Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Report

# Protective Actions in Nuclear or Radiological Emergencies - Planning Basis for Events in Emergency Preparedness Category IV

## 2020:15e

**Author:** Peder Kock, Jan Johansson, Jonas Boson, Simon Karlsson, Anna Maria Blixt Buhr, Caroline Falkengren, Leif Granholm
**Date:** April 2023
**Report number:** 2020:15e
**ISSN:** 2000-0456
**Available at www.ssm.se**

Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Author: Peder Kock, Jan Johansson, Jonas Boson, Simon Karlsson, Anna Maria Blixt Buhr, Caroline Falkengren, Leif Granholm

# 2020:15e

# Protective Actions in Nuclear or Radiological Emergencies - Planning Basis for Events in Emergency Preparedness Category IV

**Date:** April 2023
**Report number:** 2020:15e
**ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

# About the report

In this report, the Swedish Radiation Safety Authority (SSM) presents planning basis for protective actions in the event of nuclear or radiological emergencies in connection with activities and acts in emergency preparedness category IV. Activities and acts encompass events in activities with ionizing radiation that are not conducted in a specifically defined location as well as antagonistic or unintentional acts with radiation sources. To obtain an idea of what can happen and what consequences there may be for the society-at-large, the report begins with a chapter discussing how activities, acts and sources are categorised according to potential consequences. The report then describes the basics of radiation protection and what protective actions can be taken to protect the public and workers. The final chapter of the report deals with the termination of protective actions and the emergency. In an appendix to the report, there is a small glossary to facilitate understanding by readers who are not familiar with the terminology used in radiation protection.

A large number of parties need to plan in order to be able to deal with nuclear or radiological emergencies related to activities and acts in emergency preparedness category IV. The report is intended for organisations that have a responsibility to manage such emergencies. This refers for example to the public authorities responsible for civil protection and emergency services, healthcare, and public order and safety, as well as public authorities with coordination responsibilities in civil emergency preparedness.

The report is intended to be used as a planning basis for nuclear or radiological emergencies in connection with activities and acts in emergency preparedness category IV. Some elements can also be a starting point in the practical application of public protective actions and for the protection of workers against radiation hazards. The report describes the principles and concepts used in radiation protection during nuclear or radiological emergencies, and how they can be used in emergency response planning. Dose criteria and operational intervention levels for urgent and early protective actions that may need to be implemented to protect the public are described together with practical advice on protective actions for workers. To illustrate how radiological protection may be used in practice, three scenarios are presented where potential consequences and needs for protective actions are analysed.

This report builds on common positions concerning radiation protection during nuclear or radiological emergencies in the Nordic region via “The Nordic Flag Book” [1], but is limited to activities and acts in emergency preparedness category IV. This report therefore supplements the Review of Swedish emergency planning zones and distances developed by SSM, the Swedish Civil Contingencies Agency (MSB) and the relevant County Administrative Boards for events at facilities in emergency preparedness categories I, II and III [2].

The report has been produced as a joint project in collaboration with MSB and the Swedish National Board of Health and Welfare. A number of public authorities have been consulted and these are listed in Appendix 2. SSM, MSB and the Swedish National Board of Health and Welfare intend to jointly further develop practical planning support for responsible parties based on this report and other existing documentation.

# Table of Contents

# 1. Potential consequences

## 1.1. Categorisation of activities and acts

In the overall[1] safety requirements of preparedness and response for a nuclear or radiological emergency, the International Atomic Energy Agency (IAEA) states that events that may lead to nuclear or radiological emergencies be identified and analysed [3]. In order to fulfil the IAEA requirements, the Swedish Radiation Safety Authority (SSM) has analysed the risks of emergencies involving radioactive substances and classified activities and acts involving ionising radiation into four emergency preparedness categories. The emergency preparedness category is determined based on the potential consequences in the event of a nuclear or radiological emergency. Emergency preparedness category I refers to activities associated with the greatest potential consequences. The more extensive the consequences of an accident, the higher the demands on the emergency preparedness in society. Classification into emergency preparedness categories is done in accordance with SSM's regulations [4] and also takes into account the need for on-site urgent protective actions.

In Sweden, only nuclear power plants that are in operation are classified as belonging to emergency preparedness category I. Three facilities are classified as belonging to emergency preparedness category II: The central interim storage facility for spent nuclear fuel (Clab) near Oskarshamn, the fuel fabrication plant of Westinghouse Electric Sweden AB in Västerås (WSE), and the European Spallation Source (ESS) in Lund. Facilities classified as belonging to emergency preparedness category III are the decommissioned nuclear power plant in Barsebäck, which is in the process of being dismantled, as well as some facilities at the Studsvik site and at Chalmers University of Technology. Other facilities with sources of radiation in healthcare, industry and research may also be classified as belonging to emergency preparedness category III.

In its risk and vulnerability analysis [5], SSM has assessed the consequences of postulated events based on emergency preparedness category classification. The potential consequences are summarised below in a box under each category. ESS will begin routine operation in 2025 and the potential consequences of an accident at ESS are therefore not reported in the risk and vulnerability analysis. The four emergency preparedness categories are:

- **Emergency preparedness category I.** Activities involving ionising radiation where a nuclear or radiological emergency may occur which causes people to be exposed to high *doses*[2] off-site. The doses warrant taking precautionary urgent *protective actions*, urgent protective actions, early protective actions and other response actions to avoid or minimise s*evere deterministic effects* and to reduce the risk of *stochastic effects*.

| |
|---|
| A nuclear emergency can lead to catastrophic national consequences. |

[1] IAEA, General Safety Requirements (GSR Part 7) – Preparedness and Response for a Nuclear or Radiological Emergency.
[2] Concepts or terms that are italicised the first time they appear are explained in the glossary in Appendix 1.

- **Emergency preparedness category II.** Activities involving ionising radiation where there may be a nuclear or radiological emergency which causes individuals to be exposed to doses off-site. The doses warrant taking urgent protective actions, early protective actions and other response actions to avoid *deterministic effects* and to reduce the risk of stochastic effects. However, the nuclear or radiological emergency cannot give rise to severe deterministic effects off-site.

> Nuclear or radiological emergencies at facilities in emergency preparedness category II can lead to serious consequences at the local level (WSE) to regional level (Clab).

- **Emergency preparedness category III.** Activities involving ionising radiation where a nuclear or radiological emergency may arise that warrant protective actions or other response actions on-site to avoid deterministic effects, including severe ones, and to reduce the risk of stochastic effects. However, the nuclear or radiological emergency does not warrant urgent or early protective actions off-site.

> Nuclear or radiological emergencies at facilities in emergency preparedness category III can give rise to very limited consequences outside the area of the facility.

- **Emergency preparedness category IV.** Activities and acts that can give rise to a nuclear or radiological emergency at an unforeseen location warranting protective actions or other response actions.

> In the risk and vulnerability analysis, SSM has taken into account the transport of strong sources, antagonistic acts with strong sources, the deliberate dispersion of radioactive materials, nuclear-powered vessels, floating nuclear power plants, orphan sources and the accidental dispersion of material contaminated with radioactive material in emergency preparedness category IV. Activities and acts in emergency preparedness category IV can give rise to limited to severe consequences, at the local to regional level.

This report can be used as a planning basis for protective actions for the public and workers in the context of nuclear or radiological emergencies arising from *events in emergency preparedness category IV*, regardless of what causes the emergency. The term "events in emergency preparedness category IV" encompasses all activities and acts, described in the box above under emergency preparedness category IV. The meaning is consistent with IAEA's definition [3].

For facilities in emergency preparedness category I and II, emergency planning vis-à-vis the public is available in the Review of Swedish emergency planning zones and distances [2]. For facilities in emergency preparedness category III, no specific planning is needed for urgent or early protective actions for the public outside the facility. There are no foreign facilities in emergency preparedness categories I or II for which the emergency planning zones extend into Sweden. However, for foreign nuclear emergencies at greater distances, the analysis in the Review of Swedish emergency planning zones and distances [2] can be used as a planning basis regarding the possible impact on Swedish territory. The analysis refers to events at Swedish nuclear power plants, but the results for greater distances are also applicable for emergencies at foreign nuclear power plants.

## 1.2. Categorisation of radioactive sources

The IAEA has calculated potential doses from different radioactive substances for two main types of scenarios and based on these has calculated D-values[3] for different radioactive materials [6]. The D-value of a given radioactive material corresponds to a level of activity where the radioactive source can cause severe deterministic effects – in the worst case fatal or life-threatening injuries – if handled incorrectly. The IAEA has considered two main types of scenarios:

- **Exposure from an unshielded source.** In these scenarios, someone carries a source in their hand for an hour, in their pocket for ten hours, or is in the same room as the source for days to weeks. Based on these scenarios, a $D_1$ value is calculated.
- **Dispersion of radioactive material.** In these scenarios, the radioactive material is dispersed by fire, explosion, or human action. The dispersion leads to an external exposure of a person and internal exposure from inhalation or ingestion, as well as contamination from the radioactive material, depending upon the scenario. Based on these scenarios, a $D_2$ value is calculated.

The D value of a given radioactive material is then selected as the lowest of the $D_1$ and $D_2$ values.

This report uses the concept of *potentially dangerous source* for radioactive sources that could possibly cause significant or widespread harm to individuals or the community in general if handled improperly. How these sources are defined is described in the box below. Even sources with lower activity than are considered potentially dangerous sources could also cause harm if handled improperly. However, a risk-based approach should be used in emergency planning. This means that more extensive planning is needed for sources with the potential to cause severe harm. Here, the concept of potentially dangerous sources can present a guide in the form of a lower limit. The minimum activity levels for some radioactive materials commonly used in industry and healthcare, corresponding to potentially dangerous sources, are set out in Table 1.

**Potentially dangerous sources**

By calculating the ratio of the activity A of a radiation source to the D value, an A/D value is obtained which can be used to categorise the source by hazard. For the purpose of this report, the term "potentially dangerous source" means a category 1-4 source in accordance with SSM regulations [4], which includes sources with A/D values ≥ 0.01. This means that a potentially dangerous source that is handled improperly can cause harm. Potential harm depends on the activity of the source and how it is handled and can include anything from a small increased risk of cancer to life-threatening injuries.

[3] *D stands for dangerous.* A sealed source of radiation with an activity equal to or greater than the D value are referred to as a *high activity sealed radioactive source* (HASS).

**Table 1.** Activity levels for radioactive materials present in the society-at-large corresponding to a potentially dangerous source (A/D = 0.01). Values for Cs-137 and Mo-99 have taken into account decay products (Ba-137$^{m}$ and Tc-99$^{m}$ respectively).

| Nuclide | Designation | Usage | Activity (GBq) |
|---|---|---|---|
| Fluorine-18 | F-18 | Medical diagnostics | 0.6 |
| Cobalt-60 | Co-60 | Industrial radiography, fluid level measurement, medical treatment | 0.3 |
| Selenium-75 | Se-75 | Industrial radiography | 2 |
| Molybdenum-99 | Mo-99 | Medical diagnostics | 3 |
| Technetium-99$^{m}$ | Tc-99$^{m}$ | Medical diagnostics | 7 |
| Iodine-131 | I-131 | Medical treatment | 2 |
| Caesium-137 | Cs-137 | Thickness, level or density measurement | 1 |
| Iridium-192 | Ir-192 | Industrial radiography, medical treatment | 0.8 |
| Americium-241 | Am-241 | Moisture content or filling control measurements, smoke detectors | 0.6 |

# 2. Radiation protection in nuclear or radiological emergencies

## 2.1. Objectives with radiation protection

Radiation protection shall contribute to the protection of humans and the environment from the harmful effects of *ionising radiation*. The protection must be effective while not unnecessarily limiting the human activities associated with exposure. The overall objectives in radiation protection are first, to avoid or minimise severe deterministic effects; and second, to reduce the risk of stochastic effects as far as reasonably achievable.

