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Swedish Radiation Safety Authority

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Review of Swedish emergency planning zones and distances

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Summary

On 22 October 2015, the Government of Sweden commissioned the Swedish Radiation Safety Authority (SSM) to, in consultation with the Swedish Civil Contingencies Agency (MSB), relevant county administrative boards and the other authorities and stakeholders concerned, perform a review of emergency planning zones and emergency planning distances applying to activities involving ionising radiation.

In this report, SSM presents proposed emergency planning zones and emergency planning distances to surround the nuclear power plants at Forsmark, Oskarshamn and Ringhals, a proposed emergency planning zone around the fuel fabrication plant of Westinghouse Electric Sweden AB in Västerås (hereinafter 'the fuel fabrication plant'), and a proposed emergency planning distance to surround Clab, the central interim storage facility for spent nuclear fuel, which is located north of Oskarshamn. SSM also accounts for the standpoints serving as the basis of these proposals. These include overall objectives, the activities which in the assessment of SSM are encompassed by the assignment, the types of emergency planning zones and emergency planning distances that should be established, reference levels that should serve as the basis of emergency planning and dose criteria, and intervention levels for different protective actions.

SSM has postulated events for the relevant activities serving as the basis of the proposed emergency planning zones and emergency planning distances. For these events, the Authority has defined representative source terms that describe the releases assumed to follow the respective type of event. Thereafter, SSM has used dispersion and dose calculations to produce a statistical basis for estimating the distances at which it is justified to take different types of protective actions. Based on these distances, the final proposals for emergency planning zones and planning distances to surround the nuclear power plants, the fuel fabrication plant and Clab have been produced by the respective county administrative boards of Uppsala, Kalmar, Halland and Västmanland in collaboration with SSM and MSB.

It is proposed by SSM that the nuclear power plants should be surrounded by a precautionary action zone (PAZ) extending approximately 5 kilometres, and an urgent protective action planning zone (UPZ) extending approximately 25 kilometres. The emergency planning zones are to have planning in place for evacuation, sheltering and iodine thyroid blocking (ITB). Furthermore, information and ITB should be distributed in advance and warnings to the public should be pre-planned. Planning for evacuation of the public is to enable prioritisation of evacuation of the PAZ ahead of evacuation of the UPZ. It is also proposed by SSM to have an extended planning distance (EPD) surrounding the nuclear power plants that extends 100 kilometres. Within the EPD, planning should be in place for relocation based on input from measurements of ground deposition, sheltering, and limited distribution of ITB.

It is proposed by SSM to have the fuel fabrication plant in Västerås surrounded by an UPZ extending approximately 700 metres. Within the UPZ, planning should be in place for sheltering. Outside the site of the fuel fabrication plant, SSM has assessed that no ground deposition can occur in connection with emergencies that justify an EPD.

Moreover, it is proposed by SSM to have Clab surrounded by an EPD extending 2 kilometres. Within the EPD, planning should be in place for relocation based on input from measurements of ground deposition. Outside the site of the Clab facility, it has been assessed by SSM that no radiation doses can occur in connection with emergencies that

justify an emergency planning zone. For this reason, the present emergency planning zone should be discontinued.

SSM has, as part of its step-wise licensing review of European Spallation Source ERIC (ESS) in Lund, assessed that emergency planning for the public may be required outside the site of the ESS facility. However, the ESS research facility is not discussed in this report. At the time of carrying out this assignment, there was a lack of sufficient input, thus preventing a final standpoint from being taken relating to emergency planning zones or distances surrounding this facility.

As part of this review of emergency planning zones and emergency planning distances, SSM has looked into the emergency preparedness categories applying to the nuclear facilities at the Studsvik site, and has determined that none of these are to belong to emergency preparedness category II under the Authority's regulations. Therefore, in the assessment of SSM, there is no longer a need for emergency planning zones or emergency planning distances surrounding the nuclear activities taking place at the Studsvik site. Thus, the present emergency planning zone should be discontinued.

In the cases of the nuclear power plants, fuel fabrication plant and Clab, SSM also presents analyses of residual doses, i.e. the possible radiation doses that may occur assuming that the proposed protective actions that should be prepared in the emergency planning zones and emergency planning distances can be implemented in connection with a radiological or nuclear emergency. In addition, SSM presents analyses of needed measures in food production and the possible need for remediation brought about by emergencies at the relevant facilities. The results from these analyses may serve as planning input for regulatory authorities with mandates in the areas of foodstuffs and remediation in connection with releases from nuclear facilities.

SSM proposes, in consultation with MSB, the needed amendments to the *Civil Protection Ordinance (2003:789)* to enable implementation of the proposed new emergency planning zones and emergency planning distances. Together with MSB and the county administrative boards of Uppsala, Kalmar, Halland and Västmanland, SSM has estimated the economic impacts of these proposals. If the proposals are implemented, they are estimated to lead to increased administrative expenses annually totalling approximately SEK 24 million, in addition to today's appropriation of SEK 48 million. Other costs are incurred when implementing the proposals; these amount to approximately SEK 5.5 million per year over a three-year period. SSM wishes to emphasise the possibility that some of the costs may be lower than estimated, mainly depending on the choice of technical solution for warning the public in the new emergency planning zones. SSM suggests that the higher level of costs for the Swedish state brought about by the proposals should be financed by means of the emergency planning fee stipulated by *Ordinance 2008:463 concerning certain fees imposed by the Swedish Radiation Safety Authority*.

During the efforts to propose new emergency planning zones and emergency planning distances, SSM consulted with MSB and the relevant county administrative boards. Here, three areas were identified as needing further investigation. These areas are the following: systems for warning the public in the proximity of nuclear power plants, mandates for dealing with and recommending intake of ITB, and the emergency classes currently applied by nuclear facilities in Sweden.

Contents

1. Assignment and background

1.1. Emergency planning zones and distances

Emergency planning zones and emergency planning distances are geographical areas relating to certain activities involving ionising radiation. Within these areas, protective actions are prepared. These preparations give capacity for implementation of effective protective measures for the public in connection with an emergency at a facility that affects the surroundings. Certain protective actions in the emergency planning zones and emergency planning distances (hereinafter frequently condensed as 'emergency planning zones and distances') are implemented immediately when a certain emergency class is declared, e.g. sheltering in connection with a general emergency at a nuclear power plant; whereas other protective actions are taken based on a forecast sequence of events, or on the basis of input from radiation measurements. Decisions concerning protective actions that are not implemented immediately in the emergency planning zones and distances should always be adapted to prevailing conditions, e.g. weather conditions or other factors affecting the potential to carry out these actions. This means that protective actions prepared in an emergency planning zone or emergency planning distance may be fully implemented, or to some extent, or not at all, in the event of an emergency.

1.2. Present emergency planning zones and distances

The nuclear power plants in Sweden are presently surrounded by an emergency planning szone extending 12 to 15 km and an emergency planning distance extending approximately 50 km. The emergency planning zones and distances surrounding nuclear power plants are regulated by the *Civil Protection Ordinance (2003:789)*. Within the emergency planning zones, systems are in place for indoor and outdoor alarms, and iodine thyroid blocking (ITB) and information concerning measures to be taken by local residents in the event of an alert from a nuclear power plant have been predistributed; also, planning is in place for evacuation. Within the emergency planning distance, planning is in place for measuring radiation. Such measurements are to enable decision making on protective actions. The emergency planning distance also has planning in place for limited distribution of ITB.

Today, the county administrative boards of Västmanland, Kalmar and Södermanland have emergency planning zones established surrounding these facilities: Westinghouse Electric Sweden AB's fuel fabrication plant in Västerås (hereinafter 'the fuel fabrication plant'); the Swedish Nuclear Fuel and Waste Management Company's (SKB) facility, Clab, which is a central interim storage facility for spent nuclear fuel located north of Oskarshamn; and Studsvik Nuclear AB in Studsvik. However, these zones are not specified in the Civil Protection Ordinance.

1.3. Background

In 2014, SSM published the report *Emergency planning zones and emergency planning distances surrounding nuclear facilities in Sweden* (SSM 2014:36). This report provides an analysis of various factors that impact on, or which may have an influence on, the design of emergency planning zones and distances surrounding nuclear facilities in Sweden. This analysis shows that there are inadequacies in the design of today's emergency planning zones and emergency planning distances.

Geographically, emergency planning zones surrounding nuclear power plants are defined by telephone exchange areas. These areas lost their original significance in the early 1990s. Also, these obsolete telephone exchange areas lack natural geographical boundaries, which makes them unsuitable for defining today's emergency planning zones.

Emergency planning distances surrounding nuclear power plants are geographically defined on the basis of municipal and parish boundaries. However, the parishes stated in the Civil Protection Ordinance have in several cases been merged with other parishes and been renamed. This is why the Ordinance to some extent refers to parishes that no longer exist. An additional perspective is that new parishes, not belonging to the original definition of emergency planning distances, have been created as part of the merging process, which in the long term risks causing uncertainty about the geographical boundaries of the emergency planning distances. The ambition of the Swedish Government when establishing the emergency planning distances was to also enable evacuation within these distances by utilising civil defence planning for urban areas. As the civil defence system has largely been dismantled since then, there is a reduced capacity for evacuating parts of the emergency planning distances.

A new radiation safety directive (Council Directive 2013/59/Euratom) was adopted in 2013 and is to be implemented in Swedish law by 6 February 2018. The radiation safety directive does not impose explicit requirements for emergency planning zones and emergency planning distances surrounding activities involving ionising radiation. On the other hand, there are requirements for establishing reference levels and preparing emergency preparedness plans to avoid exceeding the reference levels during an emergency exposure situation. This affects the design of emergency planning zones and distances, as it is in these areas where specifically defined protective actions should be prepared. Present emergency planning zones and emergency planning distances in Sweden are not designed on this basis.

The present emergency planning zones and distances surrounding nuclear power plants do not fulfil the comprehensive standard for emergency preparedness and response that has been issued by the International Atomic Energy Agency (IAEA). In particular, there is no surrounding zone close to the nuclear power plants within which precautionary evacuation can quickly be carried out in case of a nuclear emergency.

Present Swedish emergency planning zones and distances are not sufficient for dealing with releases of the magnitude that occurred during the nuclear power plant accident that took place in Japan in 2011. Japanese authorities had already by midday on 12 March, less than 24 hours after the accident began, decided to evacuate an area extending 20 km from Fukushima Daiichi. On 15 March, the Japanese authorities advised sheltering in an area between 20 and 30 km from the nuclear power plant. On 25 March, this recommendation was changed to voluntary evacuation within the same area. In comparison, Sweden only has evacuation plans established for the emergency planning zones, i.e. the areas extending 12 to 15 km from the nuclear power plants.

In Japan, the authorities took decisions on distributing ITB, though no distribution took place following this decision. In retrospect, Japanese authorities have concluded that intake of ITB would have been justified up to 50 km from Fukushima Daiichi. In Sweden, ITB is predistributed in the emergency planning zone, i.e. at distances extending 12 to 15 km from the nuclear power plants. The county administrative boards of the counties in Sweden where the nuclear power plants are situated have stocks of iodine tablets allowing for limited distribution in the emergency planning distances, i.e. at distances up to 50 km from these plants. However, there is no plan for carrying out this limited distribution of ITB in connection with rapid event sequences. National stocks of ITB are also kept in Sweden, but there is no plan for distribution of ITB from these stocks to potentially affected parts of the population in connection with a domestic nuclear power plant accident.

1.4. Assignment

On 22 October 2015, the Swedish Government commissioned the Swedish Radiation Safety Authority (SSM), in consultation with the Swedish Civil Contingencies Agency (MSB), relevant county administrative boards and other competent authorities and stakeholders, to perform a review of emergency planning zones and emergency planning distances applying to activities involving ionising radiation (decision document M2015/03597/Ke). The assignment has the task of giving answers in the following areas:

- Emergency planning zones and emergency planning distances needed in the future
- Specific activities involving ionising radiation that should be encompassed by the Civil Protection Ordinance (2003:789)
- Recommended criteria by geographical area and pre-planned measures for the respective emergency planning zones and emergency planning distances.

Responses to the following areas in question are also to be presented:

- Proposed measures to rectify the weaknesses identified in the Swedish Radiation Safety Authority’s report, *Emergency planning zones and emergency planning distances surrounding nuclear facilities in Sweden* (SSM 2014:36)
- Proposed requisite amendments to legislation
- Potentially increased costs for central or local government, or for businesses or individuals
- Proposed financing (in the event of cost increases on the part of the Swedish state)
- Other socioeconomic impacts.

Full reporting to the Swedish Government on the assignment was scheduled for 1 April 2017 at the latest. On 1 December 2016, SSM requested an extension for completion of the assignment (SSM2015-4786-38). On 19 January 2017, the Government took the decision to have the assignment fully reported on by 1 November 2017 (M2016/02870/Ke).

1.5. Approach

A working party at SSM was in charge of carrying out the Government assignment. A steering group comprising representatives from SSM, MSB, and the county administrative boards of Uppsala, Kalmar, Halland, Västmanland, Södermanland and Skåne took decisions in areas of principal and strategic importance. An external working party comprising representatives from the same authorities that took part in the steering group dealt with all issues shared by the authorities. The representatives of the external working party were also in charge of performing tasks assigned to one's own authority.

The county administrative boards discussed the proposals with other relevant stakeholders on a regional level, such as rescue services, incident commanders designated within nuclear emergency preparedness, police officers, relevant municipal authorities, the Swedish Transport Administration, Swedish Coast Guard, and county administrative boards of adjacent counties. SSM discussed these proposals with other relevant stakeholders on a national level, e.g. the National Food Agency, Swedish Board of Agriculture, National Board of Health and Welfare, and the Swedish Meteorological and Hydrological Institute (SMHI). SSM also informed neighbouring countries in the Nordic region about the proposals within the framework of day-to-day cooperation between Nordic radiation safety authorities. SSM also communicated about the Government assignment during local safety board meetings for all the relevant nuclear facilities. For the purpose of giving opportunities to other parties to provide viewpoints on these proposals, SSM, together with the county administrative boards and MSB, held a hearing at the offices of SSM. The hearing was broadcast live on the Web. SSM also received assistance in certain core areas, from expert authorities, universities and consultants.

