be at least commensurate with it, or else the protective action will not be justified.

## A2 Derivation of ERLs for sheltering-in-place and evacuation

### A2.1 Derivation of ERLs for sheltering-in-place

*Lower ERL*

The lower ERL for sheltering-in-place is determined assuming favourable circumstances. Such circumstances are assumed to be those where: few people (up to a few thousand) would be involved in sheltering; the dose saving could be achieved over a short period; the time of day and year was such that the people asked to shelter would have intended to be indoors during that period anyway; and the resources (including monetary costs) and worker risks required to implement sheltering were minimal. Given this scenario, most of the factors discussed above as potentially influencing the ERL would be unimportant. Only three significant factors remain: the benefit of the individual averted health risk, the benefit of reassuring the public by recommending sheltering-in-place and the anxiety which the public would experience because such a protective action was deemed necessary. Of these, the benefit of the health risk averted is directly related to the level of dose averted, while the other two factors are independent of this dose level. The lowest level of dose at which sheltering-in-place would be justified is then the dose at which the weighted sum of the two positive factors (risk averted and reassurance) equals the weighted value of the negative factor (anxiety). The weights represent the relative degree of importance attached to each factor. If the values of both reassurance and anxiety associated with sheltering-in-place are assumed to be independent of the ERL, then their weighted values may be combined to give a net value of harm. The lower ERL is then the weighted averted dose which corresponds to this level of harm.

The ERLs are generic and it is not possible to assign precise quantitative values to each of the three factors. However, it is likely that the value of anxiety associated with sheltering-in-place would be equivalent to a significant risk of serious harm. The value of reassurance is likely to be related to the level of perceived risk and it is likely to be somewhat lower than the value of the anxiety associated with sheltering, since sheltering leaves people in a situation involving potential exposure to radiation. Most certainly it will not be greater. Therefore, the net equivalent value of these factors is likely to be less than the value of anxiety of sheltering-in-place alone, but significantly greater than zero. The level of dose averted which corresponds to this level of harm is judged to be fairly low, but significantly greater than the doses received in normal living (that is, a dose of a few millisieverts).

*Upper ERL*

The upper ERL is derived assuming conditions which are unfavourable for sheltering-in-place. Here the number of people involved is large and the duration of the sheltering-in-place is long (that is 1 or 2 days), so societal disruption is large and the monetary cost may no longer be insignificant. Individual disruption will increase with the duration of sheltering-in-place but with the exception of vulnerable groups who may have urgent medical needs, most people would not find the requirement to shelter for 1 or 2 days severely disruptive. Therefore, it is judged that it is the societal factors which will dominate the determination of the ERL – the upper ERL for sheltering-in-place will be determined by balancing social disruption and monetary cost against individual risk averted.

The negative factors of monetary cost and social disruption are likely to have a combined value which is significantly higher than the net value of anxiety of sheltering-in-place and reassurance discussed for the determination of the lower ERL. It is judged that an appropriate increase on the level of dose averted, compared with the lower ERL, is about a factor of ten. Therefore, the upper ERL for sheltering-in-place is determined to be a few tens of millisieverts.

### A2.2 Derivation of ERLs for evacuation

*Lower ERL*

The derivation of the lower ERL for evacuation is probably the most complex because nearly all of the factors identified have an influence on the resulting level. Bearing in mind that the lower ERL is derived assuming conditions favourable for evacuation, the physical risks are assumed to be of limited significance and social disruption is assumed to be less significant than individual disruption (as the number of people involved is small). Although it can be assumed that the monetary costs are only those associated with the evacuation of a small number of people, these may not be trivial (see Section A1.5). Thus, monetary costs may still have a significant influence on the determination of the ERL. The significance of anxiety about evacuation and individual disruption will be essentially independent of the ERL. Reassurance is clearly another input, and it is likely to be a higher value than the reassurance provided by sheltering-in-place (because people are removed from the hazardous situation). Assuming favourable conditions, doses to those implementing the evacuation should be kept within dose limits and the number of workers involved will be relatively small. Therefore, the risks to workers involved in implementing the evacuation will not form an important factor in determining the lower ERL.