## 2.2. Basic rules for radiation protection

Many different types of radiation sources are used in activities involving ionising radiation. In industry and healthcare, fixed installed equipment such as X-ray tubes, but also radioactive material in open sources (e.g. liquids) and radioactive material permanently contained in solid containers, i.e. sealed sources, are used.

This section is based on sources that consist of radioactive materials and that are present in activities involving ionising radiation in Sweden. One significant feature of radioactive materials is that it is not possible to influence the radioactive decay. X-ray equipment can be switched off, but in order to protect against the ionising radiation from a radioactive source, other approaches are needed. There are three basic rules that alone or combined together can be used to protect against ionising radiation. The basic rules apply to all sources of ionising radiation:

- **Time**
  Stay as short time as possible near a source of radiation. The dose increases linearly over time (disregarding radioactive decay). If a person spends half as long time near a source of radiation, their dose is halved.
- **Distance**
  Keep as much distance as possible between the source of radiation and yourself. For sealed gamma-ray sources (point sources), the radiation intensity is inversely proportional to the square of the distance. This means that if the distance between you and the point source is doubled, the intensity of the radiation decreases to a quarter.
- **Shielding**
  Have as much shielding material between you and the source of the radiation as possible. The amount of shielding material required to reduce radiation varies because different sources of radiation emit different types of radiation with different energies. The primary rule regarding shielding is that the greater the mass, the better the radiation shield[4], therefore heavy materials such as lead are often used as radiation shields. However, in the event of nuclear or radiological emergencies, it may be necessary to use commonly available materials, such as concrete.

[4] The primary rule does not apply to neutrons. For neutrons, materials containing light atoms (hydrogen) shield better, such as is the case with water.

If there is a risk of contamination, i.e. getting the radioactive material into a person or on to their skin and/or clothing, a fourth rule may be added:

- **Avoid getting radioactive material inside your body or on your skin**
  If the radioactive material is present in the air, it can enter the pharynx and lungs by inhalation. If the radioactive material is present in food or in the immediate surroundings, e.g. on one's skin or clothes, it can be ingested or taken up through wounds on the skin.

All protective actions presented in this report are based on these basic rules for radiation protection.

## 2.3. Exposure situations

Exposure situations are used by the International Commission on Radiological Protection (ICRP) to categorise situations where humans or the environment may be exposed to ionising radiation [7]. The situational classification aims to adapt the level of protection against ionising radiation based on external conditions, what can be predicted and the urgency of various measures. The division into exposure situations also aims to promote the use of optimisation under various conditions. In its recommendations, the ICRP uses three exposure situations covering all situations where someone or something is exposed to or may be exposed to ionising radiation:

- **A planned exposure** situation is an exposure situation where radiation protection can be planned before the exposure takes place and where the magnitude and extent of the exposure can be foreseen with reasonable certainty. The Swedish Radiation Protection Act (2018:396) designates a planned exposure situation as *activities involving ionising radiation*.
- **An emergency exposure situation** is an exposure situation that warrants prompt actions to be implemented or prepared. The Swedish Radiation Protection Act designates an emergency exposure situation as a *radiological emergency*.
- **An existing exposure situation** is an exposure situation that already exists when a decision to control it needs to be taken and which no longer warrants urgent actions to be implemented or prepared. The Swedish Radiation Protection Act designates an existing exposure situation as *an environment with ionising radiation*.

A nuclear or radiological emergency is defined in the Swedish Radiation Protection Act as a sudden event that involves a radiation source, has entailed or may entail severe adverse consequences and necessitates prompt actions. An accident is defined in Sweden as a sudden event that has entailed or may entail severe adverse consequences and necessitates prompt actions [8]. If the criteria for rescue services of the Swedish Civil Protection Act (2003:778) are fulfilled and the severe adverse consequences have been or can be caused by a radiation source, the criteria for an emergency exposure situation are also met in almost all conceivable situations. Figure 1 illustrates how the different exposure situations relate to Swedish legislation.

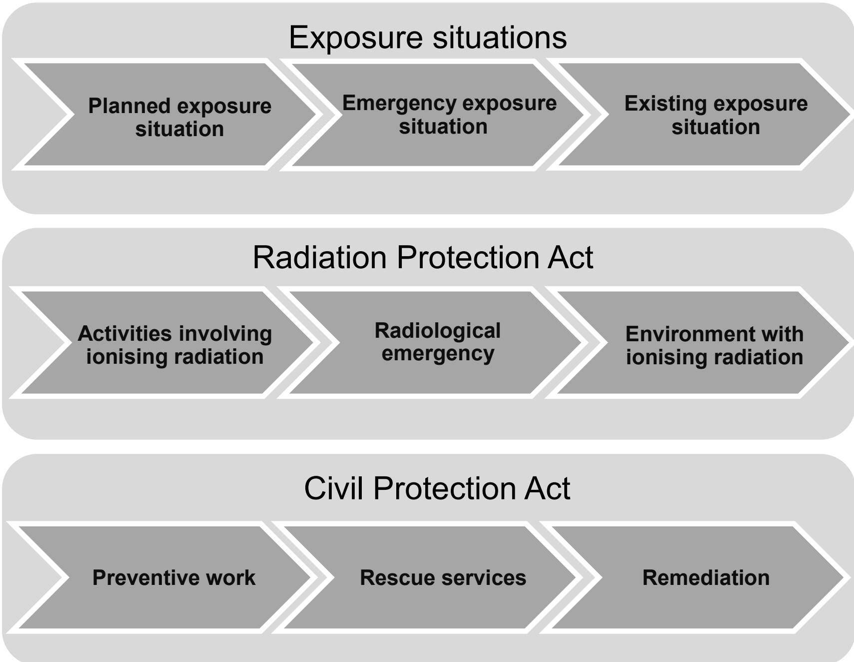


**Figure 1.** Illustration of how exposure situations relate to Swedish legislation. An existing exposure situation and an environment with ionising radiation may also occur in other contexts. The figure refers to a situation resulting from a nuclear or radiological emergency. The Swedish Radiation Protection Act designates an emergency exposure situation as a "radiological emergency", which can be a nuclear or a radiological emergency.

## 2.4. The system of radiation protection in nuclear or radiological emergencies

Radiation protection is based on science, values and experiences. The ICRP publishes international recommendations on how a system for radiation protection for the public and workers should be designed. The current system was introduced with ICRP Publication 103 [7] and is based on the exposure situations described in section 2.3, which include emergency exposure situations. The ICRP recommendations have been implemented in the EU via the Council Directive 2013/59/EURATOM [9], which Member States has implemented in national law. In Sweden, the essential elements of the EU Directive has been incorporated via the Swedish Radiation Protection Act, the Swedish Radiation Protection Ordinance (2018:506) and regulations from SSM. Sweden has also committed itself to comply with international recommendations from the IAEA regarding emergency preparedness and response [3].

The ICRP recommendations are based on the three fundamental principles of radiation protection: *justification*, *optimisation,* and the application of *dose limits.* These basic concepts are central to understanding the system of radiation protection in nuclear or radiological emergencies. The remainder of this chapter aims to explain these and the underlying concepts with a focus on how they can be used in emergency planning and response.

### 2.4.1. Justification

An action is justified under the Swedish Radiation Protection Act if its benefits exceed the harm that the action may cause. The person responsible for a decision on a protective action in a nuclear or radiological emergency must therefore determine whether the benefits in the form of reduction of potential doses exceeds the disadvantages that the protective action may lead to, before a decision is taken.

The following guidelines may provide a guide to whether protective actions for the public may be justified in a nuclear or radiological emergency. If the *effective dose* without taking protective actions is expected to be:

- higher than 100 millisieverts (mSv), it is almost always justified to take protective actions;
- higher than 10 mSv, it is normally advisable to take protective actions;
- between 1 and 10 mSv, it may be advisable to take protective actions.

For workers in nuclear or radiological emergencies, exposures leading to doses above 100 mSv effective dose are justified only in certain cases. It then becomes a matter of efforts to save lives, prevent severe radiation-related health effects or to prevent the development of catastrophic conditions.

### 2.4.2. Optimisation

Optimisation is a process to identify the best possible radiological protection in a given situation. In a nuclear or radiological emergency, optimisation means that priority should be given to those most at risk and that protective actions should be taken to keep doses as low as reasonable achievable, taking economic and societal factors into account. This is illustrated in Figure 2. Thus, protective actions that are easy to implement and that have small negative consequences may be warranted even if they lead to the avoidance of relatively low doses. Optimisation does not necessarily mean that the option leading to the lowest dose must be selected. Instead, optimisation should lead to a well-balanced compromise between lowering doses and negative consequences that arise if the protective actions implemented.

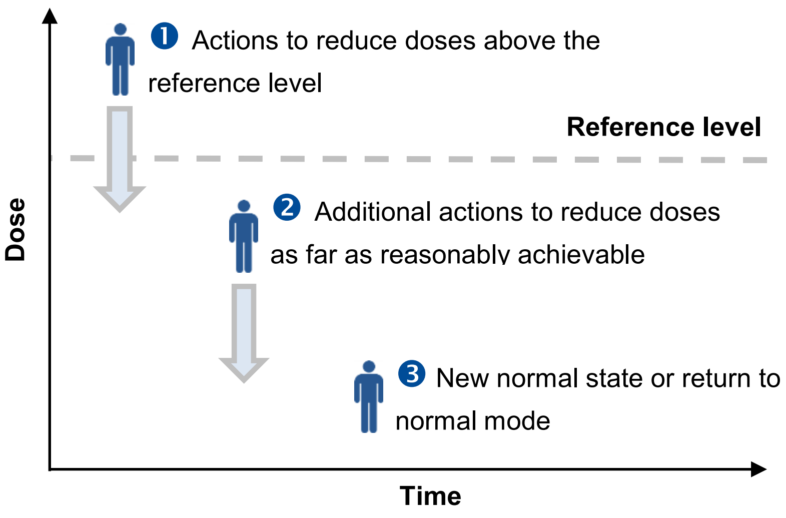


**Figure 2**. Optimisation during nuclear or radiological emergencies.

### 2.4.3. Reference levels

In this context, a *reference level* is a level of dose used as a tool to optimise the radiation protection. The reference level constitutes an aim in the preparedness phase. An emergency response plan for a particular event must, at the planning stage, enable the selected reference level not to be exceeded. Once a nuclear or radiological emergency occurs, the reference level may be considered as a benchmark where optimisation may need to start above the reference level and then continue below the reference level. Where it is possible to identify individuals or groups at risk of receiving higher doses than the selected reference level, additional protective actions for these should be prioritised, as illustrated in Figure 2. Even where a nuclear or radiological emergency is not expected to lead to doses above the selected reference level, the optimisation process shall continue, which means that additional protective actions should be considered.