The work was carried out in accordance with a plan for the Government assignment, see Table 1. When planning for execution of the Government assignment, SSM identified a number of key challenges. One key challenge was separating between facts and value judgements. Selection of postulated events serving as the basis of the proposed emergency planning zones and distances, the potential targets for preparations in the emergency planning zones and distances, plus the extent to which the proposed zones and distances should take into account unusual weather conditions, are examples of standpoints that are largely based on value judgements. In contrast, other tasks are more frequently based on the knowledge situation in Sweden and internationally. Examples of these tasks include the following: development of representative source terms, dose criteria and intervention levels, in addition to the parameters of dispersion and dose calculations. The ambition of SSM was to clearly present which tasks that are mainly based on value judgements, and which tasks that are more frequently based on the current knowledge situation.

Another key challenge that was identified is dealing with great uncertainties. An inherent part of rare events is their being characterised by many uncertainty factors, and that in many cases, there is a lack of empirical data as a starting point. This has been dealt with in the form of sensitivity analyses for the purpose of identifying the parameters of key significance for the proposed emergency planning zones and distances. SSM also presents possible alternative outcomes given the existing uncertainties, as well as the suitability of the proposed emergency planning zones and distances for other potential events, even those viewed as so unlikely that they did not serve as the basis of the proposals.

SSM also had the ambition of, as far as possible, utilising international experiences on setting up a good system for emergency preparedness and response for nuclear and radiological emergencies. The main tool for achieving this was the comprehensive standard for emergency preparedness and response, issued by the IAEA. This standard was established in consensus between all the member states, among them Sweden, and thus comprises a summary of collective international experience on the design of good emergency preparedness for nuclear and radiological emergencies.

Table 1. Plan for execution of the Government assignment.

No.	Task
1	Determine steering documents for the proposed emergency planning zones and emergency planning distances.
2	Determine the overarching objectives to serve as the basis of the proposed emergency planning zones and emergency planning distances.
3	Determine which activities involving ionising radiation that should have emergency planning zones and emergency planning distances.
4	Determine the types of emergency planning zones and emergency planning distances to be established.
5	Determine the reference levels, i.e. the targets expressed as effective dose to the representative person, given implementation of planned protective actions, to apply to the various events to serve as the basis of new emergency planning zones and emergency planning distances.
6	Produce dose criteria and intervention levels for urgent protective actions in emergency exposure situations based on selected reference levels. Also, produce intervention levels for remediation and food production.
7	Determine the postulated events to serve as the basis of emergency planning zones and emergency planning distances to surround the respective activity involving ionising radiation.
8	Produce representative source terms for the events to serve as the basis of the proposed emergency planning zones and emergency planning distances.
9	Produce statistical data including distances where dose criteria and intervention levels are exceeded. This data is to utilise dispersion and dose calculations.
10	Propose emergency planning zones and emergency planning distances based on an assessment of the percentage of occurring weather scenarios for which different protective actions should be prepared, the overarching objectives of the emergency planning zones and distances, plus the particular circumstances prevailing on the part of the respective activity.
11	Calculate residual doses to the representative person given the feasibility of different combinations of the proposed protective actions in the emergency planning zones and emergency planning distances.
12	Compute costs incurred due to the proposed emergency planning zones and emergency planning distances on the part of the state, municipal authorities, businesses and individuals; also, estimate other socioeconomic impacts.
13	Produce proposed requisite amendments to Swedish legislation if the proposed new emergency planning zones and emergency planning distances are to be implemented.
14	Produce proposals on financing of new emergency planning zones and emergency planning distances if the level of costs increases for the state.
15	Consult with other stakeholders affected by the proposed new emergency planning zones and emergency planning distances.

2. The foundations of new emergency planning zones and distances

In this chapter, SSM accounts for the standpoints and the parameters used to produce the proposed emergency planning zones and emergency planning distances. First, a presentation is made of the documents defining this work, in addition to the objectives to be met by the design of the emergency planning zones and distances. This is followed by an account of the facilities that should have emergency planning zones and emergency planning distances, as well as the types of emergency planning zones and distances that should be established. Lastly, a presentation is made of the reference levels used to produce the proposed approximate ranges of the emergency planning zones and distances, in addition to the dose criteria and intervention levels used in the calculations.

2.1. Steering documents

As part of the preparations to propose new emergency planning zones and distances, SSM identified a number of key steering documents. These documents contain requirements and recommendations relating to emergency planning zones and distances, whose fulfilment is the ultimate aim of the present proposals. Table 2 presents these documents. Requirements contained in ordinances and directives from the EU must be met. Requirements imposed by Swedish acts and ordinances must be fulfilled, with the exception of necessary amendments to Swedish legislation deriving from the proposed new emergency planning zones and distances. Requirements contained in comprehensive standards from the IAEA are to be met to the extent they are compatible with the Swedish emergency management system and with Swedish legislation.

Table 2. Key steering documents applicable to the assignment to review emergency planning zones and distances.

Document	Description
Council Directive 2013/59/Euratom of 5 December 2013 (the 'radiation safety directive')	The radiation safety directive lays down basic safety standards for protection against the dangers arising from exposure to ionising radiation. The Council Directive stipulates requirements both for emergency exposure situations and existing exposure situations arising due to nuclear or radiological emergencies. It imposes requirements for emergency management systems, emergency preparedness for emergency exposure situations, in addition to international cooperation prior to and during an emergency.
Civil Protection Act (2003:778).	The Act regulates satisfactory and uniform protection of human lives, human health, property and the environment against emergencies. It regulates the mandates for dealing with nuclear and radiological emergencies, as well as situations following such emergencies.
Civil Protection Ordinance (2003:789).	The Ordinance regulates in more detail the provisions contained in the Civil Protection Act. It regulates not only local and central government rescue services in connection with nuclear and radiological emergencies, but also remediation following emergencies at nuclear facilities.
IAEA Safety Fundamentals - Fundamental Safety Principles (IAEA SF-1)	IAEA SF-1 contains fundamental principles for radiation protection and safety.
IAEA Safety Requirements – Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (IAEA, GSR Part 3)	The IAEA's GSR Part 3 comprises the comprehensive standard in the field of radiation protection.
IAEA Safety Requirements – Preparedness and Response for a Nuclear or Radiological Emergency (IAEA, GSR Part 7)	The IAEA's GSR Part 7 comprises the comprehensive standard in the field of emergency preparedness and response.

2.2. Overarching objectives

When producing the proposed emergency planning zones and emergency planning distances, geographic ranges, and the suggestions for pre-planned protective actions, SSM based its work on the following overarching objectives:

- Severe deterministic effects can be avoided
- The risk of stochastic effects can be reduced as far as reasonably achievable.

SSM also took into consideration the following objectives for the design of the emergency planning zones and distances, and the protective actions that should be prepared:

- Enabling effective emergency response
- Facilitating information arrangements
- Facilitating resumption of normal social and economic activity
- Maintaining the trust of the public
- Facilitating self-help actions of the public.

2.2.1. Background to selection of objectives

The steering documents presented in Table 2 define overarching objectives for preparedness for, and response to, nuclear and radiological emergencies. The radiation safety directive's Article 97 formulates an overarching objective for the emergency management system for nuclear and radiological emergencies:

> “The emergency management system shall be designed to be commensurate with the results of an assessment of potential emergency exposure situations and to be able to respond effectively to emergency exposure situations in connection with practices or unforeseen events.
>
> The emergency management system shall provide for the establishment of emergency response plans with the objective of avoiding tissue reactions leading to severe deterministic effects in any individual from the affected population and reducing the risk of stochastic effects, taking account of the general principles of radiation protection [justification and optimisation] and reference levels.”

The IAEA states the following goals for emergency response in a nuclear or radiological emergency:

- To regain control of the situation and to mitigate consequences;
- To save lives;
- To avoid or to minimize severe deterministic effects;
- To render first aid, to provide critical medical treatment and to manage the treatment of radiation injuries;
- To reduce the risk of stochastic effects;
- To keep the public informed and to maintain public trust;
- To mitigate, to the extent practicable, non-radiological consequences;
- To protect, to the extent practicable, property and the environment;
- To prepare, to the extent practicable, for the resumption of normal social and economic activity.[1]

[1] IAEA, GSR Part 7

2.3. Relevant facilities

SSM suggests that the activities involving ionising radiation that are classified by the Authority as belonging to emergency preparedness categories I and II should have emergency planning zones and distances. At the present time, the relevant facilities are:

- The nuclear power plants at Ringhals, Forsmark and Oskarshamn
- The fuel fabrication plant in Västerås
- Clab at Oskarshamn
- European Spallation Source ERIC (ESS) in Lund.

2.3.1. Background to the selection of facilities

The IAEA’s requirements in the field of emergency preparedness and response are defined on the basis of the consequences that a practice or activity can give rise to in connection with a nuclear or radiological emergency. The requirements for emergency preparedness and response are more extensive in conjunction with the higher level of risk associated with a certain practice or activity. The IAEA's GSR Part 7 requires identification and analysis of events occurring in a practice or activity that could lead to a nuclear or radiological emergency. The practice or activity must subsequently be classified into one of five emergency preparedness categories, depending on the assessed impacts:

- Emergency preparedness category I is attributed to a facility where on-site events might give rise to a nuclear or radiological emergency warranting precautionary urgent protective actions, urgent protective actions or early protective actions off-site to avoid severe deterministic effects and limit the risk of stochastic effects. Severe deterministic effects are injuries that are life threatening or permanent. One example of a facility belonging to emergency preparedness category I is a nuclear power plant during normal operation up until the reactor has been permanently shut down and all nuclear material has been removed from the reactor.
- Emergency preparedness category II is attributed to a facility where on-site events might give rise to a nuclear or radiological emergency warranting urgent protective actions or early protective actions off-site to avoid deterministic effects and limit the risk of stochastic effects. However, the relevant events are not assessed as being capable of giving severe deterministic effects off-site. Examples of facilities belonging to emergency preparedness category II include certain nuclear facilities other than nuclear power plants in operation.
- Emergency preparedness category III is attributed to a facility where on-site events might give rise to a nuclear or radiological emergency warranting protective actions on-site for the purpose of avoiding deterministic effects, including severe effects, and limiting the risk of stochastic effects. These events are not assessed as warranting protective actions being taken off-site. Examples of facilities belonging to emergency preparedness category III include certain nuclear facilities, in addition to activities involving sources of radioactivity in medical services, industry and academia.
- Emergency preparedness category IV is attributed to activities that could give rise to a nuclear or radiological emergency that might warrant urgent protective action in an unforeseen location. Here, examples of emergency preparedness category IV include shipments of nuclear waste, transports of dangerous mobile sources, and radiography using mobile equipment.

- Emergency preparedness category V encompasses areas within emergency planning zones and distances in a state for a facility belonging to emergency preparedness categories I and II located in another state.

The IAEA’s GSR Part 7 requires facilities classified as emergency preparedness category I or II to have emergency planning zones and distances.

2.3.2. Rationale behind SSM's selection of facilities

SSM classifies nuclear facilities into emergency preparedness category I or II, in accordance with the Authority’s official regulations (SSMFS 2014:2), if it is assessed by SSM that events can occur at the facility that warrant taking urgent protective actions off-site. Consequently, these types of facilities should have established emergency planning zones and distances surrounding them. Nuclear facilities classified as belonging to emergency preparedness category III, or that belong to no emergency preparedness category, are assessed by SSM as being incapable of giving rise to events at the facility that would warrant taking urgent protective actions off-site. Thus, these facilities do not need to be surrounded by any emergency planning zones or distances.

SSM has classified the nuclear power plants at Ringhals, Forsmark and Oskarshamn as belonging to emergency preparedness category I, and the nuclear facilities comprising the fuel fabrication plant and Clab as belonging to emergency preparedness category II. SSM has also preliminarily classified the non-nuclear facility ESS as belonging to emergency preparedness category II in the step-wise licensing review of this facility. However, the ESS research facility is not discussed in this report. This is due to a lack of sufficient input at the time of carrying out this assignment. This has prevented a final standpoint from being taken relating to emergency planning zones or distances surrounding this facility.

In conjunction with this Government assignment to review emergency planning zones and distances, SSM has performed an analysis of the emergency preparedness categories applying to the nuclear facilities in the Studsvik area. SSM has determined that all of these may be removed from emergency preparedness category II (SSM2017-991). Therefore, in the assessment of SSM, there is no need for emergency planning zones or distances surrounding the nuclear activities taking place in the Studsvik area. Thus, the present emergency planning zone should be discontinued.

Activities involving ionising radiation that belong to emergency preparedness category IV have no predefined geographical areas in which emergency planning zones and distances could be established. For this reason, nuclear or radiological emergencies arising in connection with shipments of strong sources of radioactivity, including transports of spent nuclear fuel using the vessel M/S Sigrid, are not encompassed by this assignment. The same would apply if a reactor-powered vessel happened to drift into Swedish territorial waters in connection with a reactor accident. However, for both these situations, it is justified to develop the present emergency preparedness and response system so that it results in the possibly affected population being offered a level of protection which, as far as possible, achieves the objectives defined for the new emergency planning zones and distances.

2.4. Types of emergency planning zones and distances

SSM proposes the establishment of a precautionary action zone (PAZ), an urgent protective action planning zone (UPZ) and an extended planning distance (EPD) surrounding facilities belonging to emergency preparedness category I. SSM suggests that facilities belonging to emergency preparedness category II should be surrounded by a UPZ and an EPD as needed.