The lower ERL will therefore be determined by the appropriate balancing of the positive factors of individual risk averted and reassurance against the negative factors of monetary cost, individual disruption and anxiety about evacuation. Anxiety and reassurance can be taken to be of a similar magnitude and so offset each other. The balance can thus be reduced to one between individual risk averted, monetary cost and individual disruption. This may be compared with the balance determined for the upper ERL for sheltering-in-place, between dose averted, monetary cost and social disruption. Depending on the exact circumstances, either individual or social disruption may be afforded the greater value. Since the ERLs are generic values, it seems reasonable that the value of the lower ERL for evacuation should be the same as the upper ERL for sheltering-in-place, that ism a few tens of millisieverts.

*Upper ERL*

Evacuation under unfavourable circumstances could result in very significant levels of disruption, worker risks and for some members of the public, physical risks, so the upper ERL for evacuation must represent a saving of very significant radiation risks. In this context, the level of dose averted which is very significant is of the order of a few hundred millisieverts, whole body exposure.

## A3 References

NRPB (1990). Emergency Reference Levels of dose for early countermeasures to protect the public. Recommendations for the practical application of the Board's statement. Doc NRPB, 1, (4) 5-43 Available at: https://www.gov.uk/government/publications/radiation-emergency-reference-levels

# Appendix B Derivation of ERLs for the administration of stable iodine

## B1 Original derivation of ERLs for stable iodine administration

*Lower ERL*

The health risks associated with the administration of the recommended dosage of stable iodine are very small for most people (see below). This is interpreted here to mean that the risks are not great enough to influence significantly the decision on the value of the lower ERL. Therefore, the important factors for determining the lower ERL will be very similar to those for sheltering-in-place, namely dose averted, reassurance and anxiety from taking stable iodine. However, timely administration of stable iodine can avert practically all of the dose from inhaled radioiodine, so it is judged that the anxiety associated with the introduction of this protective action is completely offset by the reassurance provided. Thus, the health risk averted by the lower ERL for the administration of stable iodine should be slightly lower than that averted by the lower ERL for sheltering-in-place to reflect the higher reassurance. Accounting for susceptibility and lethality, the tissue weighted contribution of thyroid exposure to whole body risk is approximately 4% (ICRP, 2007). Noting the consequence of comparing whole body and inhalation doses; if the weighted risk at the lower ERL for administration of stable iodine is to be broadly similar to the whole-body risk received at the lower ERL for sheltering-in-place, the lower ERL for stable iodine should be at most a few tens of mSv equivalent dose to the thyroid.

*Upper ERL*

The main factors which are judged to influence the value of the upper ERL are averted individual risk, monetary cost, social disruption and reassurance. Individual disruption is not increased as the extent of the administration of stable iodine increases, and any anxiety introduced is judged to be offset by the reassurance provided. With the addition of reassurance, these are the same factors as those determining the upper ERL for sheltering-in-place. Therefore, on the grounds of the marginally greater but more specific reassurance offered by stable iodine is in comparison to sheltering-in-place but the greater difficulty likely in delivering it, the risk averted by the administration of stable iodine at the upper ERL can be slightly greater than that required of the upper ERL for sheltering-in-place. Thus, applying the argument used previously to gauge the threshold for the administration of stable iodine at the lower ERL implies that the upper ERL should be of the order of a few hundred mSv equivalent dose to the thyroid. However, new evidence described below, on both cancer risk and the risk from taking stable iodine (since the issuing of guidance on ERLs in the 1990’s) has resulted in refinement of the ERL values for stable iodine administration.

## B2 Review of epidemiological evidence

The applicability of previously recommended ERLs for the administration of stable iodine (NRPB, 1990) was reviewed in light of the latest available epidemiological evidence on (a) thyroid cancer risk for children from exposure to radioiodine and (b) adverse medical effects from taking stable iodine.

## B2.1 The evidence on cancer risk

The Advisory Group on Ionising Radiation (AGIR, 2011) reviewed the available information on the risks of solid cancers following radiation exposure including the risk of thyroid cancer. The AGIR report used a more recent follow-up of the bomb survivor data (Preston et al, 2007) to estimate the absolute lifetime risk of radiation-induced thyroid cancer from exposure at a particular age, based on the variation in the background lifetime incidence risk with age, of thyroid cancer to males and females in the UK. An order of magnitude estimate of thyroid cancer incidence risk for children under 15 years was 1 $10^{-2}$ $Sv^{-1}$. Furthermore, the risk to the thyroid was estimated to be higher at younger ages with, for example, the risk to children exposed under the age of 5 was approximately 1.6 $10^{-2}$ $Sv^{-1}$. These new data can be compared to the lifetime incidence risk of thyroid cancer of 5 $10^{-3}$ $Sv^{-1}$ proposed by Stather et al (1988) that were used as the basis for earlier NRPB advice (NRPB, 1990). The comparison indicates that the estimated mean risk for children under 15 years of age is elevated by a factor of 2 and for younger children by a factor of 3 over the risk originally proposed by Stather et al (1988). These findings indicate that the absolute risk of thyroid cancer in young children is higher than understood at the time of the 1990 recommendations by NRPB.