**The Public**

When a nuclear or radiological emergency occurs, dose limits do not apply. Instead, the Radiation Protection Directive specifies a range of permitted reference levels for the public between 20 and 100 mSv annual effective dose for emergency exposure situations. In Sweden, reference levels for the public in emergency exposure situations are established in the Swedish Radiation Protection Ordinance. For nuclear or radiological emergencies arising from events in emergency preparedness category IV, a reference level for the public of 20 mSv effective dose applies during the first year. This report is based on this reference level for the public. The choice of the reference level of 20 mSv for these events is also in line with the common guidelines developed by the radiation protection and nuclear safety authorities in the Nordic region [1].

**Workers**

The dose limits for workers also do not apply when a nuclear or radiological emergency occurs. For workers, however, there are requirements in the Swedish Radiation Protection Ordinance stating that if possible the exposure should remain below the dose limits, even during nuclear or radiological emergencies. This means primarily that the exposure should remain below the value of the dose limit for annual effective dose, 20 mSv. Where it is not considered realistic to keep an exposure below the values of the dose limits, it is specified that the person in charge of the emergency response should set the reference levels to be applied. The reference levels for workers in nuclear or radiological emergencies may not exceed 100 mSv effective dose unless it is necessary to save lives, prevent severe radiation-related health effects or to prevent the development of catastrophic conditions. In such cases, the reference level may exceed 100 mSv effective dose, but not 500 mSv effective dose.

A decision on reference levels for workers above the dose limits during a nuclear or radiological emergency is based on an assessment of the radiation situation and the preconditions for the response efforts. In connection with the planning for how such reference levels can be established, it is important to remember that the reference level is not a limit, but rather a tool for optimisation of radiation protection before and during the emergency response. By establishing, communicating and anchoring the reference level, it clarifies a level of dose that should not be exceeded and below which optimisation should continue. Therefore, when the emergency response is evaluated retrospectively, the reasonableness of the assessment of *projected doses* and how the reference level was communicated is likely to be the key overall consideration. Radiation protection for workers in nuclear or radiological emergencies is described in more detail in Chapter 4.

**Emergency response planning**
In connection with the development of new emergency plans, or review of existing plans, responsible parties and employers need to ensure that doses to the public and workers can stay below the reference level. To evaluate whether an emergency response plan can lead to doses below the reference level, *residual dose* is used. When estimating residual doses, all exposure pathways must be taken into account, which means that both internal exposure from inhalation and ingestion of radioactive material as well as external exposure are included in the assessment. Estimated residual doses should then remain below 20 mSv effective dose.

### 2.4.4. Dose criteria

*Dose criteria* are used in emergency response planning and as a starting point for taking protective actions during emergency response. A dose criterion is expressed in projected dose, i.e. dose to an *unprotected person* during a specific period of time. The dose criteria may be expressed as effective dose, *absorbed dose* or *equivalent dose* to an organ. The dose criteria are not calculated but rather selected so that the reference level, 20 mSv effective dose, for most potential nuclear or radiological emergencies will not be exceeded. In a nuclear or radiological emergency, this means that if protective actions are taken when the dose criteria for each protective action are estimated to be exceeded, the effective dose should stay below the reference level given the successful implementation of the protective actions.

Dose criteria for public protective actions in connection with events in emergency preparedness category IV are presented in this report. Dose criteria for protective actions in connection with events in emergency preparedness category I and II are presented in other reports: Review of Swedish emergency planning zones and distances [2], Need for personal decontamination for the public in connection with a Swedish nuclear accident [10] and Distance calculations around Swedish nuclear power plants – Basis for health and medical care when planning for nuclear accidents in Sweden [11].

### 2.4.5. Operational intervention levels

In the operational management of a nuclear or radiological emergency, protective actions may be taken on the basis of measurable quantities. These can be measured values from both basic monitoring with a dose rate instrument – e.g. SRV-2000 – as well as from measurements of individual radioactive isotopes. Linked to each protective action and dose criterion, one or more *operational intervention levels* (OIL) may be derived. The planning proceeds from the assumption that when the OIL for a particular protective action is exceeded or expected to be exceeded, the protective action should be taken. An OIL thus makes it easy to relate monitoring results to a single protective action, which can facilitate the management of the nuclear or radiological emergency.

While the use of OILs allows for a simple approach, the concept also has a number of weaknesses:

- An OIL only takes one exposure pathway into account. What is measured often estimates the external exposure from radioactive materials in the environment, but does not take into account other pathways, e.g. via inhalation. This can be exemplified by measuring a dose rate with a dose rate instrument. It can then be difficult to determine whether the radioactive material is lying on the ground or is dispersed in the air and may cause inhalation doses.

- The OIL may need to be revised during emergency response. For the purpose of corresponding to the selected dose criterion, the OIL may need to be revised as dose rates and activity concentrations change over time, e.g. due to radioactive decay. It is therefore important to communicate that OILs are not static but rather aim to translate the dose criterion into practical application.
- Decisions concerning protective actions based on individual OILs are no guarantee that the residual dose will be lower than the selected reference level. Even if an OIL for a protective action is not exceeded, several protective actions may need to be taken to ensure that the selected reference level is not exceeded.

For these reasons, emergency response planning should primarily be based on the reference level and dose criteria, but may in some cases be complemented by OILs for less complex situations. This report therefore sets out dose criteria for all protective actions for the public but only one OIL, as shown in the next chapter. The methodology of the emergency response planning and the various steps from the reference level to the OILs are illustrated in Figure 3.

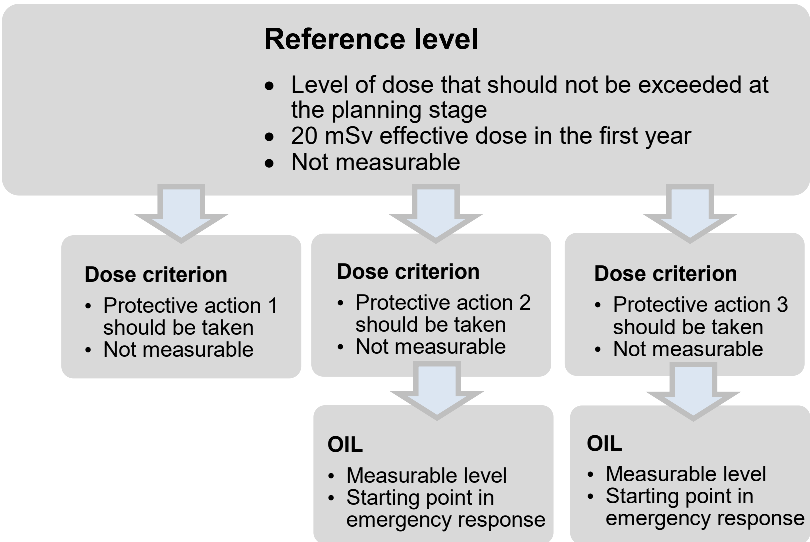


**Figure 3.** Illustration of the methodology for emergency response planning for nuclear or radiological emergencies arising from events in emergency preparedness category IV where combinations of protective actions may need to be considered.

# 3. Public protective actions

## 3.1. Protective actions in nuclear or radiological emergencies

All protective actions related to a nuclear or radiological emergency aim to keep public exposure to ionising radiation as low as reasonably achievable, taking societal and financial factors into account. As part of the rescue services, the need for protective actions is continuously assessed. This assessment also includes the expected duration of the protective actions. Protective actions taken initially in connection with the nuclear or radiological emergency may gradually be either continued, expanded, reduced or terminated. New protective actions may be initiated as information from radiation monitoring becomes available. Where necessary, actions are also taken to reduce the further dispersion of radioactive material.

In the event of a nuclear or radiological emergency, protective actions should protect all groups of the population. Members of some groups, such as children and pregnant women, may need to be prioritised due to the fact that children and foetuses are more sensitive to ionising radiation. Figure 4 presents relevant urgent and early public protective actions that may be considered during nuclear or radiological emergencies arising from events in emergency preparedness category IV. Actions may also be taken to: protect property; the environment; activities essential to the community; industry and trade; agriculture; and the production of food, feed and drinking water. However, such actions are not addressed in this report.

In this chapter, public protective actions are described separately, but may together form a basis for emergency response planning for nuclear or radiological emergencies arising from events in emergency preparedness category IV. In connection with each protective action in the chapter, there is a scenario that provides an example of when and how the various protective actions may need to be taken. All dose criteria set out in this report are also listed in Appendix 3.


**Figure 4**. Urgent and early protective actions to be considered for the public during nuclear or radiological emergencies arising from events in emergency preparedness category IV.

## 3.2. Sheltering

An incident commander is responsible for rescue services in case of a nuclear or radiological emergency in Sweden. The incident commander may recommend sheltering by issuing an Important Public Announcement (*Viktigt meddelande till allmänheten*, or ”VMA” in Swedish). In the event of a VMA, the public is encouraged to go indoors, close doors, windows, and ventilation and listen to Radio Sweden on channel P4. Sheltering reduces the inhalation of radioactive materials present in the air and limits the external exposure from radioactive materials in the air and on the ground. Sheltering can therefore be an effective protective action for events that may lead to releases where radioactive materials are dispersed or there is a risk that they will be dispersed in the air, for example by a fire or explosion. The protection offered by sheltering depends on several factors such as building type, air filtration and type of ventilation. Staying in a basement or in a multi-residence dwelling provides better protection against external exposure than staying in a detached house.

The best course of action would be to start sheltering before the exposure is expected to occur. Decisions to recommend sheltering therefore need to be taken in sufficient time to inform the public and to prepare and implement the protective action. If possible, windows and doors should be closed and ventilation switched off in residential buildings, office buildings and production facilities within the area where sheltering has been recommended.

A dose criterion for sheltering during nuclear or radiological emergencies arising from events in emergency preparedness category IV is given below. The dose criterion should be compared with the projected dose from all exposure pathways that an unprotected person would receive during the release. To ensure that the entire release is captured, a time period of seven days is used in emergency response planning.

**Dose criterion for sheltering:**

- 10 mSv effective dose

The expected duration of sheltering is an important factor in the decision to continue recommending this protective action. The recommendation to shelter should be lifted as soon as the plume has passed and there is no risk of further significant releases. If the release is expected to last for a long time or only affects a few people, evacuation may be considered instead. Sheltering due to the release of radioactive materials is in this respect not different from sheltering recommended due to other hazardous substances.

In the event of nuclear or radiological emergencies involving radioactive sources where there is no risk of dispersion of radioactive materials to the air, evacuation and cordoning off of a small area adjacent to the source is normally a better option to reduce the risk of external exposure and contamination.

**Scenario 1 — Accident on a nuclear-powered vessel**

The following scenario aims to provide an example of an event in emergency preparedness category IV where sheltering may be warranted [5]. The analysis is general and does not take into account other protective or response actions that might also be relevant in the scenario and its consequences.

**Description of the scenario**

A nuclear-powered vessel becomes inoperable just outside Swedish territorial waters and starts drifting towards Sweden. The captain of the vessel considers that they are in distress at sea and seeks a protected place (port of refuge). The vessel is in Swedish jurisdictional waters and is directed by the Swedish Transport Agency to an anchorage with calm and protected waters to which the vessel is towed, two kilometres off the coast of Sweden. After a few more hours, it emerges that the vessel has lost the cooling of the reactor core and a severe reactor accident with release of radioactive material is imminent. At this time, an incident commander has been appointed by the County Administrative Board to lead the emergency response efforts since an accident on a nuclear-powered vessel is managed by civil protection services on the regional level in Sweden. On the coast, there is a densely populated urban area located downwind from the vessel. Through an Important Public Announcement, the incident commander encourages people in the urban area to shelter.