2.4.1. Background to the selection of emergency planning zones and distances

The IAEA's GSR Part 7 states that facilities belonging to emergency preparedness category I should have two emergency planning zones and two emergency planning distances, and that facilities belonging to emergency preparedness category II should have one emergency planning zone and one or two emergency planning distances as needed. The emergency planning zones and distances stipulated by GSR Part 7 are:

- Precautionary action zone (PAZ): An emergency planning zone surrounding a facility with emergency preparedness in place for taking urgent protective actions before a release of radioactive materials takes place, based on conditions at the facility, for the purpose of avoiding or minimising severe deterministic effects.
- Urgent protective action planning zone (UPZ): An emergency planning zone surrounding a facility with emergency preparedness in place for taking urgent protective actions to reduce the risk of stochastic effects. If possible, these actions should be taken before a release of radioactive materials occurs that has significance from a radiation protection point of view, based on conditions at the facility. During and after a release of radioactive materials, actions are taken based on an assessment of the radiological situation or on radiation measurements. No protective actions should be taken within a UPZ that delay protective actions within a PAZ.
- Extended planning distance (EPD): An emergency planning distance surrounding a facility having planning in place for radiation monitoring and assessing situations for identification of areas in which protective actions may be necessary within 24 hours and up to several weeks following a release of radioactive materials. The purpose is to reduce the risk of stochastic effects.
- Ingestion and commodities planning distance (ICPD): An emergency planning distance surrounding a facility within which planning should be in place for protection of the food chain and sources of drinking water, in addition to protection of other commodities from becoming contaminated due to a release of radioactive materials. A plan should also be in place for protection of the population from intake of contaminated foodstuffs and from using contaminated goods.

2.4.2. Rationale behind SSM's proposed emergency planning zones and distances

The IAEA's GSR Part 7 requires establishment of a PAZ surrounding facilities where there is a risk of severe deterministic effects arising due to exposure to ionising radiation. These effects can only arise at facilities belonging to emergency preparedness category I. Within the PAZ, the protective action comprising evacuation should be possible based on the conditions at the facility, also before a release of radioactive materials has occurred.

For the purpose of reducing radiation doses during the release phase in connection with a nuclear or radiological emergency, and thus reducing the risk of stochastic effects, it is warranted to take urgent protective actions such as evacuation or sheltering. Within the proposed UPZ to surround the nuclear power plants and facilities belonging to emergency preparedness category II, these protective actions should be pre-planned and capable of implementation on short notice. The protective actions to be prepared within the proposed emergency planning zones may differ between facilities.

An EPD should be established at greater distances where the potentially affected area is difficult to foresee and where protective actions are less urgent. Examples of protective actions that can be taken outside the emergency planning zones include sheltering, relocation taking place based on data from measurements of ground deposition, and distribution of ITB.

According to the IAEA, the ICPD should extend 300 km from a nuclear power plant. SSM's calculations have demonstrated that protective actions in the food sector may be warranted at even greater distances. Based on this factor, and not only the geographical locations of Swedish nuclear power plants but also foreign nuclear power plants in the proximity of Sweden, SSM is of the opinion that this kind of fundamental planning is necessary throughout Sweden. The analyses of protective actions in the food sector do not serve as the basis of the proposed emergency planning zones and distances, though they may nevertheless help support the emergency preparedness planning of the authorities concerned. For this reason, SSM wishes to urge the authorities in charge of decision making and advising on measures in the food and commodities industries to take into account the distances within which actions may be warranted, in addition to the timeframe within which decision making and recommendations must be implemented in accordance with the calculations presented in this report. Moreover, SSM wishes to urge the authorities concerned, as appropriate, to take into account the particular circumstances relating to foodstuffs that will prevail in connection with releases of alpha-emitting materials, owing to difficulties in measuring these materials.

2.5. Reference levels for emergency exposure situations

In the case of the postulated event at a nuclear power plant without functioning mitigation systems (see section 4.1), SSM has used the reference level 100 millisieverts (mSv) annual effective dose as a basis for developing the proposed emergency planning zones and distances. In the case of all the other postulated events, SSM has used the reference level 20 mSv annual effective dose as a basis for developing the proposed emergency planning zones and distances.

Optimisation of radiation protection is required when planning for emergency exposure situations. Consequently, an emergency planning zone or distance may also be justified for facilities at which no events are anticipated to lead to effective doses exceeding the selected reference level, though where protective actions can be taken that result in more benefit than detriment. This can apply to facilities belonging to emergency preparedness category II where pre-planned procedures for prompt sheltering may be justified, even if no events at the facility are expected to lead to effective doses to the public exceeding 20 mSv.

2.5.1. Background to and justification for the selected reference levels

Emergency planning zones and distances are geographical areas surrounding facilities belonging to emergency preparedness categories I and II. Within these zones and distances, pre-planned protective actions for the public are required. Here, a protective action refers to a measure taken to reduce ongoing or potential human exposure to radiation. The main protective actions, for which planning should be in place within the proposed emergency planning zones and distances, are evacuation, sheltering, iodine thyroid blocking and relocation.

Pre-planned protective actions have the purpose of keeping residual doses below the selected reference level for the event or events serving as the basis of the emergency planning zones and distances. An emergency response plan which, at the planning stage, does not enable achievement of this objective should be revised. If a nuclear or radiological emergency should arise, the reference level should instead be viewed as a benchmark where optimisation might first need to focus on people who risk receiving doses exceeding the selected reference level. Thereafter, optimisation should continue below the selected reference level as low as reasonably achievable.

Under the radiation safety directive, reference levels for emergency exposure situations are to be set within the interval 20-100 mSv acute or annual effective dose. The requirements contained in the radiation safety directive regarding setting of reference levels for emergency exposure situations can be fulfilled by setting a general reference level for all events that might lead to such situations, in the form of established individual reference levels for different events that can lead to emergency exposure situations, or through a compromise between both these alternatives. In order to facilitate the work to produce an effective emergency response, SSM is of the view that the number of reference levels should be small.

A reference level of 20 mSv effective dose for the public is in line with the level of ambition for workers in connection with emergency exposure situations. The radiation safety directive stipulates that the value of the dose limit for workers, at 20 mSv effective dose over the course of one year, should if at all possible not be exceeded even during emergency exposure situations. This ambition also encompasses workers, for instance within rescue, police and emergency medical services, who would in all likelihood not be exposed to ionising radiation while on duty during a year, either before or after the emergency exposure situation. As far as concerns the population in the proximity of the relevant facilities, SSM is of the view that the target for radiation protection in corresponding situations should at least have the same level of ambition. What's more, the reference level of 20 mSv effective dose is in line with the agreement of 2013 reached between the Nordic radiation safety authorities concerning shared guidelines for protective actions in nuclear or radiological emergencies. Consequently, SSM is of the view that, to the extent that it is feasible, the reference level of 20 mSv effective dose should be applied to the postulated events serving as the basis of the proposed new emergency planning zones and distances in Sweden.

In the case of the postulated event at a nuclear power plant without functioning mitigation systems (see section 4.1), SSM is however of the view that the reference level of 100 mSv effective dose should serve as a basis for the proposed new emergency planning zones and distances. This event represents a worst-case scenario in terms of release magnitude from a nuclear power reactor. This kind of event is deemed as so unlikely that it does not need to be taken into account when designing mitigation systems at nuclear power plants, according to a Government decision of 1986. On the other hand, this category of event must be taken into account as part of emergency preparedness planning; however, it is not feasible then to use the reference level of 20 mSv effective dose. The cost of sustaining this kind of emergency preparedness would become very high at the same time as the probability is low of carrying out successful evacuation of the large areas that would then be encompassed.

2.6. Dose criteria and intervention levels

Reference levels should be applied when planning for emergency exposure situations. These levels should also serve as the basis of emergency preparedness planning. However, the practical benefit of reference levels in the event of an emergency exposure situation is small, nor are they of immediate use when dimensioning the emergency planning zones and distances. This is because reference levels are expressed as annual radiation dose when protracted exposures can be foreseen. Protective actions, both during an emergency as well as in the planning phase, are instead mainly based on radiation doses received during shorter periods of time, or on dose rate values or activity levels. These parameters are called 'dose criteria' and 'intervention levels'. For more information about dose criteria and intervention levels, see Appendix 1.

2.6.1. Dose criteria for protective actions

A dose criterion for a protective action is defined as the value of a dose to an individual, without taking into consideration protective actions, which when the criterion is exceeded or risks being exceeded, usually implies that the protective action is warranted. A dose criterion is defined for each separate protective action. Dose criteria are selected so that the total dose is to remain below the selected reference level provided that protective actions are taken when the respective dose criterion has been exceeded.

Dose criteria refer to effective, equivalent or absorbed dose received by an unprotected human when exposed to ionising radiation during a given period of time. Calculations of the dose contribution from external exposure include dose from the passing cloud and ground deposition. Calculations of the dose contribution from internal exposure include committed dose from inhalation of radioactive materials contained in the cloud.

Dose criteria have been defined for the respective protective action taken on the basis of the conditions at the facility, or based on a dispersion calculation for the release. Dose criteria refer to the integrated dose over the course of seven days as of the point in time when the release was initiated. This approach includes the total dose contributions from the passing cloud, even during prolonged release sequences.

Dose criteria for the protective actions of evacuation, sheltering and iodine thyroid blocking apply to both adults and children, where children are represented by the age group one-year-olds. Children are more sensitive to exposure to ionising radiation than adults, warranting separate calculation of radiation doses for adults and children. The reason why all children are represented by the age group one-year-olds is because this age group is the most sensitive age group among children.[2] When it comes to the protective action

[2]Other age groups are more sensitive to certain nuclides and exposure pathways. However, in the case of the events and dose criteria/intervention levels applied as part of this project, the assumption concerning one-year-olds applies.

comprising iodine thyroid blocking, the dose criterion also encompasses pregnant women, with the aim of protecting the foetus.

2.6.2. Intervention levels for protective actions

An intervention level is a value of a measurable quantity associated with a certain protective action which, when it is exceeded or likely to be exceeded, implies that the protective action should be taken in most cases. Thus, intervention levels are defined for the protective actions which above all are taken based on measurement data. The intervention levels refer to deposited activity per surface unit on the ground comprising a certain nuclide, and are stated as kilobecquerels per square metre (kBq/m^2). The intervention levels only serve to provide guidance as they, in contrast to dose criteria, only take into account a particular exposure pathway. As the intervention levels relate to measured levels of ground deposition, they may need to be adapted to the prevailing situation. This means that it also may be appropriate to take protective actions in connection with higher or lower levels.

2.6.3. Shielding factors

Intervention levels for relocation and remediation are calculated based on the additional dose received from ground deposition during the first year after a release of radioactive materials. Additional dose for example depends on assumptions made concerning the periods of time spent outdoors and indoors. The concept of shielding factor is used to convey the effect of protection due to sheltering. The shielding factor is defined as the ratio between indoor radiation dose and outdoor radiation dose without any protection at the same location and during the same period of time. This means that the lower the shielding factor, the better the protection provided by sheltering.

The shielding factors used as part of this project for estimating the effectiveness of the protective action of sheltering during an ongoing release are 0.5 for detached houses and 0.1 for multi-residence dwellings or other premises offering increased protection. The shielding factors used for determining intervention levels for relocation and remediation based on ground deposition of radioactive materials are 0.5 for detached houses and 0.25 for multi-residence dwellings. These shielding factors are calculated by assuming sheltering over 80 per cent of the period of time. Appendix 1 contains a detailed presentation of how shielding factors for sheltering were developed.

2.6.4. Dose criteria for precautionary evacuation

The highest priority objective for radiation protection during an emergency exposure situation is to avoid severe deterministic effects. In the cases where these effects might arise, precautionary evacuation should be possible based on the conditions at the facility, also before a release of radioactive materials has occurred.

Dose criteria for precautionary evacuation are based on threshold doses for severe deterministic effects. Severe deterministic effects are injuries that are life threatening or permanent. Threshold doses, which refer to absorbed dose to an organ, imply an increased incidence of severe deterministic effects among those receiving radiation doses exceeding this level. For both adults and children, the limiting organ dose is absorbed dose to red bone marrow. Embryos and foetuses are particularly sensitive to exposure to ionising radiation during particular weeks of pregnancy, for which reason separate dose criteria are needed for embryos and foetuses. Table 3 illustrates these dose criteria, which are used for determining the approximate range of the PAZ surrounding Swedish nuclear power plants.

Table 3. Threshold doses for protective actions in order to avoid severe deterministic effects.

Dose	Dose criterion	Comment
Absorbed dose to red bone marrow (adults and children)	1,000 mGy	Threshold dose corresponding to 1 per cent mortality without medical care
Absorbed dose to embryo	100 mGy	Threshold dose for the induction of malformations (2 to 7 weeks post conception)
Absorbed dose to brain of a foetus	300 mGy	Threshold dose for induction of severe mental retardation (8 to 15 weeks post conception)

2.6.5. Dose criteria for evacuation

The radiation protection objective having second highest priority during a nuclear or radiological emergency is reducing the risk of stochastic effects as far as reasonably achievable. In order to achieve this objective, it must be possible to carry out evacuation either due to the conditions at the facility or based on a dispersion calculation.

Dose criteria for evacuation are based on effective dose. An evacuation that is carried out according to plan will terminate the exposure to ionising radiation, and for this reason, the dose criteria for evacuation are set at the same level as the reference levels. Thus, the dose criterion for the protective action of evacuation is 20 mSv effective dose to both adults and children for all events, with the exception of the postulated event without functioning mitigation systems at a nuclear power plant (see section 4.1). For this event, the dose criterion is 100 mSv effective dose. These dose criteria are the main basis for determining the approximate range of the UPZ to surround Swedish nuclear power plants.