## B2.2 The evidence on the risk of stable iodine

Spallek et al (2012) undertook a systematic review of the available information on the adverse medical effects of administering stable iodine. This concluded that people with normal thyroid function will not have severe adverse reactions even when comparatively high doses of stable iodine are given; groups such as neonates, the elderly and those with thyroid dysfunction are at greater risk of adverse reactions.

An analysis of the consequences arising from the very large numbers of people who took stable iodine in Poland after the Chernobyl accident was undertaken by Nauman and Wolff (1993). A total of 10.5 million doses of potassium iodide solution were given to children and 7 million doses were given to adults with the amount per dose calibrated by age for newborns, children 5 years of age or less and all others. Among the 34,491 participants of a subsequent population-based survey by Nauman and Wolff (1993) very few adverse effects were noted. In particular, no differences in thyroid function were found between children receiving stable iodine and those that didn’t. Similarly, no differences were seen in the thyroid function of adults examined in 1989 after having received doses of stable iodine in 1986 and a comparison group that had not received treatment. Some extra-thyroidal adverse effects were observed including headache, abdominal pain, diarrhoea, vomiting, dyspnoea and eczema. However, the authors postulated that some of the small number of effects observed were exacerbated by the mode of delivery (as a liquid) and would not have been as prevalent had tablets been available. In summary, Nauman and Wolff (1993) concluded that 0.2% of the population studied had medically significant adverse effects. However, among these, only two severe adverse reactions were seen, both in adults with known iodine allergy. This quantification of the risk of adverse effects from large doses of stable iodine was not available when NRPB (1990) ERL values were derived.

### B2.3 Risk summary for administration of stable iodine

The Life Span Study (Preston et al, 2007) estimates an increased mean thyroid cancer risk, possibly by up to a factor of 3, compared with the earlier work of Stather et al (1988). Furthermore, the epidemiological findings reported in 1993 and more recently indicate that the risks of adverse health effects from administration of stable iodine are lower than assumed when the original ERL advice was produced (NRPB, 1990). Therefore, if all other factors relevant to planning for this protective action remain unchanged, it would be appropriate to consider the introduction of stable iodine at lower levels of averted dose.

### B2.4 The provision of guidance

PHE advocates the development of appropriate plans for the use of stable iodine as part of an emergency response tailored to the needs of particular sites and circumstances. The use of lower and upper ERL values support this approach by providing a refinement to the single generic intervention level of the international basic safety standards (IAEA, 2014). This latter quantity is designed to be a starting point in the planning process and for specific local intervention or trigger levels to be optimised to take into account practical, operational, social and economic factors. The specification of a lower and upper ERL in the UK emphasises the importance of this optimisation within a framework of practical and radiological constraints likely to be generally acceptable. The evidence from the review of thyroid cancer risk from exposure to radioiodine and on risk from the administration of stable iodine suggests it would be appropriate to consider the introduction of stable iodine at lower levels of averted dose than previously considered. However, changes to well established ERLs are likely to impact the wider costs and benefits of introducing a protective action. These wider impacts are discussed below in the context of possible reductions to the lower and upper ERLs separately.

## B3 Recommendations for the revision of ERLs for administration of stable iodine

#### *B3.1.1 Lower ERL for administration of stable iodine*

The derivation of the lower ERL is based on an assessment of the risks and benefits of implementing protective actions when the risks from the protective action and its implementation are both comparatively low. From a practical perspective, a reduction in the numerical value of the lower ERL will result in a substantial increase in the planned extent and complexity of tablet distribution, particularly for sites located near large population centres. At the very least, this will require purchase and maintenance of larger stocks of stable iodine tablets and there will be an increased administrative burden in ensuring distributed tablets are maintained within their legal shelf lives and that those receiving them can continue to locate them. Currently, emergency plans require stable iodine tablets to be either pre-distributed within the whole of the DEPZ or distributed 'on-the-day' following a triggering event to the households, businesses and schools affected. Where ‘on the day’ distribution is planned, a much larger number of people will need to be engaged in implementing the distribution than at present. This will not only have cost implications, but is likely to result in an increased exposure to those distributing the tables in the dispersing plume and the balance in health benefits to the public relative to the increase in health costs to those implementing the protective action must be taken into account.