**Analysis of potential consequences**

There are events in emergency preparedness category IV that could possibly lead to radiation doses for the public exceeding the dose criterion for sheltering. Sheltering could thus be warranted for radiological reasons in these events. According to the scenario above, with a severe nuclear accident on a nuclear-powered vessel near the coast, the dose criterion for sheltering can be exceeded locally in the direction downwind from the vessel. Sheltering may be warranted within an area at risk extending a few kilometres from the vessel [18]. By going indoors and closing doors, windows and ventilation, external exposure from radioactive material in the plume and internal exposure via inhalation is reduced. Sheltering can reduce overall exposure by between 50 and 90 %, depending on the type of building [2]. In the absence of detailed information on building types and periods of indoor stay, sheltering may be assumed to reduce doses by 50 %.

## 3.3. Evacuation

In the event of a nuclear or radiological emergency, the incident commander may decide to evacuate the public from an area at risk. The police may also decide to evacuate a particular site for the purpose of protecting life and health, and/or property against the risk of crime. Evacuation is an effective protective action insofar as the exposure ceases when people are moved to an area that is not affected by the event.

In this report, there is a distinction between a large-scale evacuation and evacuation of small areas. The reason is that the possibilities for optimisation of protective actions and emergency planning differ significantly depending on the size of the potentially affected area and the number of people potentially affected.

### 3.3.1. Large-scale evacuation

Extensive areas may be affected by an atmospheric release of radioactive material and the subsequent ground contamination resulting from deposition of radioactive materials on the ground. A general dose criterion for a large-scale evacuation is presented in this report. The objective of maintaining exposures below the reference level in connection with a nuclear or radiological emergency can be achieved by timely evacuation. The dose criterion is therefore identical to the reference level. For evacuation in connection with the release of radioactive material, the dose criterion refers to one week, while for evacuation due to ground contamination (relocation) it refers to the "first year", i.e. from the end of significant releases to one year from the onset of the emergency taking effects of remediation into account. For events in emergency preparedness category IV, it is unlikely that a need for large-scale evacuation will arise.

**Dose criterion for evacuation of large areas:**

- 20 mSv effective dose

### 3.3.2. Evacuation of small areas

A smaller area may need to be evacuated and cordoned off in the event of signs of, or risk of, the dispersion of radioactive materials or as a result of external exposure from a radiation source. Emergency response planning should then be based on initial sizes for cordoned off areas and operational intervention levels rather than dose criteria, as the number of individuals affected by the decision and the area to be evacuated is limited. It is generally easier and faster to evacuate a smaller area and thus the threshold for when evacuation can be considered warranted is lower than for the evacuation of large areas, but this depends strongly on the situation.

An operational intervention level for the evacuation of smaller areas as a result of events in emergency preparedness category IV is presented in this report. The OIL refers to ambient dose equivalent rate measured with an instrument intended for environmental monitoring. Because measured dose rates do not take all exposure pathways into account, dose rate values at lower levels than the OIL for evacuation should be used with caution when lifting the evacuation or reducing the size of the evacuated area. Instead, assessment of projected doses should be the basis for terminating the evacuation. The dose assessment will in turn be based on monitoring results, including identification and mapping (including airborne activity) of the radioactive materials.

**Operational intervention level for evacuation of small areas:**

- 100 microsieverts per hour (µSv/h)

When evacuating small areas in connection with events in emergency preparedness category IV, it should be possible to keep residual doses to the public low. Therefore, in most cases an optimised emergency response plan would result in residual doses well below the reference level of 20 mSv. Doses on par with the value of the dose limit for the public, 1 mSv annual effective dose, may instead be a benchmark. The far-reaching possibilities for optimisation are illustrated in scenario 2.

Table 2 provides guidance on the size of the inner cordoned off area that may initially need to be established and evacuated as a result of events in emergency preparedness category IV. The evacuated area may need to be reduced or expanded as monitoring results become available, or due to other factors or circumstances.

**Table 2**. Initial inner cordoned off areas and premises that may need to be evacuated in connection with events involving potentially dangerous sources in emergency preparedness category IV. The table may be used for potentially dangerous sources present in the community apart from nuclear activities.

| **Outdoors** | **Initial inner cordoned off area (radius)** |
|---|---|
| A potentially dangerous source without or with damaged shielding or liquid sources<br>(no risk of explosion or fire) | 50 metres |
| In the event of a fire, explosion or fumes from a potentially dangerous source | 300 metres |
| **Indoors** | **Premises that may need to be evacuated** |
| A potentially dangerous source without or with damaged shielding, or in the event of spillage from a liquid source (no risk of explosion or fire) | Rooms where the source is located and adjoining rooms including rooms on floors above and below |
| In the event of a fire, explosion or fumes from a potentially dangerous source where there is a risk of radioactive materials being dispersed, e.g. via ventilation | Rooms where the source is located or is likely to move to and adjoining rooms including rooms on floors above and below or throughout the building |

The inner cordoned off areas in Table 2 may be used for potentially dangerous sources occurring in the community with the exception of nuclear activities. The sizes of the inner cordoned off areas are the same as recommended for solid radioactive substances or vapours in the Swedish Civil Contingencies Agency's response measures calendar [12]. For nuclear emergencies in emergency preparedness category IV, for example in the event of reactor accidents on nuclear-powered vessels or floating nuclear power plants or during transport of spent nuclear fuel, protective actions may need to be taken in a wider area. The planning for such nuclear emergencies should instead be based on risk analyses conducted for the specific nuclear activity, as illustrated in scenario 1.

The inner cordoned off areas in Table 2 take into account radiological consequences only. For other hazardous substances or risks in combination with radioactive materials, it may be necessary to evacuate at different initial risk distances. These are reported in the response measures calendar [12].

Guidelines for radiation protection of first responders and the public during a transport accident involving radioactive materials are also given in Appendix 4.

## Scenario 2 — Transport accident with a potentially dangerous source

The following scenario aims to provide an example of an event in emergency preparedness category IV where evacuation of a small area may be warranted [5]. The analysis is general and does not take other protective or response actions into account that could possibly also be relevant given the scenario and its consequences.

**Description of the scenario**

A bus carrying about 40 passengers collides with a passenger car carrying Class 7 dangerous goods (ADR). The radioactive source is a potentially dangerous sealed point source of Co-60 (in a steel capsule) with an activity of 3 GBq, which is transported in a type A package (the source surrounded by a 6 cm thick lead shielding fixed with Styrofoam in a cardboard box). The driver of the passenger car is severely injured but the occupants of the bus only sustain minor injuries and are gathered outside the bus at the scene where the accident occurred when rescue services, ambulance services, and police arrive.

The first responders begin lifesaving efforts for the driver of the passenger car and, as a result of the Class 7 transport, establish an inner cordoned off area of 50 metres and order passengers from the bus to leave the area. The source was transported in the rear of the passenger car, about 2 metres from the unconscious driver. In the scenario, it is assumed that the shielding of the source has been completely or partially lost (this may have occurred due to the lid of the lead shielding falling off, or melted lead shielding in the event of fire). The dose rate at the driver's seat where the first responders are working to free the driver is about 250 μSv/h. The value of the dose limit of 20 mSv effective dose would, with this conservative assumption, risk being exceeded after approximately 80 hours of work near the driver's seat. When measuring the dose rate around the passenger car, the OIL for evacuation of small areas, 100 μSv/h, would be exceeded out to approximately 3 metres from the source. The dose rate at a distance of 50 metres is approximately 0.5 μSv/h, i.e. just above the background level.

**Analysis of potential consequences**

A transport accident involving radioactive material does not pose a radiation protection problem as long as the transport container's radiation shield is intact. The requirements for what conditions a transport container must withstand are higher for sources that pose a higher risk. However, without access to monitoring instruments at the scene of the accident, it is difficult to ensure that the transport container is intact. In the absence of monitoring instruments, life-saving actions should be taken and, where possible, injured individuals should be removed from the area at risk. All further work should be conducted taking distance, time and shielding into account. For example, in the above scenario, the source does not pose a radiation protection problem in life-saving activities, even if the radiation shielding is assumed to be completely lost. It is reasonable to assume that life-saving actions need never be delayed for radiation protection reasons, as sources that cause a dose limit for workers to be exceeded in a short time (minutes) during emergency response are rare and subject to specific safety requirements.

During the emergency response, an inner cordoned off area may need to be evacuated. The recommended distances listed in Table 2 are conservative, which means that in the vast majority of cases an area at risk established based on the OIL 100 μSv/h will be smaller. In the event of a fire or leakage, the emergency services' personal protective equipment – protective clothing fully covering their body including a protective mask – also provides good protection against contamination. It is also worth noting that personnel working in a radiation environment on par with the OIL can work for many days without risking exceeding the dose limits for workers.

## 3.4. Decontamination of individuals

In a nuclear or radiological emergency where radioactive materials are dispersed in liquid form or released into the air, individuals may become contaminated on skin and clothing. For events in emergency preparedness category IV, both workers and the public may be contaminated. Depending upon the deposition of radioactive materials on the skin, various protective actions may need to be taken to avoid severe deterministic effects or deterministic effects on the skin and to reduce the risk of stochastic effects.

This section presents dose criteria and recommendations for different types of decontamination measures involving individuals from the public. At the end of the section, a scenario is presented where external monitoring and possibly organised decontamination of individuals may be warranted for radiation protection reasons (scenario 3).

### 3.4.1. Types of decontamination of individuals

Different types of decontamination of individuals may be warranted depending on the dose criterion that is at risk of being exceeded. The purpose of decontamination of individuals is to reduce or discontinue the exposure from hazardous substances present on a person's skin – in this case, radioactive materials. Four different types of decontamination of individuals are used in emergency services and healthcare in Sweden.

**Life-saving decontamination of individuals:** Immediate decontamination of persons for the purpose of saving lives. Life-saving decontamination of individuals is conducted by the rescue services at the scene of the nuclear or radiological emergency.

**Complete decontamination of individuals:** Decontamination of individuals for the purpose of removing, as far as possible, all harmful substances from a person's skin. Complete decontamination of individuals is carried out by the Swedish healthcare service in a hospital or at the exit from the warm zone at the scene of the nuclear or radiological emergency (c.f. section 4.5).

**Organised decontamination of individuals:** Decontamination of individuals that individuals perform by themselves (self-decontamination) by showering with soap and water in a designated place, e.g. a sports hall or a bathhouse. If necessary, a change of clothes is also included. The responsibility for the planning of organised decontamination of individuals lies with the public authority responsible for civil protection and the emergency services.

**Individual self-decontamination:** Decontamination that individuals perform themselves by showering with soap and water in a place of their choice. Individual self-decontamination may also include changing clothes as well as regular washing of the hands. The responsibility for individual self-decontamination lies with the individual.

### 3.4.2. Planning for decontamination of individuals

The following should be taken into account when planning for decontamination of individuals and external (skin) monitoring[5] of individuals from the public:

1. Decontamination of individuals and skin monitoring must never delay life-saving actions or the care of the injured persons. Valuable time may be wasted and the condition of the injured person may worsen while waiting for skin monitoring and decontamination of individuals. See also section 4.6 concerning life-saving actions.
2. In emergency planning, it is important to determine in advance in which situations skin monitoring and decontamination of individuals (other than individual self-decontamination) are likely to be warranted, i.e. when the actions are expected to do more good than harm. For example if persons have been evacuated before a release has occurred, neither decontamination of individuals nor skin monitoring are warranted. The same applies to radiological emergencies involving radioactive sources where the source remains intact.
3. Instead of organised decontamination of individuals, general advice on what the individual can do to reduce their dose may be effective. Individual self-decontamination is usually quite sufficient and the intended effect is achieved without any major public efforts, delay or intervention.
4. It is difficult to use operational intervention levels to initiate various forms of personal decontamination. The reasons are the same as in a nuclear accident [10], i.e. it is usually difficult to relate a monitoring result to a dose criterion and a monitoring result close to the skin may be misinterpreted due to internal contamination. Instead, in connection with decontamination of individuals, skin monitoring may be conducted to determine when the deposition on the skin no longer decreases in the course of repeated decontamination and to identify radioactive fragments in wounds or the like.