2.6.6. Intervention levels for relocation

Intervention levels for relocation have been developed with the purpose of limiting the effective dose from external exposure due to ground deposition over the longer term. They were developed for nuclides with a relatively long half-life and are set at a level limiting the effective dose to 20 mSv from these nuclides during the first year. Relocation should be considered in areas where the intervention level has been exceeded. Intervention levels for relocation have been used for determining the range of the EPDs surrounding Swedish nuclear power plants and the interim storage at Oskarshamn; within this range, it should be possible to perform radiation measurements for decision-making input within one week.

When rescue services are concluded following an emergency, this is also when the emergency exposure situation ceases. If the event has led to a release of radioactive materials giving rise to long-term exposure, the emergency exposure situation transitions into an existing exposure situation. Under the radiation safety directive, 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. Consequently, identifying and evacuating areas in which ground deposition can give an effective dose exceeding 20 mSv during the first year are requisite actions for terminating the nuclear or radiological emergency.

Table 4 shows the intervention levels that indicate when relocation needs to be considered. Each intervention level has been calculated using the shielding factor 0.5, which is based on an assumption of residency in a detached house in combination with an assumption of the population staying indoors 80 per cent of the time. Events at the fuel fabrication plant in Västerås cannot give rise to a significant ground deposition of long-lived, gamma-emitting nuclides which warrants relocation due to hazards of external exposure. Thus, for this facility, no intervention levels are provided for relocation.

Table 4. Intervention levels for relocation where external exposure from ground deposition comprising selected nuclides could give rise to an effective dose of 20 mSv during the first year.

Facility	Nuclides	Intervention level (kBq/m^2)
Nuclear power plant	Cs-137 + Cs-134	2,000
Clab	Cs-137 + Cs-134	3,000
	Co-60	1,000

2.6.7. Dose criteria for sheltering

Sheltering is a relatively simple protective action that does not require as much preparation as evacuation or iodine thyroid blocking. If sheltering can be kept to a limited duration, sheltering also implies avoiding serious negative consequences for the population. For this reason, SSM views it as reasonable to use the same dose criterion for sheltering on the part of all events, regardless of whether the reference level is 20 or 100 mSv effective dose.

According to the Nordic agreement from 2013 regarding shared Nordic guidelines for protective actions in early and intermediate phases of a nuclear or radiological emergency, also in accordance with the principles for optimisation in emergency exposure situations, protective actions should be considered even in cases where the event is not anticipated to lead to radiation doses exceeding the selected reference level. Nordic radiation safety authorities are in agreement on the general suitability of taking protective actions if the projected effective dose is expected to exceed 10 mSv. For this reason, SSM has set the dose criterion for sheltering at 10 mSv effective dose.

2.6.8. Dose criteria for iodine thyroid blocking (ITB)

The thyroid gland is sensitive to radiation and accumulates radioactive iodine in connection with inhalation while the radioactive cloud passes. Intake of stable iodine prevents uptake of radioactive iodine in the thyroid. ITB should be taken before a radioactive release occurs. Consequently, this is a protective action that requires considerable planning to enable its implementation in practice, either in the form of predistributed ITB, or through urgent distribution of ITB during the event in question. The basis of planning for ITB is the dose criterion 50 mSv committed equivalent dose to the thyroid on the part of adults, children and pregnant women.

In the case of a release from a nuclear power plant in connection with the event, with functioning mitigation systems (see section 4.1), the level of 10 mSv equivalent dose to the thyroid can be used to communicate when intake of predistributed ITB is advisable.

ITB has little effect on adults above the age of 40. Therefore, if the supply of tablets is limited, children and pregnant women should be prioritised. Intake of ITB is normally combined with sheltering and seldom used as the sole protective action.

2.6.9. Intervention levels for food production

Already at low levels of ground deposition of radioactive materials, concentrations of radioactivity in foodstuffs may arise exceeding the EU's limits for radioactive materials in foodstuffs and animal feed. These limits have the purpose of keeping the effective dose from intake of foodstuffs below 1 mSv during the first year. Intervention levels for foodstuffs have been developed by SSM. These levels apply to drinking water, milk, meat, grains, leafy vegetables, and potatoes. Ground deposition of radioactive materials exceeding the intervention levels implies that protective actions within food production should be considered. In this context, the protective actions that may become applicable include measurement and inspection programmes, limiting intake by banning sale, or by providing dietary advice, in addition to various kinds of countermeasures in the animal breeding and agricultural sectors in order to reduce plant and animal uptake of radioactive substances.

Intervention levels for food production were not used to determine the extension of emergency planning zones or distances. However, the levels do indicate within which distances basic planning should be in place for protection of the food chain and sources of surface drinking water in order to protect the population from intake of radioactive materials. Examples of intervention levels for food production include 10 kBq/m^2 for the total activity of the isotopes Cs-134, Cs-136 and Cs-137, in addition to 5 kBq/m^2 of the isotope I-131. In connection with deposition on pasture land, these intervention levels might lead to exceeding the maximum permitted levels of radioactive substances in milk. The intervention level 1 kBq/m^2 for the total activity of the isotopes Cs-134, Cs-136 and Cs-137 might, in connection with deposition on pasture land, lead to excessive levels of radioactive substances in these meats: lamb, beef and reindeer. Appendix 1 provides a complete account of intervention levels for food production.

2.6.10. Intervention levels for remediation

Remediation is a protective action with the purpose of reducing the dose to the population, or making an evacuated area habitable once again. A wide range of factors determine the actual remediation measures that are justified following a release of radioactive materials, as well as the intervention levels at which these measures should be implemented. These factors include available resources, the level of costs, and waste quantities. For this reason, the intervention levels for remediation have been defined at several different levels.

With one exception, intervention levels for remediation are calculated for the same nuclides and using the same calculation presumptions as the intervention levels for relocation (see section 2.6.4). This is for the purpose of limiting effective dose from external exposure due to ground deposition over the longer term. The intervention levels for remediation are set at levels that give estimated additional doses from these nuclides of between 1 and 50 mSv effective dose during the first year. For this reason, the intervention level for the additional dose of 20 mSv effective dose will be identical to the intervention level for relocation. Intervention levels for remediation of gamma-emitting nuclides were not used to determine the extension of emergency planning zones or distances. For more information on the intervention levels for remediation, see Appendix 1.

In the case of events involving releases of uranium at the fuel fabrication plant in Västerås, SSM has chosen to set the intervention level for remediation in line with the level for clearance of rooms and buildings in accordance with SSM's clearance regulations. Calculations demonstrate that only limited areas can be affected by significant ground deposition, for which reason SSM considers it feasible to have remediation considered down to this level.

3. Method for determining the range of new emergency planning zones and distances

SSM has determined postulated events for the relevant facilities serving as the basis of the proposed emergency planning zones and distances. For these events, the Authority has defined representative source terms that describe the releases assumed to follow the respective type of event. Thereafter, SSM carried out dispersion and dose calculations using historical weather data for the purpose of estimating the distances at which it is warranted to take different types of protective actions.

3.1. Postulated events

For each facility in Sweden, SSM selected postulated events to serve as the basis of the proposed new zones and distances. The number of events mainly depends on the facility in question and the nature of the radioactive materials occurring at the facility. These events are postulated while having taken into account different aspects. Certain events have been selected due to the short period of time between the initial event and a release, which may limit the potential to carry out effective protective actions for the public. Other events have been selected as they represent a worst-case scenario in terms of release magnitude.

The events selected are physically possible, though in some cases are so improbable that they do not need to be taken into account when designing safety systems or mitigation systems. Safety systems and, when applicable, mitigation systems, are therefore assumed to function as designed, or in part, or not at all.

Certain delimitations were made when selecting the postulated events. For instance, not all conceivable malicious acts or major airplane accidents affecting the facilities have been taken into account. Nor have highly improbable natural disasters, such as a meteorite hitting the facility, or extremely powerful earthquakes, been taken into account. In this respect, SSM has striven to treat the different facilities in a uniform manner to prevent assumptions and prerequisites for separate activities from having unjustified differences.

3.2. Representative source terms

For each postulated event, SSM developed a representative source term that describes the release of radioactive materials to the surroundings. These representative source terms provide information about the nuclides included in the release as well as the quantity of respective nuclide released. The source term also describes the height of the release, the duration and any heat content. As opposed to the postulated events that were selected, source terms for the postulated events have been calculated on the basis of existing knowledge, while also representing one of several possible outcomes from the same event. The source term calculations used conservative, though realistic assumptions concerning the inherent parameters. Uncertainties were estimated by means of sensitivity analyses in which the influence of a change to a certain inherent parameter was studied. Depending on the facility in question, different calculation tools and sources of reference literature were used. This is because the assumptions differ between facilities such as a nuclear power plant and a fuel fabrication plant. The calculations are subject to great uncertainty.

3.3. Dispersion and dose calculations

3.3.1. Atmospheric dispersion calculations

Atmospheric dispersion calculations provide information about the dispersion of radioactive materials described by the representative source terms, into the surrounding atmosphere by means of physical processes, to ultimately form deposits on the ground and thereby give rise to radioactive ground deposition. The outcome of the dispersion calculations is given in the form of airborne activity, time-integrated airborne activity and ground deposition activity for the respective nuclide, as a function of time and space. Radiation doses can subsequently be calculated using knowledge about activity concentrations in the air and on the ground.

Ground deposition is modelled while taking into account both wet and dry deposition, i.e. whether the deposition occurs simultaneously with precipitation or when there is no precipitation. The latter is possible to derive because the meteorological information used for the dispersion calculations also contains data on precipitation. Calculating deposition also takes into account the influence of variable ground conditions.

Atmospheric dispersion calculations are commonly used to obtain information about a geographical area that might be affected by a release from a given source at a certain point in time, in addition to the magnitude and time period of this effect. This outcome is usually presented on a map illustrating one or more activity or dose quantities as a function of time (see Figure 1). The types of questions formulated in this investigation are, however, somewhat different. For the purpose of investigating to which extent areas should be encompassed by emergency preparedness planning, calculations are instead performed for a source term to identify the largest distances on the mainland or on islands where dose criteria or intervention levels are exceeded for the various protective actions.

For the purpose of shedding light on the effects of varying meteorological conditions, a large number of dispersion calculations with varying points in time for releases distributed over a 10-year period (February 2006–February 2015) were performed for each facility and representative source term. These calculations were based on meteorological data from SMHI. In order to take into account not only 24-hour but also seasonal variations, the calculations were performed assuming a release taking place every 26th hour during the period, giving approximately 337 calculations per year. Each release was modelled during a period comprising 72 hours. Examples of calculation results are illustrated by Figure 2.

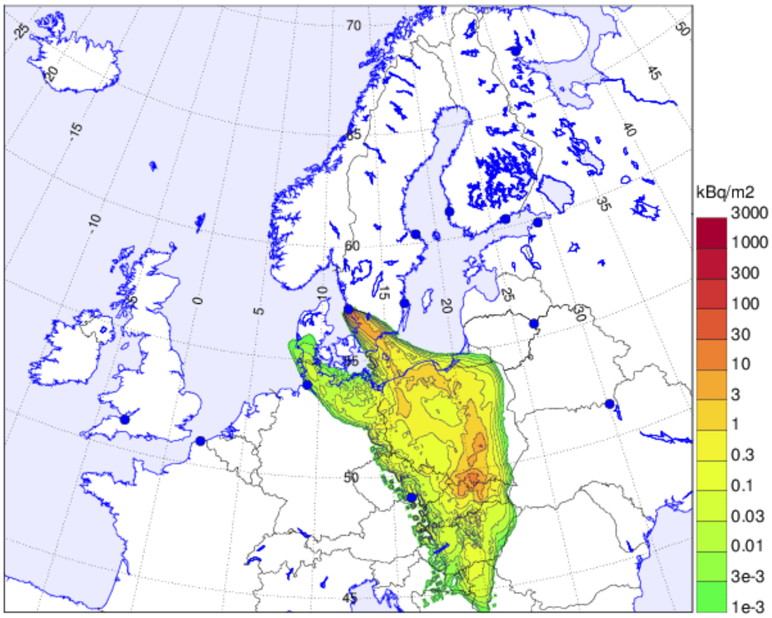

Figure 1. Example of outcome from an atmospheric dispersion calculation. This illustration is based on a fictitious release of Cs-137 from the nuclear power plant at Ringhals. The figure shows the resulting ground deposition (expressed in kBq/m2) that this release would give rise to 48 hours after the start of the release.

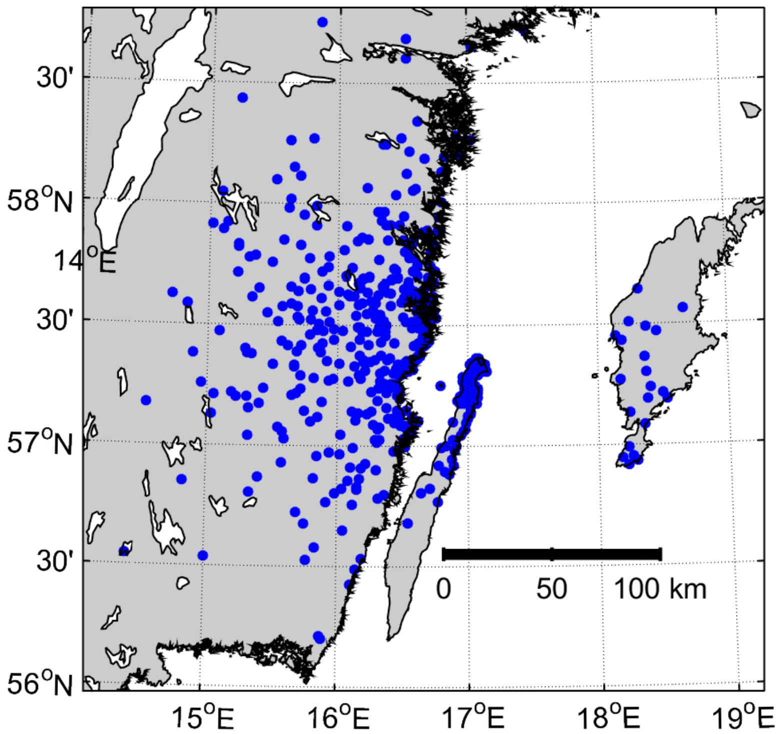

Figure 2: Example of outcome for a given dose criterion from dispersion calculations (943 in total) for a fictitious release from the Oskarshamn nuclear power plant. The blue dots represent the greatest distance at which the dose criterion was exceeded in an individual calculation, i.e. for a specific weather scenario.