As stated earlier, the administration of stable iodine is not a standalone protective action and it should be accompanied by either sheltering-in-place or evacuation. A reduction in the lower ERL for stable iodine would therefore not only increase the size of the area for tablet distribution as described above, but also increase the area subjected to sheltering-in-place. An increase in the area under shelter is likely to disrupt the lives of more people and have a greater societal impact; in rural areas, consideration would have to be given to minimising distress to livestock, whilst in urban areas, the impact on infrastructure would have to be taken into account.

The above discussion indicates that a relatively small change to the lower ERL will result in significant changes to wider factors, such as cost, disruption, anxiety. On balance, PHE judges that the anticipated benefits of such a change do not outweigh the increased harms. PHE therefore recommends that no change should be made to the current value of the lower ERL for the administration of stable iodine in that, it should remain at 30 mSv averted thyroid dose. Implicit in this recommendation is that advice to shelter or evacuate will also be given when stable iodine is advised. In addition, it is recommended that all relevant nuclear sites plan for the administration of stable iodine at the lower ERL, and that priority is afforded to ensure provision of tablets to neonates, infants, children, adolescents to 18 years and pregnant and lactating women. This position is simpler than that adopted in many other European counties, which apply age-stratified criteria with ERL values between 10 mSv and 50 mSv for children and higher values for adults (European Commission, 2010).

### B3.2 Upper ERL for administration of stable iodine

Application of the upper ERL should only be considered in the event of an emergency where conditions are unfavourable and lead to comparatively high risks from implementation, such as extreme weather limiting the ability to distribute tablets or the arrival of a cloud of radioactivity from a remote location into an area without pre-distributed tablets. However, as noted above, every effort should be made to ensure that stable iodine can be provided for neonates, infants, children, adolescents to 18 years and pregnant and lactating women at the lower ERL notwithstanding the prevailing circumstances. To emphasise this point, noting that only limited side effects arose following the large-scale use of stable iodine, and to allow for the estimated factor of 3 increase in the mean risk used to guide the setting of ERL values it is appropriate to consider a reduction in the upper ERL. A lowering of the upper ERL, whilst maintaining the current value of the lower ERL, represents a narrowing of the range of averted dose, emphasising the importance of the radiological risk to be avoided.

PHE recommends a reduction in the upper ERL from 300 mSv to 100 mSv in recognition of the more substantial evidence now available of the benefits of administration of stable iodine in conjunction with reduced evidence of potential harm from taking it. On the assumption that all planning for distribution within the DEPZ is based on the lower ERL, this still provides some flexibility for provision of stable iodine following an emergency, in circumstances where a much wider population is potentially exposed, whilst ensuring that the potential impact on health from intake of radioiodine are fully recognised. Implicit in this proposal is that advice to use stable iodine continues to be supplemented with advice to shelter or evacuate. As noted above, the upper ERL represents the likely upper bound in the practical and operational optimisation of the protective action. It should be noted that since the IAEA generic criterion (IAEA, 2014) is 50 mSv projected dose (thyroid), reducing the upper ERL maintains the approximate relationship between the two[†††]. Reducing the upper ERL to 100 mSv also matches the highest single criterion (applicable to all ages) reported in the European Commission survey (2010).

### B3.3 Summary

For planning and response to radiation emergencies involving releases of radioiodine, a lower ERL of 30 mSv averted thyroid dose and an upper ERL of 100 mSv averted thyroid dose are recommended. The reduction in the upper ERL whilst retaining the current value of the lower ERL is justified on the basis of known practical constraints. It is recommended that the advice to take stable iodine tablets should be accompanied by advice either to shelter-in-place or to evacuate. Furthermore, it is recommended that all relevant nuclear sites plan for the implementation of stable iodine at the lower ERL and that priority is afforded to ensure that administration of stable iodine at the lower ERL will be available to neonates, infants, children, adolescents to 18 years and pregnant and lactating women. The range in ERLs proposed are consistent with those used in other European countries (10 - 100 mSv thyroid dose) and bound the single criterion of 50 mSv projected dose that was adopted by the IAEA (IAEA, 2014).

## B4 References

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[†††] Previously, the upper ERL was a factor of 3 more than the (former) IAEA generic criterion of 100 mSv projected dose; if reduced, it would be a factor of 2 more than the current IAEA value of 50 mSv projected dose.