Dose criteria for life-saving, complete and organised decontamination of individuals are set out below. A dose criterion for when information to the public is warranted for the purpose of reducing inadvertent ingestion of radioactive materials deposited on the skin is also given.

The dose criteria may be used in emergency planning for events in emergency preparedness category IV where many people are at risk of being contaminated. For minor incidents where a few people are affected, it may be warranted to carry out e.g. complete decontamination of individuals in a hospital even at projected skin doses below the dose criterion. In cases where a few people have been contaminated on skin and clothing, the far-reaching possibilities for optimisation should be taken into account. In these cases, a reasonable objective may be, when possible, to keep skin doses below the dose limit for the public.

### 3.4.3. Monitoring of members of the public

In connection with decontamination of individuals, monitoring may be conducted to find contamination on the skin or radioactive fragments stuck in wounds and to evaluate the decontamination efforts. Personal data and results from the skin monitoring should be registered by authorities authorised to handle such personal data. Healthcare professionals

[5] Monitoring of external dose rate from an individual. The contamination may be attached on the skin, in the hair, in wounds or on clothes. These types of monitoring are summarised by the term ‘skin monitoring’ in this report.

and radiation protection expertise should be available where the skin monitoring is conducted, not least for the purpose of answering questions related to the results of the monitoring. Skin monitoring associated with decontamination of individuals should mainly be aimed at determining when the contamination on the skin no longer decreases after repeated decontamination efforts. Skin monitoring can also be used to find radioactive fragments and provide a basis for information to those affected. If a large number of individuals are to undergo decontamination, the decontamination itself should take precedence over monitoring.

### 3.4.4. Life-saving and complete decontamination of individuals

Life-saving decontamination of individuals and complete decontamination of individuals should be conducted for the purpose of avoiding severe deterministic effects that may occur due to high skin doses. The dose criterion for life-saving decontamination of individuals is independent of age and refers to RBE[6]-weighted absorbed dose. The dose criterion represents a lower threshold for when severe deterministic effects may occur, although unlikely. The dose criterion refers to the absorbed dose to the skin (100 $cm^2$, depth 0.4 mm) received in 10 hours and assumes that the skin dose comes from gamma and beta radiation.

**Dose criterion for life-saving and complete decontamination of individuals:**

- 2 Gy RBE-weighted absorbed dose to the skin

Even in the case of life-saving and complete decontamination of individuals, the urgency of the response and measures taken should be set in relation to other necessary measures. The care of injured persons and ensuring life-saving actions must be a priority over the decontamination of individuals.

### 3.4.5. Organised decontamination of individuals

Organised decontamination of individuals with radioactive materials on the skin is conducted with the aim of avoiding, as far as possible, deterministic effects in the skin. The dose criterion for organised personal decontamination is independent of age as it refers to the equivalent dose (1 $cm^2$, depth 0.07 mm) to the skin received in seven days.

**Dose criterion for organised decontamination of individuals:**

- 500 mSv equivalent dose to the skin

Organised decontamination of individuals must never delay the care of injured persons.

### 3.4.6. Information to reduce inadvertent ingestion

Radioactive materials on the skin, clothing or hair can lead to inadvertent ingestion, meaning that a person unintentionally gets the substance into their body. To reduce the risk of stochastic effects from inadvertent ingestion, information is often a more effective measure than decontamination. A dose criterion is given to provide guidance on when

[6] Relative Biological Effectiveness (RBE) is used to reflect the biological effect of different radiation types and dose rates on different biological systems.

information to reduce inadvertent ingestion may be necessary. Members of the public who may exceed the dose criterion should be informed about actions they themselves can take, such as self-decontamination. The information should therefore include advice on changing clothes, showering and washing hands for the purpose of reducing exposure.

The dose criterion refers to a *committed effective dose* from internal exposure from radioactive materials. Because children and pregnant women (foetuses) are more sensitive to ionising radiation than adults, this information may need to be directed specifically to reach these groups.

**Dose criterion for information to reduce inadvertent ingestion:**

- 1 mSv committed effective dose

## Scenario 3 – Antagonistic incident with a potentially dangerous source

The following scenario seeks to provide an example of an act in emergency preparedness category IV where organised decontamination of individuals may be warranted [5]. The analysis is general and does not take other protective or response actions into account that could possibly also be relevant given the scenario and its consequences.

**Description of the scenario**

A terrorist organisation has obtained a potentially dangerous source, 30 GBq Cs-137, in powder form. The radioactive source is dispersed by an explosive device detonating in an open place in a city centre. In this scenario, a number of people in the vicinity were killed or seriously injured by the explosion. When the explosion occurs, part of the source is released and dispersed by the wind. The airborne particles contaminate an area within a few hundred metres downwind. Outside the area directly affected by the explosion itself, the dispersion results in a ground contamination of up to 10 MBq/m$^2$, with strong local variations. A person staying outdoors during the plume passage is assumed to get up to 1 MBq/m$^2$ on their clothes and unprotected parts of their body. After a few minutes, the plume has passed the area and the bulk of the activity is deposited on the ground.

The police and other emergency services quickly arrive at the scene and establish an inner cordoned off area. Police cordon off a 300 metre area downwind after indication of elevated radiation levels in several locations.

**Analysis of potential consequences**

In the scenario above, which is based on dispersion experiments published in scientific literature [19], the dose criteria for life-saving or complete decontamination of individuals are not exceeded for any individual not directly affected by the explosion. It would take about 100 times more activity on the skin to exceed the dose criterion for organised decontamination of individuals. However, it cannot be excluded that individual highly active fragments or particles are present [17]. Persons who have been in the direct range of the explosion may have radioactive shrapnel in wounds or fragments on their clothing or skin, or in their hair. Therefore, it may be warranted for the rescue services and healthcare services to carry out skin monitoring of unharmed or mildly injured individuals as they leave the area where the incident occurred for the purpose of locating radioactive fragments. Organised decontamination of individuals can be offered in connection with the monitoring. However, injured persons should be taken into care according to normal procedures and subsequently possibly offered complete decontamination.

The activity concentrations required for severe deterministic effects in the skin to occur are very high. It is therefore unlikely that an antagonist would achieve skin contamination on a large number of people that would exceed the dose criterion for life-saving or complete decontamination of individuals. Skin contamination exceeding the dose criterion for organised decontamination of individuals for the purpose of avoiding deterministic effects is also difficult to achieve via the deliberate dispersion of radioactive materials. The discovery of radioactive material in connection with an antagonistic act risks leading to delay and uncertainty in the handling of the incident. A delay due to excessive caution in the actions of rescue services and medical personnel risks, in the worst case, leading to injured persons not receiving the necessary treatment in time.

This can be avoided by means of emergency planning and training. The personnel's ordinary personal protective equipment and hygiene procedures provide good protection against the spread of contamination from injured individuals. Dose rates near an individual with contamination of their skin and clothing according to the scenario above are low and do not pose a radiation protection problem for first responders at the scene where the incident occurred. It is therefore important that personnel are trained and informed on the risks, so that they feel safe, and are able to respond effectively.

# 4. Protective actions for workers

## 4.1. Radiation protection for workers

Radiation protection for occupational exposure is regulated by the Swedish Radiation Protection Act, the Swedish Radiation Protection Ordinance and SSM regulations. It is permissible for workers exposed to ionising radiation in their professional practice to be exposed to higher doses than the public. These rules apply to radiation protection regardless of the exposure situation and is reflected, for example, in the fact that there are different dose limits for workers and the public for planned exposure situations. One reason for differences in the governing rules is that workers exposed as a result of their work have been educated on the risks of ionising radiation. Workers also benefit from the work, even if they do not benefit from the exposure itself. Another reason for differences in the rules governing exposure of workers and the public is that workers are generally adults, while the public also encompasses children, who are more sensitive to ionising radiation. More strict regulations are therefore in place for protecting certain workers such as people under the age of 18, and pregnant or breastfeeding women [7].

During nuclear or radiological emergencies, dose limits do not apply to workers. However, the Swedish Radiation Protection Ordinance states that the primary goal in the protection of workers is that doses as far as possible should remain below the values of the dose limits, even in nuclear or radiological emergencies. Since the scope of this report is radiation protection in nuclear or radiological emergencies and to emphasise that what is referred to is the dose itself rather than a limit, the expression “value of the dose limit” is used.

When reference levels for workers should be set in the context of nuclear or radiological emergencies, effective dose will be the most useful protection quantity. The primary reason for this is that it should be possible to keep equivalent doses to the extremities, skin and lens of the eye low if adequate personal protective equipment is used by workers in the emergency response. This is also reflected in the fact that reference levels for workers in nuclear or radiological emergencies are only expressed in effective dose in the Swedish Radiation Protection Ordinance. Effective dose may be estimated based on measured values with a radiation protection instrument or personal dosimeter. The value of the effective dose limit for workers of 20 mSv is therefore of the greatest practical importance in the planning for, and response to, nuclear or radiological emergencies.

## 4.2. Emergency workers

Emergency workers means workers who, pursuant to Chapter 2, Section 3 of the Swedish Radiation Protection Act, have been assigned specific tasks in connection with the nuclear or radiological emergency and who, in the performance of these tasks, may be exposed to ionising radiation. There are three categories of emergency workers [13]:

1. The first category consists of the workers employed by a licensee who, according to the applicable emergency response plan, have been assigned specific tasks in the event of a nuclear or radiological emergency. The worker may also have been assigned such tasks by the individual at the licensee in charge of the emergency response to a nuclear or radiological emergency at the time of its emergence.
2. The second category includes workers in a public authority responsible for the management of a nuclear or radiological emergency. In order to be considered an emergency worker, the employee must have specific tasks in accordance with the

applicable emergency response plan. This category also includes workers assigned specific tasks in the event of a nuclear or radiological emergency. Such tasks must have been assigned by the individual in charge of the emergency response at the responsible public authority.

3. The third category includes members of the public who are assigned specific tasks in the event of a nuclear or radiological emergency. Such tasks must have been assigned by the individual in charge of the emergency response at the responsible public authority.

Work tasks that may lead to exposure in a nuclear or radiological emergency may only be assigned to workers over 18 years of age who can rule out pregnancy. Therefore, the employer is obligated to ask the personnel about pregnancy, after which it is up to the employee to decide whether pregnancy can be ruled out. Persons who are not emergency workers according to one of the three categories above are to be considered as members of the public for radiation protection matters.