3.3.2. Dose calculations

Dispersion calculations are used to quantify activity concentration on the ground and in the air. They were used to calculate effective dose and equivalent dose to the thyroid. Effective dose was calculated for a period of time comprising seven days, and is the sum of doses from three different exposure pathways: external exposure to radioactive materials in the plume (the radioactive cloud dispersed in the air), external exposure to radioactive materials deposited on the ground, and internal exposure from inhalation of radioactive materials in the plume. The effective dose from inhalation of radioactive iodine was also used to calculate equivalent dose to the thyroid, by the effective dose from iodine being divided by the tissue weighting factor for the thyroid.

Special calculations were performed for dose to red bone marrow, dose to embryo and dose to the brain of a foetus from the different exposure pathways. For the purpose of enabling protective actions, and thus ultimately preventing severe deterministic effects from occurring, these estimates were performed to identify the largest distances at which dose criteria will be exceeded.

3.3.3. Statistical data analysis

The outcome from dispersion and dose calculations is given in the form of a greatest distance at which a dose criterion or an intervention level has been exceeded. The distribution of these distances has been compiled in the form of cumulative histograms. For a certain dose criterion or a certain intervention level, each histogram illustrates the percentage of weather scenarios encompassed as a function of distance. Distributions of distance as illustrated by Figure 3 give input for adopting standpoints on the proportion of occurring weather scenarios that should have different pre-planned protective actions. The distance encompassing a certain percentage of weather scenarios (x) is called the 'percentile', which is denoted by P_x.

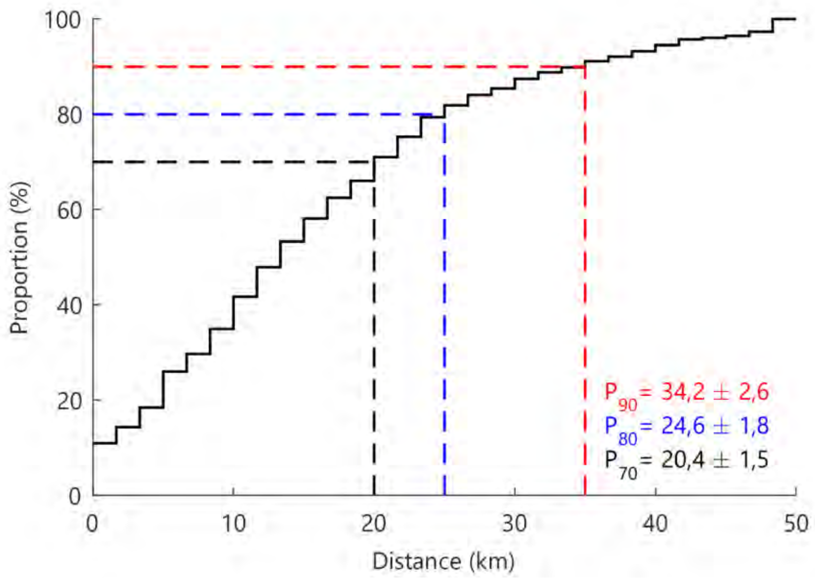

Figure 3. Example of distribution of distances for a certain dose criterion, illustrated by three selected percentiles (P70, P80 and P90) as shown. In 90 per cent of the weather scenarios, the greatest distance at which the dose criterion is exceeded is shorter than 34.2 km; in 80 per cent of the weather scenarios, it is shorter than 24.6 km; and in 70 per cent of the weather scenarios, shorter than 20.4 km.

The proposed approximate ranges of the emergency planning zones and distances suggested by SSM in this report encompass between 70 and 90 per cent of all occurring weather scenarios. This means that not all weather scenarios have impacted on the proposed approximate ranges of the emergency planning zones and distances. If emergency preparedness planning is to take into account the most extreme weather scenarios, this would lead to protective actions needing to be prepared for substantial distances and thus give rise to onerous socioeconomic consequences. This is illustrated by Figure 3, where the increase in the percentage of weather scenarios that are encompassed levels off with increasing distance. In this context, SSM wishes to emphasise that there is a general capacity throughout Sweden for dealing with the consequences of national emergencies. This capability can be utilised regardless of the extent of the emergency and its impacts.

SSM has not taken any account of the prevailing direction of winds when designing the emergency planning zones and distances; in other words, the same approximate distances were applied in all directions on the mainland as a basis for this proposal. In the assessment of SSM, predictions of total probability for a certain outcome, e.g. that a severe nuclear power accident occurs only during certain weather conditions, are so uncertain that they should not serve as a basis for a shorter or longer distance in certain directions from the facilities in question.

For reasons of physics, dispersion of radioactive materials in air differs depending on whether the plume passes over a body of water or across a body of land. Consequently, the greatest distance at which a given dose criterion or intervention level is exceeded is, on average, somewhat larger at islands out to sea than compared with a situation where the release might only have passed over the mainland. This factor is considered as part of the dispersion model, but also needs to be taken into account when calculating the distribution of distances. For the same reason, islands located at greater distances may also be encompassed by the emergency preparedness planning. This is why the relevant islands were given particular attention during data analysis.

Average values and the uncertainty in the evaluation of the percentiles were estimated by means of bootstrap analysis, a statistical method. In short, this method involves using existing data on repeated occasions to calculate the percentiles, whereby the average value and the uncertainty of this average value can be estimated. Each individual calculation is based on a random selection from the input data. The outcome of the data analysis is stated as an average value and an uncertainty, where the uncertainty is represented by two standard deviations. The average values and uncertainties illustrated by Figure 3 were calculated using this method.

See Appendix 2 for a more detailed presentation of the dispersion and dose calculations, in addition to the statistical analysis of the data.

4. Nuclear power plants

There are three nuclear power plants in Sweden: Forsmark, Oskarshamn and Ringhals. Forsmark and Oskarshamn have three reactors each and Ringhals has four reactors. The owners of the Oskarshamn NPP decided in 2015 to decommission two reactors; these have already been shut down. The owners of the Ringhals NPP have decided to shut down and decommission one reactor in 2019 and an additional reactor in 2020. No final date has been set for the reactors that are still in operation. The owners plan to operate them for 60 years. Provided that no additional decisions on decommissioning are made, at least one reactor will remain in operation at the respective NPP up until the mid-2040s. This means that there is a need for emergency preparedness planning encompassing the respective NPP for at least an additional 25 years.

In this chapter, SSM presents postulated events, representative source terms, outcomes of dispersion and dose calculations, input data for determining the ranges of emergency planning zones and emergency planning distances, in addition to the proposed design of these zones and distances to surround the NPPs of Forsmark, Oskarshamn and Ringhals. Outcomes are also presented from sensitivity analyses and calculations of the residual doses which a release can give rise to, provided that the protective actions proposed by SSM can be implemented. Lastly, an account is provided of needed measures on the part of food production and required remediation in connection with releases occurring as part of the respective events that have been analysed. Appendix 3 provides a more detailed account.

4.1. Postulated events

SSM has determined two postulated events serving as the basis of the proposed emergency planning zones and emergency planning distances to surround the NPPs:

- **An event with functioning mitigation systems.** An event representing a severe accident involving core meltdown, vessel melt-through and releases occurring via the filtered containment venting system, where the mitigation systems function in accordance with requirements.
- **An event without functioning mitigation systems.** An event representing a severe accident involving core meltdown, vessel melt-through and releases, where the mitigation systems malfunction and where reactor containment leak tightness is lost in connection with vessel melt-through. This event corresponds to a conceivable worst-case scenario in terms of release magnitude from a Swedish nuclear power reactor.

The first event must be taken into account when designing the mitigation systems of nuclear power plants, whereas the second event is deemed as so improbable that it does not need to be taken into account when designing these systems. Both events lead to a release of radioactive materials formed inside the reactor. What differs between these events is mainly the extent of impacts on the surroundings, in the form of radiation doses and ground deposition, where the consequences are more extensive from the more serious event.

In the case of the event to be taken into account when designing the mitigation systems, SSM applies the reference level 20 mSv effective dose as a starting point when dimensioning emergency preparedness measures. In the case of the more serious event, SSM instead applies the reference level 100 mSv effective dose as a starting point when dimensioning emergency preparedness measures, i.e. the upper limit defined by the radiation safety directive.

4.1.1. Selecting postulated events

SSM has based its postulated events on the accident sequence total loss of AC power and, in the case of Ringhals, a loss of a steam-driven core cooling system as well. This sequence is also usually referred to as a loss of all power systems without battery back-up, which implies that all standby diesel generators, which supply pumps with power and ensure adequate cooling of the reactor core, are put out of commission, though with intact battery power for instrumentation and valve control. This sequence is referred to as Station Blackout (SBO). This sequence resembles the events that took place at Fukushima Daiichi. However, at Fukushima Daiichi, the supply of battery power was also put out of commission at the same time as certain steam-driven systems functioned initially.

Thus, both these postulated events are based on the same initiating event (total loss of all power systems without battery back-up, in addition to all steam-driven systems). However, in the latter case, the filtered containment venting system was postulated as disconnected and to instead comprise an exhaust pathway from the reactor containment. It was postulated that the exhaust pathway was open at the point in time for melt-through of the reactor vessel. The purpose of SSM's assumptions was to produce a worst-case scenario based on as few postulates and hypotheses as possible.

The selected accident sequence is the same sequence that served as the design basis for the mitigation systems installed at the NPPs in the 1980s, owing to a government decision of 1986, covering aspects such as the filtered containment venting system. Without successful countermeasures, the sequence leads to a severe accident. A severe accident is characterised by the reactor core, after just under one hour, becoming overheated, increasing the risk of generating a large quantity of hydrogen through reactions arising between the fuel cladding and the steam produced in the reactor. The hydrogen subjects the reactor containment to pressure and risks causing, in unfortunate circumstances, the formation of a combustible mixture of hydrogen and oxygen with subsequent deflagrations or detonations, as demonstrated by the accident sequence at Fukushima Daiichi. During the continued accident sequence, the reactor core melts, including the structural materials, to after around four hours ultimately penetrate the reactor vessel and end up in the reactor containment. The energy from the core meltdown's residual heat ultimately ends up in the reactor containment, which, to prevent damage from overpressure, has its pressure released via the filtered containment venting system.

Another category of event that empties the reactor vessel of water is a loss of cooling accident (LOCA) by pipe break. If a large break LOCA is not followed by emergency core cooling injection, this event will also lead to a severe accident. A severe accident owing to a large break LOCA is characterised by leading to quicker core damage compared with the accident sequence loss of all power systems without battery back-up; at the same time, however, this situation does not result in the same extensive production of hydrogen.

SSM has considered the category of large break LOCA as an initiating event for the postulated events. SSM is nevertheless of the view that the selected accident sequence is a better starting point for description of a severe accident. This sequence is well known as it belongs to the licensees' safety analysis report and is the design basis for the mitigation systems, while also comprising a representative sequence that takes into account different phenomena characterising severe accidents. The fact that the sequence is well-known facilitates review work and confirmation of feasibility.

4.2. Representative source terms

SSM has developed representative source terms describing releases on the part of the postulated events. The representative source terms provide the following information:

- The released level of activity per nuclide and time interval plus duration of release
- Selection of nuclides
- Height of release
- Distribution between organic, elemental and particulate iodine in the release
- Heat energy in the release.

SSM used analyses of reactor unit four at Ringhals (R4) as input for the representative source terms for the postulated events. These analyses were performed by the German technical support organisation GRS (Gesellschaft für Anlagen- und Reaktorsicherheit), as commissioned by SSM. These analyses are based on the core inventory of R4 for the thermal power 3253 MW and a degree of burn-up for the fuel assembly of 53 MWd/kg of uranium. As part of the complete representative source terms, SSM used this input to calculate released activity per nuclide and hour for all the 285 nuclides belonging to the declared core inventory for releases taking place over a period of 48 hours.

SSM compared the analyses from GRS with corresponding input from the licensees of Swedish nuclear power plants. GRS uses the MELCOR computer code for analysis, whereas the licensees use the MAAP computer code. The differences between source terms for different reactor types, produced using the same computer code for analysis, are comparable with the differences between source terms produced using different computer codes for the same reactor type. With the exceptions of release height and distribution of iodine forms in the release, SSM is consequently of the assessment that it is unwarranted to use different representative source terms for boiling water and pressurised water reactors. Moreover, in the assessment of SSM, the differences in thermal power between the reactors that will remain in operation over the next few years are not of a magnitude warranting production of different representative source terms for reactors with different thermal power output. SSM's overall conclusion is that all Swedish reactors may be represented by the same source terms.

4.2.1. Selection of nuclides

The duration of time needed to perform dispersion and dose calculations is long, and largely linear, depending on the number of nuclides in the source term. Therefore, it is justified to reduce the number of nuclides in the source terms by excluding nuclides that do not give a significant dose contribution. This makes it possible to analyse a greater number of weather scenarios during a given period of time.