Some countries use the term "helper" for a member of the public who voluntarily engages in tasks to respond to a nuclear or radiological emergency. In order to be considered as an emergency worker in Sweden, such individuals must receive the task from the individual at the appropriate public authority in charge of the emergency response. In order to ensure the appropriate assignment of liability and responsibility, and the validity of insurance cover, those individuals should be assigned tasks by invoking the obligation to perform official duties under the Swedish Civil Protection Act. All individuals who reach a minimum of 18 years of age and a maximum of 65 years of age during the calendar year are subject to the obligation to perform official duties in such a situation to the extent that knowledge, health and physical ability permits. Members of the public who voluntarily engage in tasks for the purpose of responding to a nuclear or radiological emergency, whether or not they have been assigned duties pursuant to an obligation to perform official duties, may not carry out tasks where the values for the dose limits for workers are at risk of being exceeded.

## 4.3. Exposure of emergency workers

Protection of emergency workers against radiation must be taken into account both in the emergency response planning and during the emergency response. The following requirements are contained in the Swedish Radiation Protection Act and the Swedish Radiation Protection Ordinance regarding emergency workers:

- The person in charge of the emergency response must ensure, to the extent possible, that the exposure of emergency workers remains below the values of the dose limits for workers (20 mSv effective dose).
- Where this is not realistic, the person in charge of the emergency response may set reference levels for external exposure of emergency workers in nuclear or radiological emergencies to a level not exceeding 100 mSv effective dose.
- If necessary to save lives, prevent severe radiation-induced health effects or prevent the development of catastrophic conditions, the person in charge of the emergency response may set reference levels for external exposure of emergency workers exceeding 100 mSv effective dose, but not exceeding 500 mSv effective dose. The different options for reference levels for emergency workers are illustrated in Figure 5.

- An employer engaging someone to carry out tasks related to a nuclear or radiological emergency must ensure that the emergency worker is informed of related health risks and available protective actions in advance.
- Emergency workers must use protective equipment and take any other measures as determined by the individual responsible for radiation protection.
- If, given the circumstances, it is likely that the dose received will exceed the dose limits for workers, the person in charge of the emergency response must ensure that emergency workers undertake any assigned tasks voluntarily.
- In the event of exposure of emergency workers where the worker shows signs of a health effect which may be caused by ionising radiation or if the dose exceeds a dose limit for workers, the employer must ensure that the worker undergoes a medical examination as soon as possible.
- Work tasks for emergency workers must be planned so that a breastfeeding child does not risk receiving a dose exceeding a dose limit for the public.

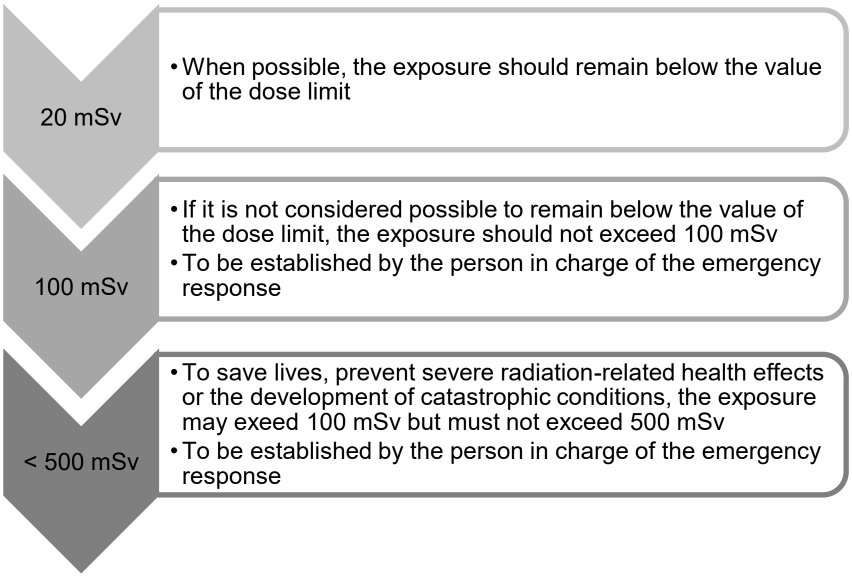


**Figure 5.** Illustration of how reference levels for emergency workers may be established.

## 4.4. Monitoring of doses

The Swedish Radiation Protection Act also requires that an employer who engages someone to carry out tasks related to a nuclear or radiological emergency monitors workers' exposure in an appropriate manner given the circumstances. Prior to undertaking actions in a nuclear or radiological emergency, the potential expected dose must be assessed and a plan for monitoring doses incurred during the work must be developed. If personal dosimeters are not available, the dose should, if possible, be assessed on the basis of the external dose rate at the place where the work is to be conducted and the working time. If monitoring instruments are not available, an assessment of potential doses is to be conducted in connection with the emergency response efforts.

In order to document and control doses to emergency workers, the following measures should be taken into account at the planning stage and in connection with the emergency response:

- Document the working hours and locations where the work is performed.
- If direct-reading personal dosimeters or a common dosimeter for a working group are available, these are to be used.
- If alarming dosimeters are used, the alarm levels should be adjusted where possible so that doses can remain below the selected reference level.
- If a dose rate instrument is used instead of a dosimeter, the dose rate should be recorded at regular intervals. However, some dose rate instruments may record accumulated doses and can therefore be an alternative to a dosimeter.
- In the absence of a dose rate instrument, potential doses are assessed on the basis of available information from transport documents or other documentation on e.g. radionuclide, activity data and radiation shielding. From such information, potential doses can be estimated based on working hours and location in relation to the source.
- If the situation persists for an extended period of time, the working time should be planned and limited in order to ensure that doses do not exceed the values of the dose limits for workers.

Table 3 provides a summary of the maximum length of stay depending on the selected reference level and external dose rate. Even in environments with an external dose rate several hundred times higher than the background levels, work can be conducted over an extended period of time without exceeding the values of the dose limits for workers.

**Table 3**. Maximum time periods in hours or minutes for different reference levels and external dose rates. The calculations assume that the worker has adequate personal protective equipment to avoid doses from internal exposure completely.

| | Maximum time periods (hours) for different reference levels | | | |
|---|---|---|---|---|
| **Dose rate (μSv/h)** | **20 mSv** | **50 mSv** | **100 mSv** | **500 mSv** |
| 10 | 2,000 | 5,000 | 10,000 | 50,000 |
| 100 | 200 | 500 | 1,000 | 5,000 |
| 500 | 40 | 100 | 200 | 1,000 |
| 1,000 | 20 | 50 | 100 | 500 |
| 5,000 | 4 | 10 | 20 | 100 |
| 10,000 | 2 | 5 | 10 | 50 |
| 50,000 | 24 min. | 1 | 2 | 10 |
| 100,000 | 12 min. | 30 min. | 1 | 5 |

## 4.5. Personal protective equipment

For events involving radioactive materials, civil protection and emergency services including the police and medical services will divide the site of the event into three zones: cold zone, warm zone, and hot zone, with various recommendations regarding the personal protective equipment of workers in each zone [12]. In the cold zone, there are no requirements for personal protective equipment; in the warm zone, personal protective equipment should be adapted to the situation; and in the hot zone, special personal protective equipment should be used.

The need for personal protective equipment to prevent external and internal contamination depends upon the situation at hand, in particular whether airborne activity is present, and on the work to be conducted. Therefore, no general intervention level can be specified concerning when personal protective equipment should be used. For example, there is no reliable link between the measured dose rate and the concentration of radioactive materials in the air. Therefore, decisions concerning personal protective equipment must be based on an assessment of the circumstances and conditions prevailing in the actual exposure situation.

When planning radiation protection for emergency workers, the following points should be taken into account regarding the need for personal protective equipment:

- Protective clothing should be considered in contaminated areas that are cordoned off, evacuated or where sheltering is recommended for the public.
- In connection with emergency response efforts and medical examinations of individuals who may be contaminated, it is important to protect emergency responders. Ordinary personal protective equipment and hygiene procedures are effective in limiting the spread of contamination.
- Respiratory protection should be used in situations where significant amounts of airborne activity may occur. This may be the case, for example, in situations of ongoing fire in combination with radioactive materials, where there is a risk of the radioactive materials being released.
- When the release has ceased, respiratory protection is normally not warranted. One exception is situations where significant *resuspension* can be expected, for instance in dusty work on contaminated soil.

Based on concentrations of radioactive materials in the air, Table 4 can be used to assess committed effective doses. Normally, information on air concentrations is not available in connection with emergency response. Instead, the table can be used as a reference in planning in order to provide a general idea of potential doses from inhalation of different types of radioactive materials present in the air.

**Table 4.** Committed effective dose after inhalation of radioactive materials at various concentrations in the air. The values are calculated based on an exposure for 8 hours for an unprotected person with a breathing rate of 1 $m^3/h$. The listed nuclides with associated choice of dose coefficients [14] may be considered to be conservatively representative of each type of radiation.

| **Air concentration (Bq/m³)** | **Committed effective dose for 8 hours (mSv)** Gamma-emitters (Cs-137) | Beta-emitters (Sr-90) | Alpha-emitters (Am-241) |
|---:|---:|---:|---:|
| 1 | 0.00 | 0.00 | 0.31 |
| 10 | 0.00 | 0.01 | 3.1 |
| 100 | 0.01 | 0.12 | 31 |
| 1,000 | 0.05 | 1.2 | 310 |
| 10,000 | 0.54 | 12 | 3,100 |
| 100,000 | 5.4 | 120 | 31,000 |
| 1,000,000 | 54 | 1,200 | 310,000 |

## 4.6. Life-saving actions

Prompt actions to save lives can be taken in all practically conceivable cases:

- Remove the exposed person from the area at risk,
- Regularly rotate emergency responders if for some reason the exposed person cannot be easily moved from the area at risk.

Life-saving actions in this context refers to a prompt intervention to save lives in a radiological emergency. Nuclear emergencies are not considered in this section. An example of such a radiological emergency would be a severely injured person near a source who needs immediate medical care. In many potential cases, the exposure is not life-threatening, but other circumstances are. Nevertheless, exposure to ionising radiation is always an aggravating circumstance, not the least for the personnel who are to carry out the life-saving actions.

This section is based on the potentially dangerous sources that may occur in activities and acts involving ionising radiation giving rise to a radiological emergency, such as transport accidents involving a radioactive source. As a planning basis for life-saving actions, Table 5 and Table 6 present activity levels for different radioactive materials at various distances where an emergency worker at work for a few minutes is at risk of exceeding the value of the dose limit, 20 mSv effective dose. The tables show that high levels of activity are required before emergency workers carrying out a prompt life-saving action are exposed to levels above the value of the dose limit.

**Table 5.** Activity levels for different radioactive materials at three different distances where an emergency worker at work for one minute is at risk of exceeding the value of the dose limit, 20 mSv effective dose. The calculations assume that the emergency worker wears a protective mask that prevents inhalation of radioactive material. When comparing to numbers in Table 1, note that the units used here are terabecquerels, 1 TBq = 1,000 GBq.

| | Activity (TBq) for sources where work for 1 minute gives 20 mSv | | |
|---|---|---|---|
| **Nuclide** | **1 metre** | **2 metres** | **5 metres** |
| Fluorine-18 | 7.5 | 30 | 180 |
| Cobalt-60 | 3.2 | 13 | 81 |
| Selenium-75 | 18 | 75 | 460 |
| Molybdenum 99 | 36 | 140 | 900 |
| Technetium-$99^m$ | 54 | 210 | 1,300 |
| Iodine-131 | 19 | 77 | 480 |
| Caesium-137 | 13 | 52 | 320 |
| Iridium-192 | 9.1 | 36 | 220 |
| Americium-241 | 63 | 250 | 1,500 |

Strong radiation sources at the activity levels presented in the tables are subject to far-reaching requirements regarding, among other things, storage, handling and transport. It is therefore unlikely that a source with an activity at the same level as those listed in the tables will be found completely unshielded in, for example, an accident involving transport of radioactive materials. The calculations on which the tables are based provide a significant safety margin in most cases, since it is assumed that the source is for some reason completely unshielded.

In Table 5, the emergency worker is assumed to be near the source for one minute. The table can be used to plan for prompt life-saving actions, for example, when one or more persons need to be moved away from a source. In emergency planning, it is important for responsible parties to investigate what activities are conducted in the area where the party has a responsibility and what types of sources can be expected. Based on this inventory, a risk analysis that takes into account potential radiological emergencies can be conducted. Only in isolated cases will the analysis include radiation sources with activities at the levels presented in Table 5. Such isolated cases should be subject to specific planning.

In Table 6, the life-saving actions are instead assumed to last for five minutes and the activity levels in the table are therefore one-fifth of the values presented in Table 5, disregarding rounding errors. Table 6 can be used to support planning for more complex life-saving actions, e.g. when for some reason a person cannot be easily moved from the area at risk. In order for doses to remain below the value of the dose limit, i.e. 20 mSv, the personnel may need to be rotated if the work is expected to take longer.

**Table 6.** Activity levels for different radioactive materials at three different distances where an emergency worker at work for five minutes is at risk of exceeding the value of the dose limit, 20 mSv effective dose. The calculations assume that the emergency worker wears a protective mask that prevents inhalation of radioactive material. When comparing to numbers in Table 1, note that the units used here are tera-becquerels, 1 TBq = 1,000 GBq.

| | Activity (TBq) for sources where work for 5 minutes gives 20 mSv | | |
|---:|---:|---:|---:|
| **Nuclide** | **1 metre** | **2 metres** | **5 metres** |
| Fluorine-18 | 1.5 | 6.0 | 37 |
| Cobalt-60 | 0.65 | 2.6 | 16 |
| Selenium-75 | 3.7 | 15 | 93 |
| Molybdenum 99 | 7.2 | 28 | 180 |
| Technetium-$99^m$ | 10 | 43 | 270 |
| Iodine-131 | 3.8 | 15 | 96 |
| Caesium-137 | 2.6 | 10 | 65 |
| Iridium-192 | 1.8 | 7.3 | 45 |
| Americium-241 | 12 | 50 | 310 |

In the vast majority of potential radiological emergencies, the radiation source has an activity well below the levels listed in Tables 5 and 6. Prompt life-saving actions during emergency response for a few minutes near the source will then result in doses below the value of the dose limit for workers even if the source would be completely unshielded. It is also possible to set higher reference levels for emergency workers in connection with life-saving emergency response efforts (see 4.3). From a radiation protection perspective, it is therefore a reasonable conclusion that prompt life-saving actions should, as a general rule, always be possible to effectuate, as is made clear in the summary box at the beginning of this section.

During a radiological emergency, information on the source and monitoring data provide the radiological situation on site. However, so as not to delay the life-saving actions, simple guidelines concerning rotating personnel regularly, such as every minute, are appropriate while waiting for the monitoring results. For this reason, plans for emergency response including life-saving actions should include time limits for rotation of emergency responders. The planning should also encompass how time limits are to be adapted to the prevailing circumstances.

# 5. Termination of a nuclear or radiological emergency

## 5.1. Prerequisites for the termination

A transition from the nuclear or radiological emergency to a planned or existing exposure situation may begin once the nuclear or radiological emergency is under control, i.e. when:

1. there is no longer a need to take additional urgent or early protective actions;
2. new events that may result in the need for urgent or early protective actions are unlikely;
3. the future development of the situation is well understood [15].

Under the Swedish Radiation Protection Ordinance, the reference level for an existing exposure situation is not allowed to be set higher than 20 mSv effective dose over the course of one year. Thus, establishing a reference level below this limit is one of the prerequisites for terminating the emergency. For smaller incidents with minor consequences, the transition and termination can take place relatively quickly, while for incidents with extensive releases and dispersion of radioactive materials, it may take longer before it is possible to bring the nuclear or radiological emergency under control and terminate it.

The nuclear or radiological emergency can be terminated by the decision of the incident commander to terminate rescue services. The emergency can therefore be terminated at different times in different areas, depending upon where and when the criteria for rescue services under the Swedish Civil Protection Act are no longer met. Upon termination of rescue services, the owner or the holder of the right-of-use to the property subjected to the emergency response efforts must, when feasible, be informed of the need for monitoring, residual value protection, decontamination, and restoration. Finally, other parties will take over responsibility after the termination of rescue services, which means that any decision on continued protective actions needs to be made on the basis of legislative provisions other than the Swedish Civil Protection Act, for example for evacuated areas where the public cannot return due to exposure from ground contamination.

## 5.2. Termination of public protective actions

### 5.2.1. Sheltering

As mentioned earlier, sheltering is warranted for radiological reasons if the nuclear or radiological emergency may lead to the dispersion of radioactive materials in the air in such quantities that the dose criterion may be exceeded. Decisions on when sheltering should be terminated are based, among other things, on information that the release of radioactive materials has ceased, which gradually leads to reduced activity concentration in the air. Time (duration) is also an important factor. Since prolonged sheltering quickly entails many disadvantages for the individual and the society-at-large, other protective actions or lifting the recommendation to shelter should be considered if the overall length of sheltering becomes too long. How quickly problems arise during sheltering depends on external factors and on the individual. For example, for people in need of medical care at home, problems can arise after a few hours.

Once the radioactive materials from the release are deposited on the ground, sheltering provides only limited protection. Sheltering should then be terminated as soon as practicable. If the ground deposition is too high for the public to remain in the area after sheltering has been terminated, evacuation pending the restoration of the area may need to be considered.

### 5.2.2. Evacuation

In the event of an emergency at a nuclear power plant, extensive areas may need to be evacuated. For most events in emergency preparedness category IV, small areas are potentially affected, such as the place and immediate surrounding area where the accident occurred in the event of an accident during the transport of radioactive materials, individual premises and buildings, or parts of a community in the event of the dispersion of radioactive materials. The basic prerequisites for terminating evacuation are that the situation is under control and that projected doses to residents in the evacuated area can be calculated and found to be lower than the dose criterion for evacuation. Additional conditions in connection with the termination of evacuation are discussed above in the section on prerequisites for the termination. It is therefore unlikely that evacuation will be terminated before the termination of the emergency and rescue services.

## 5.3. Protection of the public

After the termination of the nuclear or radiological emergency, an area with elevated radiation levels will constitute an existing exposure situation. After most events in emergency preparedness category IV, no extensive area is likely to be contaminated at levels that pose a radiation protection problem. If an area nevertheless becomes contaminated, a reference level for the public in the existing exposure situation may be established by the Government of Sweden or SSM under the Swedish Radiation Protection Ordinance. Measures to keep the exposure below the reference level will then need to be taken, including remedial actions to reduce the contamination and facilitate the return to normal life.

However, for small areas with residual contamination following an event in emergency preparedness category IV, it is unlikely that anything other than the complete restoration would be acceptable to the general public. In practice, this means that remedial actions will need to be taken to comply with clearance levels that apply for planned exposure situations, in accordance with SSM regulations [16]. This means, among other things, that radioactive contamination should be removed as far as feasible and reasonable, and that the expected dose to the public from the contamination must be less than 0.1 mSv per year. The work with the restoration of such areas will therefore bear many similarities to the decontamination and clearance of areas contaminated by planned activities involving ionising radiation.

If no areas have residual contamination after the termination of the emergency, there is no existing exposure situation. Instead, in this case, there will be a direct return to the exposure situation that prevailed before the nuclear or radiological emergency.

## 5.4. Protection of workers during decontamination activities

Exposure of workers performing tasks in an area with elevated radiation levels after the termination of a radiological emergency should be considered to be a planned exposure situation [7]. Decontamination of an area contaminated in connection with a nuclear or radiological emergency is an activity subject to the obligation to obtain a licence under the Swedish Radiation Protection Act and, as for other planned activities, the radiological protection principles of justification, optimisation, and the application of dose limits apply. Provisions concerning radiation protection for those operating or engaged in decontamination activities, i.e. activities with ionising radiation, are contained in the Swedish Radiation Protection Act, the Swedish Radiation Protection Ordinance and SSM regulations [4].

## Contributions to the report

The authors appreciate the valuable contributions of all the consultative bodies that have submitted comments and made suggestions for improvement. In particular, we wish to express our appreciation to Karl Östlund, Pelle Postgård and Mats Ardbreck at the Swedish Civil Contingencies Agency, Åsa Ljungquist at the Swedish National Board of Health and Welfare and the National Board of Health and Welfare's Nuclear Medical Expert Group (RN-MeG).

# References


[1] Nordic radiation protection and nuclear safety authorities, ”Protective Measures in Early and Intermediate Phases of a Nuclear or Radiological Emergency, Nordic Guidelines and Recommendations, 2014,” 2014.

[2] Swedish Radiation Safety Authority, ”Report 2017:27e Review of Swedish emergency planning zones and distances,” 2017.

[3] International Atomic Energy Agency (IAEA), ”Preparedness and Response for a Nuclear or Radiological Emergency, GSR Part 7,” 2015.

[4] ”The Swedish Radiation Safety Authority's regulations concerning basic provisions for licensable activities involving ionising radiation (SSMFS 2018:1)”.

[5] Swedish Radiation Safety Authority, ”Risk- och sårbarhetsanalys (SSM2018-3446) (In Swedish),” 2018.

[6] International Atomic Energy Agency (IAEA), ”Dangerous Quantities of Radioactive Material (D-Values),” 2006.

[7] International Commission on Radiological Protection (ICRP), ”Publication 103 - The 2007 Recommendations of the International Commission on Radiological Protection,” 2007.

[8] Government of Sweden 1985/86:170, ”om räddningstjänstlag, m.m. (In Swedish),” 1986.

[9] Council of the European Union, Council Directive 2013/59/Euratom of 5 December 2013, 2013.

[10] Swedish Radiation Safety Authority, ”Rapport 2019:11 Behov av personsanering för allmänheten i samband med svensk kärnkraftsolycka (In Swedish),” 2019.

[11] Swedish Radiation Safety Authority, ”Rapport 2019:28 Avståndsberäkningar kring svenska kärnkraftverk – Underlag till hälso- och sjukvården vid planering av beredskapen för kärnkraftsolyckor i Sverige (In Swedish),” 2019.

[12] Swedish Civil Contingencies Agency (MSB), ”Först på plats vid händelser med farliga ämnen CBRNE (In Swedish),” MSB1423, 2019.

[13] Government of Sweden 2017/18:94, ”Ny strålskyddslag (In Swedish),” 2018.

[14] International Commission on Radiological Protection (ICRP), ”Publication 119 - Compendium of Dose Coefficients based on ICRP 60,” 2012.

[15] International Atomic Energy Agency (IAEA), ”Arrangements for the Termination of a Nuclear or Radiological Emergency, GSG-11,” 2018.

[16] ”The Swedish Radiation Safety Authority's regulations concerning exemptions from the Radiation Protection Act and concerning the clearance of materials, building structures and sites (SSMFS 2018:3)”.

[17] Harper F. T. et al., ”Realistic radiological dispersal device hazard boundaries and ramification for early consequence management decisions,” Health Physics 93(1): 1-16, 2007.

[18] Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), ”The 2000 Reference Accident Used to Assess the Suitability of Australian Ports for Visits by Nucelar Powered Warships,” 2000.