The representative source terms are used to estimate distances at which dose criteria and intervention levels are exceeded for different protective actions. The dose criteria are defined as effective dose, absorbed dose to an organ, or equivalent dose to the thyroid, over a period of seven days, and the intervention levels are defined as ground deposition of relevant nuclides after the release has ceased. Thus, the selection of nuclides for calculating dose and ground deposition took place in accordance with the following criteria:

- Nuclides giving a significant contribution to effective or absorbed dose over a period of seven days
- Iodine isotopes giving a significant contribution to thyroid dose over a period of seven days
- Nuclides of significance for estimating effective dose from ground deposition during the first year
- Nuclides of significance for identifying the need for remediation
- Nuclides of significance for identifying the need for measures linked to food production.

Only nuclides giving a significant contribution to radiation doses and ground deposition according to the criteria above are included in the final representative source terms.

One conclusion that has been drawn from the analyses serving as the basis of the selection of nuclides is that, in the case of the postulated event without functioning mitigation systems, the main contribution to effective dose during the first seven days will be from radioactive iodine. In the case of the postulated event with functioning mitigation systems, the main contribution to effective dose during the first seven days will instead come from noble gases. The relative contribution from different nuclide groups may vary between weather scenarios, though the main distribution of the nuclide groups of significance still applies.

4.2.2. Other parameters in the source terms

SSM has assumed in its calculations that the release height corresponds to the height of the stack for the filtered containment venting system on the part of the postulated event with functioning mitigation systems. The height of the stack up to the filtered contamination venting systems differs between boiling water and pressurised water reactors, for which reason the release heights are different for the boiling water reactors at the NPPs of Oskarshamn and Forsmark (27 m) compared to the pressurised water reactors of the Ringhals NPP (48 m).

Should a rupture take place in the reactor containment, there is no justification to assume that this release would pass via the stack to the filtered containment venting system, or via the main stack. There are joints and penetrations at differing heights which are more likely to rupture first. For this reason, SSM has set the release height at 27 m, corresponding to an approximate average value of the height of potential release pathways in the case of the postulated event without functioning mitigation systems.

Radioactive iodine in the reactor vessel and reactor containment will occur in both volatile and non-volatile forms. Iodine forms that are water soluble have limited volatility, whereas iodine both in particulate and gas forms is volatile and occurs in the containment atmosphere, where the latter mainly consists of elemental and organic iodine. The filtered containment venting system is assumed to have a good and equivalent capacity to filter out a release of particulate and elemental iodine, whereas organic iodine is assumed to behave like a noble gas and thus avoids being captured by the filtered containment venting system.

It is assumed in the case of a release that does not pass through the filtered containment venting system that the distribution between organic, elemental and particulate iodine in the release is the same as in the atmosphere of the reactor containment. However, in the case of a release during the event in which the mitigation systems are functioning, the composition of iodine forms in the release will change because the different iodine forms are filtered out to varying extents by the filtered containment venting system. An additional perspective is that the filtered containment venting system for pressurised water reactors is more effective than the corresponding system for boiling water reactors. Consequently, for this event, the composition of iodine forms in the release will differ between these reactor types.

SSM has set the heat content of the releases at zero in the representative source terms for the postulated events. This means that SSM does not expect any plume rise to occur due to thermal energy contained in the release. Nor does SSM expect any plume rise owing to vertical movements of the release. Calculations of plume rise are subject to great uncertainty. In order to exclude possible underestimation of the calculated doses, SSM has applied a conservative assumption that no plume rise will occur.

SSM has estimated the briefest feasible period of forewarning for the respective representative source terms. The period of forewarning refers to the duration as of an alert issued about abnormal operation at an NPP up until a release warranting consideration of protective actions for the public. SSM has set the briefest feasible period of forewarning at approximately four hours for the postulated events.

4.2.3. Summary account of the source terms

Table 5 provides a summary account of the selected nuclides, in addition to total released activity to the atmosphere per nuclide for the postulated events with and without functioning mitigation systems.

SSM has compared the total release of activity to the atmosphere per nuclide for the postulated event, without functioning mitigation systems, with the estimated total release to the atmosphere of corresponding nuclides in connection with the nuclear power accidents of Fukushima Daiichi and Chernobyl. The release for the postulated event without functioning mitigation systems is on a par with the total atmospheric release from Fukushima Daiichi, though of a smaller magnitude than the atmospheric release from Chernobyl.

Table 5. Summary presentation of selected nuclides and total released activity to the atmosphere per nuclide for the postulated events with and without functioning mitigation systems.

Release group	Nuclide	Functioning mitigation systems (Bq)	Without functioning mitigation systems (Bq)
Noble gases	Kr-85m	1.7E+17	2.1E+17
	Kr-87	2.2E+16	3.9E+16
	Kr-88	2.4E+17	3.2E+17
	Xe-133	5.4E+18	5.3E+18
	Xe-133m	1.7E+17	1.7E+17
	Xe-135	2.2E+18	2.2E+18
	Xe-135m	3.4E+17	3.9E+17
Halogens	I-130	1.2E+13	1.9E+15
	I-131	1.2E+15	1.8E+17
	I-132	1.6E+15	2.5E+17
	I-133	1.6E+15	2.6E+17
	I-134	5.7E+12	2.4E+15
	I-135	6.1E+14	1.0E+17
Alkali metals	Rb-88	2.9E+13	9.2E+15
	Cs-134	1.1E+14	2.6E+16
	Cs-136	2.4E+13	5.8E+15
	Cs-137	7.8E+13	1.9E+16
Tellurium group	Sb-127	1.4E+12	5.9E+15
	Te-127m	5.5E+12	9.3E+14
	Te-129m	2.5E+13	4.2E+15
	Te-131m	6.2E+13	1.0E+16
	Te-132	5.3E+14	9.0E+16
Ba and Sr	Sr-89	1.9E+12	1.4E+15
	Sr-90	1.8E+11	1.3E+14
	Ba-140	3.4E+12	2.5E+15
Noble metals	Mo-99	4.2E+12	8.5E+16
	Tc-99m	4.0E+12	8.2E+16
Lanthanides	Cm-242	3.5E+08	8.3E+11
	Cm-244	4.6E+07	1.1E+11

4.3. The basis for emergency planning zones and distances

In this section, SSM provides a summary account of outcomes from dispersion and dose calculations, the standpoints serving as the basis of the proposed approximate ranges of the emergency planning zones and distances, as well as the recommended distances within which the protective actions of sheltering and iodine thyroid blocking (ITB) should be prepared. SSM also presents recommended requirements for warnings and predistribution of information materials.

SSM performed dispersion and dose calculations based on historical weather data for the purpose of estimating the greatest distances at which dose criteria and intervention levels are exceeded. Weather data from the period 2006-2015 was used in the dispersion calculations. In total, the data material contains approximately 4,240 dispersion and dose calculations per representative source term and nuclear power plant. This gives a sufficient statistical basis for taking into account variations in weather conditions around the nuclear power plants.

The calculations show that the outcomes differ somewhat between NPPs. In the assessment of SSM, however, the differences are not of a magnitude warranting proposals for different ranges of emergency planning zones or distances to surround the three NPPs. The rationale behind SSM's standpoint is that the uncertainties in the representative source terms, as well as the uncertainties associated with the type of dispersion and dose calculations performed by SSM, will lead to a total level of uncertainty characterising the calculated distances which is at least of the same magnitude as the differences between the NPPs. For this reason, SSM's analysis is based on average values from the outcomes for the three NPPs of Forsmark, Oskarshamn and Ringhals.

4.3.1. Precautionary evacuation

SSM's proposals:

1. A PAZ extending approximately 5 km should be established.
2. Planning should enable evacuation of the entire PAZ within approximately 4 hours after a decision taken by the incident commander.
3. Planning should enable evacuation of the PAZ with a level of priority that is higher than for evacuation at greater distances.

Regardless of the circumstances at an NPP, the primary purpose of the PAZ is to create potential for meeting the highest priority objective of radiation protection during a nuclear or radiological emergency: to avoid severe deterministic effects. Consequently, distances at which threshold doses for severe deterministic effects might be exceeded serve as the basis of the proposed range of the PAZ. Emergency preparedness planning for the PAZ should also enable limited evacuation around the NPP at an early phase of an event to serve as a precautionary measure should the situation deteriorate.

The calculations show that evacuation out to approximately 5 km provides a good margin of safety to sufficiently avoid, in 90 per cent of all occurring weather scenarios, an increased incidence of mortality among both adults and children in the case of the event without functioning mitigation systems. Evacuation out to approximately 5 km is also sufficient to avoid, in just under 90 per cent of all occurring weather scenarios, an increased incidence of severe mental retardation affecting foetuses. Moreover, in just under 70 per cent of all occurring weather scenarios, evacuation out to a distance of approximately 5 km is sufficient to avoid an increased incidence of malformations affecting embryos. If the level of ambition is avoiding an increased incidence of malformations affecting foetuses in 90 per cent of all occurring weather scenarios, this presupposes evacuation to a distance of just over 10 km, or, alternatively, combining evacuation with other protective actions, e.g. sheltering.

SSM has estimated the briefest feasible period of forewarning at approximately 4 hours for the postulated events. For this reason, SSM assesses that a feasible objective when planning for evacuation of the PAZ is to have it concluded within approximately 4 hours after this decision has been taken by the incident commander.

The required range of the PAZ presupposes consideration of not only the objective of helping to avoid severe deterministic effects, but also the objective of enabling an effective response during a nuclear or radiological emergency. In the shared opinion of both SSM and incident commanders who have taken part in the work, it is a major challenge to manage evacuation out to a distance of up to approximately 5 km in the short space of time of 4 hours. If an even larger area needs to be evacuated, this increases the risk that evacuation will take more than 4 hours. An additional perspective is that this could complicate evacuation of the population closest to the nuclear power plant and who thus have the greatest need for protection.

The overall assessment of SSM is that the PAZ should extend approximately 5 km. The proposal of SSM is in line with recommendations from the IAEA stating that the maximum range of the PAZ should be approximately 5 km to enable fast evacuation.

The postulated event with functioning mitigation systems does not influence the range of the PAZ. The threshold dose for embryo malformations is not exceeded at distances beyond a few kilometres, even if 90 per cent of all occurring weather scenarios are taken into account. Other threshold doses for severe deterministic effects are not exceeded outside the sites of the NPPs, even if 90 per cent of all occurring weather scenarios are taken into account.

4.3.2. Evacuation

SSM’s proposals:

1. A UPZ extending approximately 25 km inland on the mainland should be established.
2. The part of northern Öland that is within a distance of approximately 30 km from the Oskarshamn NPP should belong to the UPZ.
3. The UPZ should be divided into areas enabling evacuation of different sectors and different distances, depending on the event and prevailing circumstances.
4. If early information is available concerning abnormal operation at the NPP and the general circumstances allow evacuation to be carried out, it is advisable to have the planning enable evacuation of the areas located in the expected direction of the wind, out to a distance of approximately 25 km within 12 hours following a decision taken by the incident commander.
5. If these conditions are not met, the planning should instead enable evacuation of the areas located in the expected direction of the wind, out to a distance of approximately 15 km within 12 hours following a decision taken by the incident commander. At the same time, the planning should enable sheltering in combination with intake of ITB to be advised in the areas within approximately 15 to 25 km located in the expected direction of the wind.
6. Planning should make it possible to give priority to children and pregnant women during evacuation, also that patients and nursing home residents can remain in the evacuated areas.

The purpose of the UPZ is to create potential for achieving the radiation protection objective having second highest priority during a nuclear or radiological emergency, i.e. reducing the risk of stochastic effects as far as reasonably achievable. SSM's calculations show that the postulated event without functioning mitigation systems determines the range of the UPZ, despite the fact that the reference level for this event is five times higher than the reference level for the postulated event with functioning mitigation systems. Consequently, the dose criterion of 100 mSv effective dose during the first seven days on the part of the postulated event without functioning mitigation systems serves as the basis of the proposed range of the UPZ.

The calculations show that evacuation out to a distance of just over 20 km is adequate for keeping effective doses to children and adults below 100 mSv in the case of the event without functioning mitigation systems in 70 and 80 per cent, respectively, of all occurring weather scenarios. The calculations also show that evacuation out to a distance of approximately 30 km is adequate for keeping effective doses to children and adults below 100 mSv in 80 and 90 per cent, respectively, of all occurring weather scenarios. Also, keeping effective dose to children below 100 mSv in 90 per cent of all occurring weather scenarios presupposes evacuation out to a distance of approximately 40 km.

The time between a declared general emergency and a release warranting urgent protective actions for the public is in the order of 12 hours, according to the Swedish definition of a general emergency. Consequently, in the assessment of SSM, a feasible target when planning for evacuation of the UPZ is to enable evacuation of the areas located in the anticipated direction of the wind within a period of approximately 12 hours after a decision being taken by the incident commander. Although the releases of the postulated events commence approximately four hours after the initiating event, it is nevertheless the opinion of SSM that precautionary evacuation outside the PAZ is impossible to carry out in as short a space of time as four hours. If no advance information is available about abnormal operation at the NPP, the circumstances of the event will have to lead to determination as to whether it is better to recommend sheltering combined with intake of ITB, or to carry out evacuation during an ongoing release.

The final range of the UPZ constitutes a balance between the objective of reducing the risk of stochastic effects as far as reasonably achievable, the objective of enabling effective response, and the objective of facilitating resumption of normal life.

The objective concerning effective response during a nuclear or radiological emergency is linked to the potential to carry out successful evacuation within 12 hours of the part of the UPZ located in the expected direction of the wind. It is a major challenge to carry out emergency evacuation of large areas, and urban areas in particular. It is not possible to rule out the following risks: that evacuation takes so long to carry out that many people either cannot be evacuated before a release takes place, or that they are being evacuated at the same time as a large release takes place. One option that may offer better protection in this kind of situation is sheltering combined with intake of ITB during the release, followed by evacuation being carried out based on the levels of ground deposition, if this is proved necessary after a significant release from a radiation protection point of view has ceased. This particularly applies to urban areas if the planning for sheltering takes into account the possibilities for better protection offered in the form of buildings with thick walls, cellar spaces, and civilian shelters.