[19] ”The Special Issue on Experiments Involving the Outdoor Energetic Release of Radioactive Materials,” Health Physics 110(5), 2016.

# Appendix 1 – Glossary

**Absorbed dose** is a physical quantity indicating how much energy the ionising radiation deposits in a material, such as tissue or an organ in the body. The unit for absorbed dose is the gray (Gy).

**Committed dose** is the integrated equivalent or effective dose during 50 years for adults and 70 years for children from internal exposure after inhalation or ingestion of radioactive materials.

**Deterministic effects** are health effects characterised by a threshold dose and increasing severity with increased dose. The threshold dose for a deterministic effect to arise depends on the type of health effect and to some extent also on the individual. An example of a deterministic effect is erythema. At high doses where the health effect is not transient, severe deterministic effects may occur.

**Dose** is absorbed, committed, equivalent, or effective dose.

**Dose criterion** is a value of dose that a person may receive if no protective actions are taken. Where a dose criterion for a particular protective action has been exceeded or is likely to be exceeded, as a general rule the protective action should be taken. See section 2.4.4.

**Dose limit** is a value of dose that may not be exceeded for a given individual during a specified period of time.

**Dose rate** is dose per unit of time and is given in sievert (Sv) per unit of time. Radiation levels at a site can be measured by an instrument that usually indicates ambient dose equivalent per unit of time (ambient dose equivalent rate or only dose rate).

**Effective dose** is a protection quantity that is a measure of the overall risk of stochastic effects. The effective dose is calculated as the sum of all equivalent doses from the tissues and organs of the body, weighted by a factor that takes into account the fact that different tissues and organs have different sensitivities to exposure from ionising radiation. The unit for effective dose is the sievert (Sv).

**Equivalent dose** is a protection quantity that is a measure of the risk of stochastic effects for a specific tissue or organ. The equivalent dose is calculated as the sum of all the absorbed doses by the different types of radiation, weighted by a factor that takes into account the biological effects of different radiation types in tissues and organs. The unit for equivalent dose is the sievert (Sv).

**Events in emergency preparedness category IV** include nuclear or radiological emergencies that may occur in activities involving ionising radiation or as a result of accidents and criminal acts, but where the location is not known in advance. Examples of events in emergency preparedness category IV are accidents involving nuclear-powered vessels or transport accidents involving radioactive sources and antagonistic acts with radioactive materials.

**Ionising radiation** is electromagnetic radiation or particle radiation with enough energy to ionise matter, i.e. release electrons from atoms and molecules.

**Operational intervention level (OIL)** is a value of a measurable quantity (e.g. dose rate) linked to a particular protective action which, when exceeded or expected to be exceeded, means that in most cases the protective action should be taken. See section 2.4.5.

**Optimisation** of radiation protection means limiting, as far as reasonably achievable, and taking existing technical knowledge and financial and societal factors into account: 1) the likelihood of exposure; 2) the number of persons exposed; and 3) the size of the individual dose. See section 2.4.2.

**Potentially dangerous source** is a term used in this report and refers to a category 1-4 source according to SSM regulations (SSMFS 2018:1).

**Projected dose** is the dose that can be expected to be incurred by an unprotected person if no protective actions are taken.

**Protective actions** are actions taken to reduce ongoing or potential human exposure to ionising radiation.

**Reference level** is a value for dose or activity concentration for optimising the radiation protection. See section 2.4.3.

**Residual dose** is the dose incurred after protective actions are implemented (or not).

**Resuspension** is a process by which radioactive substances deposited are then released again, e.g. by the wind or mechanical influence.

**Severe deterministic effects** are deterministic health effects (tissue reactions from ionising radiation) that arise as a direct result of exposure to ionising radiation and that are so severe that they are fatal, life-threatening or result in permanent harm that impairs quality of life.

**Stochastic effects** are random health effects that may arise in the long term as a result of exposure to ionising radiation. Their probability of occurring increases with increasing dose. However, the severity of the health effect, if it occurs, is independent of the size of the dose. One example of a stochastic health effect is cancer.

**Unprotected person** is a person that is outdoors without personal protective equipment and has not been evacuated.

# Appendix 2 – List of consultative bodies

Public Health Agency of Sweden
Swedish Coast Guard
Swedish Food Agency
Swedish Civil Contingencies Agency
Swedish Police Authority
Swedish National Board of Health and Welfare
Swedish Board of Agriculture
National Veterinary Institute
Swedish Security Service
Swedish Customs
Swedish Armed Forces
Swedish Defence Research Agency
County Administrative Board of Blekinge
County Administrative Board of Dalarna
County Administrative Board of Gotland
County Administrative Board of Gävleborg
County Administrative Board of Halland
County Administrative Board of Jämtland
County Administrative Board of Jönköping
County Administrative Board of Kalmar
County Administrative Board of Kronoberg
County Administrative Board of Norrbotten
County Administrative Board of Skåne
County Administrative Board of Stockholm
County Administrative Board of Södermanland
County Administrative Board of Uppsala
County Administrative Board of Värmland
County Administrative Board of Västerbotten
County Administrative Board of Västernorrland
County Administrative Board of Västmanland
County Administrative Board of Västra Götaland
County Administrative Board of Örebro
County Administrative Board of Östergötland
Fire and Rescue Service Syd
Fire and Rescue Service Greater Göteborg
Greater Stockholm Fire Brigade
Swedish Maritime Administration
Swedish Association of Local Authorities and Regions
Swedish Transport Administration
Swedish Transport Agency

# Appendix 3 – Dose criteria and operational intervention levels

Dose criteria public protective actions presented in this report are summarised in Table 7 and in Figure 6. For the evacuation of small areas, an operational intervention level is specified instead: 100 µSv/h. The dose criteria for various public protective actions presented in the table are identical to those previously published in connection with nuclear or radiological emergencies from events at facilities belonging to emergency preparedness categories I-III [2] [10].

**Table 7.** Summary of dose criteria for different public protective actions.

| Protective action | Dose criterion |
|---|---|
| Sheltering | 10 mSv effective dose in seven days |
| Evacuation of large areas | 20 mSv effective dose in seven days (during release) or one year (ground deposition) |
| Life-saving decontamination of individuals<br>Complete decontamination of individuals | 2 Gy RBE-weighted absorbed dose to the skin in 10 hours (100 $cm^2$ at a depth of 0.4 mm) |
| Organised decontamination of individuals | 500 mSv equivalent dose to the skin in seven days (1 $cm^2$ at a depth of 0.07 mm) |
| Information to reduce inadvertent ingestion | 1 mSv committed effective dose |

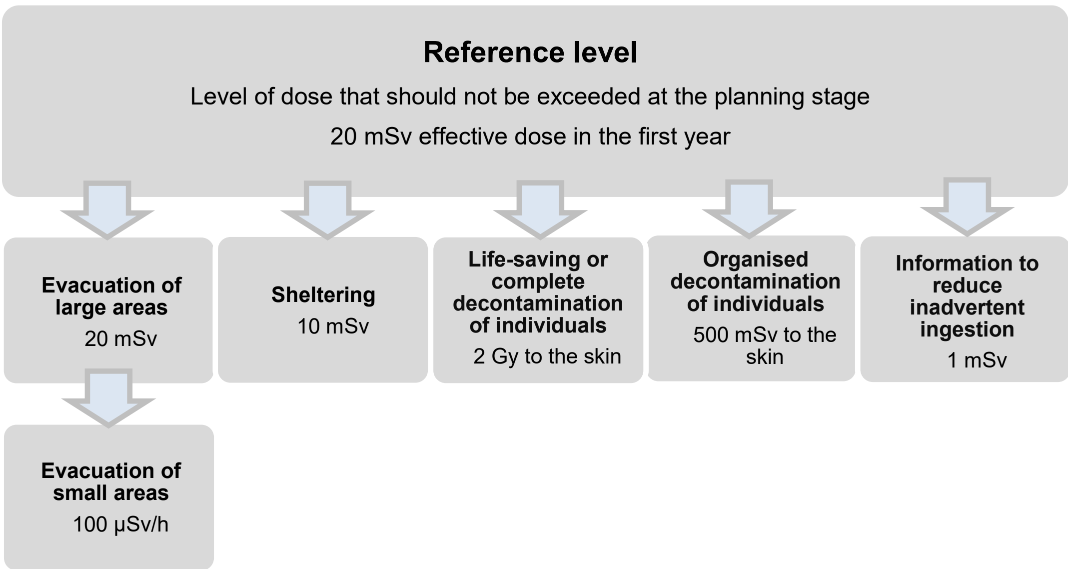


**Figure 6.** Illustration of the reference level, dose criteria and operational intervention levels of the various public protection actions presented in this report.

# Appendix 4 – Radiation protection in a transport accident, Class 7

This Appendix presents concise guidelines on radiation protection for first responders in the event of a transport accident with dangerous goods in Class 7 (radioactive materials). The appendix builds on the Swedish Civil Contingencies Agency's response measures calendar [12].

> If there is no reason to believe that the transport container is damaged, the accident may be dealt with according to ordinary procedures.

### Initially

If there is an indication of a damaged container, a leakage, spillage or fire, initially consider the following:

- Move individuals away from the source. Give first aid to any injured. Never delay life-saving actions due to the risk of radiation exposure. It is possible to stay for a short time even in high dose rates without exceeding the values of the dose limits.
- Always wear respiratory protection if there is a risk of release of radioactive materials into the air, for example by fire.
- Establish an initial inner cordoned off area according to Table 2 (50 - 300 metres).
- If monitoring instruments are available, establish the inner cordoned off area at a dose rate of 100 µSv/h. Ensure that risk of the effective dose to personnel exceeding the value of the dose limit (20 mSv = 20,000 µSv) is minimised.
- Use direct-reading dosimeters if they are available.
- Remain as short time as necessary in the area at risk.
- Keep the greatest practical distance from the source.
- Shield the source using, for example, concrete or steel.
- Make sure that no more personnel than necessary are present in the inner cordoned off area (no pregnant women).
- Do not touch objects within the inner cordoned off area unless necessary. If touching objects is necessary, wear gloves.
- Rotate personnel to limit the time each person stay in the inner cordoned off area.
- Note (if feasible under the circumstances), how long each person remains in the inner cordoned off area.

### Then

- Contact the Officer on Duty (TiB) at SSM via SOS Alarm on 08-454 24 66 or via the emergency number 112. TiB responds to calls within ten minutes and can provide advice on radiation protection based on available information from e.g. transport documents or monitoring results.
- Consider decontamination of individuals only if people may have been contaminated. Life-saving decontamination of individuals is unlikely to be needed

even in the event of dispersion of radioactive materials. Regular protective clothing and hygiene procedures used by the emergency services and healthcare professionals provide good protection.

## Finally

- If it is necessary to handle the source, do so only when monitoring instruments and access to radiation protection expertise are available.

The Swedish Radiation Safety Authority works proactively and preventively with nuclear safety, radiation protection and nuclear non-proliferation in order to protect people and the environment from the harmful effects of radiation, now and in the future.

You can download our publications from www.stralsakerhetsmyndigheten.se/en/publications. If you need alternative formats such as easy-to-read, Braille or Daisy, contact us by email at registrator@ssm.se.

**Strålsäkerhetsmyndigheten**
171 16 Stockholm
08-799 40 00
www.stralsakerhetsmyndigheten.se
registrator@ssm.se



E-print AB, 2023