For these reasons, SSM is of the opinion that the UPZ should be divided into areas enabling evacuation of different sectors and different distances depending on the event and the prevailing circumstances. Consequently, the 30° sectors applied today should remain in place. It should also be possible to have the UPZ evacuated in different phases depending on the distance from the NPP, where the circumstances dictate whether it is better to recommend sheltering combined with intake of ITB, instead of evacuation. In the assessment of SSM, it is suitable to have the planning take place with an approach that allows for separate evacuation of a distance corresponding to just over half of the range of the UPZ.

The objective concerning resumption of normal life is linked to the fact that it is more difficult to resume normal life after having been evacuated, compared with after sheltering over a limited period of time. If no release takes place, it is probably easy to return home following an evacuation. On the other hand, if a release takes place, lessons learned from the accident at Fukushima Daiichi have demonstrated that it can take a very long time before evacuees are allowed to return, even to areas that were unaffected or were only slightly affected by deposition.

SSM's overall conclusion is that the UPZ should have a range of approximately 25 km. If early information is available concerning abnormal operation at an NPP, implying that preparations for evacuation can be made at the same time as the general circumstances allow evacuation to be carried out, SSM is of the opinion that the areas located in the expected direction of the wind, out to a distance of approximately 25 km, should be possible to evacuate within 12 hours after a decision has been taken. If these preconditions are not met, SSM is of the view that precautionary evacuation at distances greater than approximately 15-20 km from the Swedish NPPs is an unsatisfactory alternative. The rationale behind SSM's standpoint is the location of several large communities at these approximate distances from the NPPs. Without time for preparations, or if the circumstances are complex, SSM is of the view that there is little potential to carry out successful evacuation of these communities within 12 hours. Instead, a better alternative is sheltering combined with intake of ITB in the areas located in the expected direction of the wind, from approximately 15 km out to a distance of approximately 25 km. Carrying out this alternative should presuppose residents in the affected areas having access to not only predistributed ITB, but also advance information concerning protective actions. The approximate range of the UPZ proposed by SSM is in line with recommendations issued by the IAEA, which state that the range of the UPZ should extend between 15 and 30 km.

Moreover, SSM assesses that a large proportion of northern Öland should belong to the UPZ surrounding the NPP at Oskarshamn, even at distances greater than 25 km. Marine dispersion can give higher radiation doses at corresponding distances compared to mainland dispersion. Having the same level of ambition as for the mainland, SSM’s calculations show that an approximate range of 30 km is advisable for defining the size of northern Öland that should belong to the UPZ surrounding the Oskarshamn NPP.

Lessons learned from evacuation in connection with the nuclear power plant accidents of Chernobyl and Fukushima Daiichi show that separate planning is required for certain parts of the population. Consequently, in the assessment of SSM, parts of the population that are more sensitive to exposure to ionising radiation, such as children and pregnant women, as well as groups with special needs, e.g. the infirm and elderly care patients, should be identified in the planning phase. Emergency preparedness planning should make it possible to give vulnerable groups priority in connection with an evacuation. It should also be considered during the planning phase whether parts of the population with special needs can remain in place despite a decision to evacuate. This would presuppose detailed planning for sheltering for the affected operations in the UPZ, see also section 4.3.4.

The postulated event with functioning mitigation systems does not affect the range of the UPZ. The lower dose criterion for evacuation of 20 mSv effective dose will not be exceeded at distances greater than approximately 10 km, neither in the case of adults or children, even if 90 per cent of all occurring weather scenarios are taken into account for this event.

4.3.3. Relocation due to ground deposition

SSM's proposals:

1. An EPD extending 100 km should be established.
2. The capability to carry out radiation measurements should be dimensioned to make it possible to perform these measurements with a sufficient geographical resolution over the entire area, as defined by the EPD, within around one week from cessation of the release.
3. Radiation measurements should be carried out using a flexible method allowing definition of the area to be measured during the event, including areas at distances greater than 100 km.
4. Planning should enable urgent decision making concerning relocation based on outcomes from radiation measurements.

The key purpose of the EPD is to create potential for reducing the risk of stochastic effects as far as reasonably achievable by deciding on relocation based on levels of ground deposition, of which the latter is estimated via radiation measurements. For this reason, the intervention level of 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 serves as the basis of the proposed range of the EPD to surround the NPPs. This ground deposition gives an additional dose of approximately 20 mSv effective dose during the first year, assuming the factors concerning ground penetration, shielding and average duration for indoor stay as defined by SSM. In the assessment of SSM, it is advisable to have the areas with such high levels of ground deposition identified and the population relocated prior to the termination of the nuclear or radiological emergency, and the subsequent termination of rescue services.

The calculations show that ground deposition warranting relocation may occur at distances of approximately 120, 170 or 260 km in the respective frequencies of 70, 80 and 90 per cent of the occurring weather scenarios for the postulated event without functioning mitigation systems.

As the outcome from the radiation measurements is to serve as input for decision making concerning relocation, which is a precondition before rescue services can be terminated, SSM is of the view that the measurements must have capacity for emergency situations. Therefore, in the assessment of SSM, it is advisable to dimension the capacity for radiation measurements to enable their performance with sufficient geographical resolution throughout the area as defined by the EPD within around one week as of the release ceasing.

In the assessment of SSM, it is feasible to have the EPD extend 100 km, which encompasses nearly 70 per cent of all occurring weather scenarios. The rationale behind SSM's standpoint is the improbability of the entire area of the semicircle defined in this way being affected by high levels of ground deposition, even in the event without functioning mitigation systems. If the capability for radiation measurements is dimensioned to cover this area, the detection resources should be adequate to also be used outside the EPD as needed, in other words at distances greater than 100 km from the NPPs. A precondition for enabling SSM's proposals to lead to the desired capability is performance of radiation measurements by means of a flexible method that allows the area warranting measurements to be defined during the specific event. SSM’s proposed range is in line with recommendations from the IAEA stating that the range of the EPD should be 100 km.

The postulated event with functioning mitigation systems does not affect the range of the EPD. The intervention level for relocation owing to ground deposition is not exceeded at distances greater than approximately 2 km, even if 90 per cent of all occurring weather scenarios are taken into account.

4.3.4. Sheltering

SSM’s proposals:
1. Detailed planning should be in place for sheltering in both the PAZ and UPZ.
2. Planning should be in place for sheltering in delimited areas within the EPD.
3. At distances beyond the EPD, the pre-existing planning for sheltering in connection with an Important Public Announcement (IPA) is sufficient.

Sheltering is a relatively simple protective action that does not require as much preparation as evacuation or ITB. On the other hand, planning is required for when a recommendation concerning sheltering may be considered, as well as for dealing with sheltering that risks being prolonged. As sheltering, at least in the short term, does not imply serious negative consequences, SSM views it as reasonable to apply the same dose criterion for the postulated events with and without functioning mitigation systems, i.e. 10 mSv effective dose.

The calculations show that sheltering of children may be warranted at distances of approximately 120, 150 and 200 km if the respective frequencies of 70, 80 and 90 per cent of all occurring weather scenarios are taken into account for the event without functioning mitigation systems. In the case of adults, the calculations show that the corresponding distances are approximately 100, 130 and 180 km, respectively.

SSM considers it advisable to have detailed planning in place for sheltering within the emergency planning zones, as sheltering, combined with intake of ITB, may be an alternative to evacuation within these zones. Thus, SSM also recommends that the PAZ have detailed planning in place for sheltering. Although evacuation is the first option in the PAZ, the circumstances may make evacuation impossible. In these situations, sheltering is better than taking no protective action whatsoever.

Detailed planning for sheltering should cover the following: predistributed information to residents about sheltering, evacuation in the event of prolonged sheltering, critical operations needing to be sustained during sheltering, information distributed in advance to these operations, in addition to training of emergency workers who may be assigned tasks in an area where sheltering has been recommended. In the event that sheltering should become prolonged, evacuation is not as urgent as the preventive measure of evacuation being carried out in the PAZ and, if possible, in the UPZ, though it may become necessary after a few days in the event of a prolonged sequence of events. Experiences from the accident at Fukushima Daiichi have demonstrated that the sheltering that was recommended in the area between 20 and 30 km from the NPP, and which lasted for 10 days before a decision was taken concerning voluntary evacuation, resulted in major difficulties for the affected parts of the population.

SSM also considers that planning should be in place for sheltering within delimited areas of the EPD, mainly dealing with warranted evacuation in the event of prolonged sheltering. Outside the EPD, SSM considers that the pre-existing planning for sheltering in connection with an Important Public Announcement (IPA) is sufficient.

The postulated event with functioning mitigation systems does not affect the proposed planning for sheltering. The dose criterion for sheltering is not exceeded at distances greater than just over 15 km, neither on the part of adults or children, even if 90 per cent of all occurring weather scenarios are taken into account for this event.

4.3.5. Iodine thyroid blocking

SSM's proposals:

1. ITB should be predistributed in both the PAZ and UPZ.
2. It is advisable to have capacity for distribution of ITB within a day or two in delimited areas within the EPD.
3. The recommendation for intake of predistributed ITB should not be issued automatically in connection with the declaration of emergency class at the NPP, or in connection with decisions on protective actions. Instead, it should always be preceded by an assessment of probability and the point in time for the release.
4. An investigation should be made into the mandates for carrying out procurement, keeping stocks and supplementary/limited distribution of ITB, as well as the mandate to recommend intake of ITB. An investigation should also be made into the prerequisites for supplying ITB to children and pregnant women throughout Sweden.

Iodine thyroid blocking (ITB) is a protective action that requires considerable planning to enable its implementation in practice, either in the form of predistributed ITB, or through distribution of ITB as needed during the nuclear or radiological emergency. SSM applies the same dose criterion, 50 mSv equivalent dose to the thyroid, as a basis for the proposed planning for ITB on the part of both the postulated events: with and without functioning mitigation systems.

The calculations demonstrate that pre-planning for ITB may be warranted for children up to distances of approximately 150, 190 and 260 km in cases where the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account for the event without functioning mitigation systems. As far as adults are concerned, the calculations demonstrate that the corresponding distances are approximately 100, 120 and 160 km.

In the assessment of SSM, it is feasible to predistribute ITB within the PAZ and UPZ, in line with the recommendations from the IAEA. However, SSM considers it unnecessary to predistribute ITB at greater distances from the NPPs. The rationale behind SSM's standpoint to refrain from proposing predistribution of ITB in the EPD as well is because predistribution incurs a high level of costs, while at the same time, it is less probable that the entire area defined by the EPD will be affected by a release warranting intake of ITB. Consequently, predistribution within the EPD would give relatively little benefit in relation to the cost.

Nevertheless, SSM considers that stocks of ITB should be maintained regionally to enable limited distribution within around a day or two in areas within the EPD if the circumstances during the event so allow. This alternative is less costly than predistribution. The stocks of ITB maintained for limited distribution in these areas will however only be of benefit in connection with slow event sequences. During quicker sequences, sheltering will probably be advisable in these areas, which cannot be combined with distribution of ITB.

In the assessment of SSM, intake of predistributed ITB tablets should not be automatically implemented during the emergency classes of site area emergency or general emergency, nor in connection with decisions concerning protective actions such as sheltering and evacuation. Decisions to recommend intake of ITB should always be preceded by an assessment of the probability and point in time of releases warranting such intake. SSM considers that this kind of assessment may take place in accordance with straightforward criteria and predetermined decision templates. Without this kind of assessment, there is a risk of intake of ITB occurring at the wrong point in time and thus being less effective. This also increases the risk of needing to issue recommendations on taking additional iodine tablets, which goes against recommendations issued by the IAEA. Instead, evacuation should be considered for situations in which repeated intake of ITB might be anticipated.

The postulated event with functioning mitigation systems has no impact on the proposed planning for ITB. The dose criterion for ITB will not be exceeded at distances greater than approximately 10 km, neither on the part of adults or children, regardless of whether 90 per cent of all occurring weather scenarios are taken into account for this event.

In the assessment of SSM, the respective mandates for the procurement process, stock management, supplementary and limited distribution within the EPD, as well as the right to recommend intake of ITB, need to be investigated further. At the present time, SSM is in charge of procurement and management of national stocks; the county administrative boards and MSB are in charge of predistribution, and the county administrative boards manage regional inventories as well as supplemental and limited distribution of ITB within the EPD, despite the fact that none of these authorities have mandates to deal with pharmaceuticals under pharmaceutical legislation. An additional perspective is that the county administrative boards and SSM are presently in charge of issuing recommendations on intake of ITB if this should be needed during a nuclear or radiological emergency. This is also in contravention of pharmaceutical legislation. Additionally, SSM also considers it advisable to investigate the potential to supply ITB to children and pregnant women throughout Sweden.

4.3.6. Warnings and predistributed information

SSM’s proposals:

1. Warnings for the public should be prepared in the PAZ and UPZ.
2. Systems for warning the population in the PAZ and UPZ should be investigated before carrying out a new procurement process and distributing RDS radio receivers to the public.
3. Residents in the PAZ and UPZ should receive predistributed information on a regular basis about measures to be taken in connection with warnings from the NPP in addition to communication about radiation protection in connection with NPP accidents.
4. The pamphlet about measures to be taken in connection with warnings issued by the NPP should be updated and supplemented with information about precautionary evacuation in the PAZ.
5. A review should be carried out of the emergency classes comprising site area emergency and general emergency at the NPPs.

SSM is of the assessment that the existing requirements for warnings and predistributed information out to a distance of 12 to 15 km from the NPPs should be established in both the PAZ and UPZ. Outdoor warning systems in the form of sirens and indoor warning systems in the form of RDS[3] are currently in place within the distance of 12 to 15 km from the NPPs.

In the same area, two information pamphlets are also distributed every fifth year in connection with fresh replacements of the predistributed ITB. The pamphlets provide information about measures to be taken in connection with warnings from the NPP and protection against radiation should a nuclear power plant accident occur. In the assessment of SSM, the pamphlet about advised measures in connection with warnings issued by the NPP should be updated and supplemented. The new information should state that precautionary evacuation of the PAZ may be carried out at the early stage of an event after the emergency class of site area emergency has been declared, though at the very latest in connection with a general emergency.

In the estimate of economic impacts, SSM has presented a cost that includes distribution of RDS receivers to all households in the PAZ and UPZ, in other words, to a distance of approximately 25 km. However, in the light of new technical possibilities for warning of the population, SSM considers it advisable to review the systems for warning the population in the PAZ and UPZ prior to carrying out procurement and distribution of new RDS receivers.

The emergency class of site area emergency is to be declared if an event or abnormal operation at the NPP jeopardises safety. A general emergency is declared if an event or abnormal operation has occurred at the NPP where a release warranting protective actions for the public is taking place or cannot be ruled out within a duration of 12 hours. SSM considers it advisable to review whether the emergency classes are appropriate for alerting of public authorities, warning the population, and as input for decision making concerning measures to protect the public.

[3] RDS is an acronym for 'Radio Data System'. An RDS receiver is a special purpose radio receiver designed for warning messages.

4.4. Emergency planning zones and distances

In this section, SSM presents the proposed design of the PAZ and UPZ to surround the NPPs of Forsmark, Oskarshamn and Ringhals. SSM also provides an account of the county administrative boards affected by the proposed EPD to surround the NPPs and suggests requirements for cordoning off of areas at sea.

4.4.1. Emergency planning zones surrounding NPPs

The respective county administrative boards of Uppsala, Kalmar and Halland have developed a proposed design for the PAZ and UPZ to surround the NPPs of Forsmark, Oskarshamn and Ringhals. These proposals are based on an approximate range of the PAZ extending around 5 km and an approximate range of the UPZ extending around 25 km. These proposals have been produced in consultation with SSM, MSB and relevant regional stakeholders, such as police authorities, incident commanders and local government.

The proposed emergency planning zones are in compliance with the amendment to the Civil Protection Ordinance, as proposed by SSM (see section 7.1). One key change is that only the determined approximate ranges of the emergency planning zones are stated in the Ordinance, whereas their design is to be established by the relevant county administrative boards. Consequently, the design of the emergency planning zones may be reviewed regularly and changed in pace with changing circumstances around the NPPs that have an impact on the design. The proposed designs of the emergency planning zones presented in this report are adapted to the current circumstances of the NPPs.

The proposed design of the emergency planning zones utilises natural boundaries in the form of railways or roads. Here, the rationale is not only that the population affected must be able to understand whether they are located in an emergency planning zone, but also that these boundaries should facilitate the operations of rescue services and police officers, e.g. when setting up roadblocks.

Effectiveness is a key factor of the proposed design of emergency planning zones. Therefore, in some cases, the distance to the NPP is shorter than the proposed range; in some cases, the opposite applies. For example, this may depend on where it was possible to identify appropriate boundaries as described above. It has also been taken into account that the proposed measures, particularly evacuation, should be feasible within the specified interval of time for the respective emergency planning zones.

The nuclear power plant at Forsmark

The boundary for the PAZ runs along roads, where the assumption is that residents on both sides of these roads are subject to the same decisions concerning protective actions. Creating the boundaries this way makes it possible to block off the PAZ at different locations. What is of special significance is keeping road 76, which is the most important transport route in this part of Uppsala County, open if the circumstances are appropriate. The islands off the coast, as defined by the PAZ on the mainland, also belong to this zone. The island of Gräsö does not belong to the PAZ.

The boundary of the UPZ also runs along roads. Here, the assumption is that communities located along these roads belong to the zone regardless of which side of the roads the communities are located on. The islands off the coast, as defined by the UPZ on the mainland, also belong to the UPZ. The UPZ encompasses operations critical to society. These operations presuppose separate planning in connection with decision making concerning protective actions, e.g. for a hospital in Östhammar, and for municipal services in the communities of Östhammar, Gimo, Österbybruk and Öregrund.

The proposed PAZ and UPZ to surround the Forsmark NPP are illustrated by Figure 4.

Figure 4. The proposed PAZ and UPZ to surround the Forsmark NPP.

The nuclear power plant at Oskarshamn

The boundary for the PAZ runs along roads, where the assumption is that residents on both sides of these roads are subject to the same decisions concerning protective actions. In order to identify suitable roads, the distance in certain directions was set at slightly greater than 5 km. The islands off the coast, as defined by the PAZ on the mainland, also belong to this zone. Both Clab and the Äspö laboratory are located within the PAZ. These operations presuppose separate planning to enable certain activities to continue in connection with a decision taken on precautionary evacuation of the PAZ.

The boundary of the UPZ also runs along roads. Here, the assumption is that communities located along these roads belong to the zone regardless of which side of the roads the communities are located on. The part of northern Öland located within a distance of approximately 30 km from the NPP also belongs to the UPZ. The islands off the coast, as defined by the UPZ on the mainland and northern Öland, also belong to this zone. The UPZ encompasses operations critical to society. These operations presuppose separate planning in connection with decision making concerning protective actions, e.g. for a hospital and for municipal services in Oskarshamn.

The proposed PAZ and UPZ to surround the Oskarshamn NPP are illustrated by Figure 5.

Figure 5. The proposed PAZ and UPZ to surround the Oskarshamn NPP.

The nuclear power plant at Ringhals

The boundary of the PAZ mainly runs along Västkustbanan (West Coast Railway) past Ringhals, meaning that the entire peninsula of Värö is enclosed. The railway serves as a natural boundary that is not only easy to identify, but also control. The islands off the coast, as defined by the PAZ on the mainland, also belong to this zone. The PAZ encompasses two operations needing particular attention in connection with decisions concerning precautionary evacuation: a pulp operation and a power grid station. The power grid station can be operated remotely as necessary. The company running the pulp operation has emergency preparedness planning in place that makes it possible to run basic operations when only a small proportion of the workforce has stayed behind in protected areas of the facility.

The boundary of the UPZ runs along roads. Here, the assumption is that communities located along these roads belong to the zone regardless of which side of the roads the communities are located on. The islands off the coast, as defined by the UPZ on the mainland, also belong to this zone. The UPZ encompasses operations critical to society. These operations presuppose separate planning in connection with decision making concerning protective actions, e.g. for hospitals in Varberg and Kungsbacka, and for municipal services in several communities. The UPZ to surround the Ringhals NPP impacts on two counties: Halland and Västra Götaland. This situation presupposes cooperation in connection with decision making concerning protective actions in order to prevent the county boundaries in themselves from impacting on the protective actions taken for the population.

The proposed PAZ and UPZ to surround the Ringhals NPP are illustrated by Figure 6.

Figure 6. The proposed PAZ and UPZ to surround the Ringhals NPP.

4.4.2. EPDs surrounding Swedish nuclear power plants

SSM considers it advisable to establish an EPD extending 100 km surrounding the NPPs at Forsmark, Oskarshamn and Ringhals. The counties affected by the NPP at Forsmark are Uppsala, Stockholm, Gävleborg and Västmanland. The counties affected by the Oskarshamn NPP are Kalmar, Östergötland, Jönköping, Kronoberg and Gotland. The counties affected by the NPP at Ringhals are Halland, Västra Götaland, Jönköping and Kronoberg. The NPPs at Forsmark and Ringhals also affect relatively small areas of Dalarna and Skåne counties. However, SSM considers that the affected parts of these counties are too small to warrant planning for relocation based on input data from radiation measurements of ground deposition, preparations for limited distribution of ITB in new areas, or enhanced planning for prolonged sheltering.

4.4.3. Cordoning off of areas at sea

SSM has not performed calculations of distances at which threshold doses, dose criteria or intervention levels are exceeded over bodies of water. Consequently, SSM proposes no approximate ranges of the emergency planning zones to apply to the open sea. Instead, SSM advises that areas at sea should be cordoned off to the north and south of the NPPs in accordance with the same principles as today governing emergency preparedness planning. The size of the area at sea to be cordoned off should be adapted to the following: the geography, protective actions decided for the mainland, the islands belonging to the emergency planning zones, in addition to the circumstances of the event.

4.5. Sensitivity analyses

SSM has conducted sensitivity analyses for the purpose of looking into the feasibility of the proposed emergency planning zones and distances to surround the NPPs in relation to events that deviate from the postulated events defined by SSM. In this section, SSM presents the outcomes from analyses of events having other release sequences, events affecting fuel pools, events involving simultaneous releases from several reactors at the same NPP, in addition to events in which well-functioning mitigation systems are involved.

4.5.1. Events with a brief period of forewarning

The period of time as of an alert concerning abnormal operation at an NPP, up until a release warranting consideration of protective action for the public, is referred to as the period of forewarning. The period of forewarning is of crucial importance for the time needed to take protective action. If the period of forewarning is less than a few hours, actions such as evacuation, even within a delimited area near an NPP, are difficult to perform within the given timeframe, or even impossible. The postulated event without mitigation systems corresponds to a conceivable worst-case scenario in terms of release magnitude, though not in terms of the period of forewarning. There are conceivable events that have a briefer period of forewarning. However, these events do not have an impact on determining the ranges of emergency planning zones or distances, or on the pre-planned protective actions. If this kind of event should occur, this would instead require selection of a quicker protective action having a lower level of effectiveness, than compared to a slower protective action having greater effectiveness, e.g. sheltering instead of evacuation.

4.5.2. Events with protracted release sequences

The duration of the releases encompassed by the postulated events defined by SSM is 48 hours. Both Chernobyl and Fukushima Daiichi demonstrated that release sequences may far exceed this period of time. However, such release sequences do not define the parameters for the ranges of emergency planning zones or distances, as protracted release sequences imply a lower level of releases per unit of time given that the same total quantity of radioactive materials is released, resulting in lower doses. Protracted release sequences may nevertheless warrant termination of the protective action of sheltering, to be replaced by evacuation.

4.5.3. Events affecting spent fuel pools

Introduction

The nuclear power plant accident at Fukushima Daiichi serves as a reminder that spent fuel pools can be affected by emergencies. During the accident sequence, there was uncertainty about the state of reactor 4's spent fuel pool. For some time, there were concerns that the spent fuel kept there was no longer submerged in water. With this rationale in mind, SSM has conducted a sensitivity analysis that includes releases from spent fuel pools. As the spent fuel pools of both boiling water and pressurised water reactors are situated outside the reactor containment, events that put the cooling of spent fuel pools out of commission risk leading to large releases.

For this sensitivity analysis, SSM defined an event involving a loss of cooling of spent fuel pools. Thereafter, SSM performed dispersion and dose calculations on the part of the three NPPs of Forsmark, Oskarshamn and Ringhals. Using the estimates as a starting point, the Authority analysed the need for various protective actions in relation to the event involving loss of cooling of spent fuel pools, as well as assessed the extent to which the proposed emergency planning zones and distances can meet these needs.

Analysis

For the event loss of cooling of spent fuel pools, precautionary evacuation in the expected direction of the wind to a distance of approximately 25 km would be sufficient to considerably reduce the risk of severe deterministic effects. This event would involve the release commencing after 56 hours; consequently, the parts of the UPZ located in the expected direction of the wind should be possible to evacuate before the release begins. For this reason, it is reasonable to assume that severe deterministic effects can be avoided by the emergency preparedness planning proposed by SSM.

In the event loss of cooling of spent fuel pools, evacuation in the expected direction of the wind at distances greater than 100 km may be warranted for the purpose of ruling out the risk of effective doses exceeding 100 mSv. In spite of this, however, SSM considers it infeasible to conduct detailed planning for evacuation outside the UPZ. It is not only difficult to predict the areas that might be affected at greater distances, it is also difficult in practice, even under satisfactory external conditions, to carry out evacuation of areas this large. The larger the areas needing evacuation, the higher the risk of negative impacts owing to the evacuation. This makes sheltering a better option, which SSM considers feasible at large distances and in large areas. The event involving loss of cooling of spent fuel pools would also give time to carry out sheltering in premises offering better protection than a detached house, even at greater distances. This would considerably reduce the risk of effective doses exceeding 100 mSv. Consequently, enhanced planning for evacuation prior to a release, i.e. outside the UPZ, would only give a limited increase in capability in relation to the costs incurred by sustaining the planning and potential to carry out this kind of evacuation.

In the event involving loss of cooling of spent fuel pools, evacuation due to ground deposition may be warranted at distances greater than 500 km. SSM's proposals would imply pre-planning of evacuation due to ground deposition as well as associated radiation measurement within the EPD, i.e. to a distance of 100 km. Nonetheless, SSM considers the proposed dimensioning of the capability for performing radiation measurements to be adequate. First of all, the measurement resources proposed by SSM should be available for distances exceeding the EPD, and secondly, the measurement resources from the other counties where nuclear power plants are located can be used in the affected areas at greater distances. As also proposed by SSM, this particularly applies to radiation measurements. These measurements should be performed by means of a more flexible method than now, where the new method allows definition of the areas to be measured during the event in question.

For the event involving loss of cooling of spent fuel pools, sheltering may be warranted at distances greater than 500 km. Owing to the difficulty of predicting the areas that might be affected at great distances, enhanced planning for dealing with prolonged sheltering outside the EPD would only give a small increase in capacity in relation to the costs incurred for sustaining this kind of planning. Consequently, SSM considers that the pre-existing planning for sheltering in connection with an Important Public Announcement (IPA) is acceptable outside the EPD.

For the event involving loss of cooling of spent fuel pools, iodine thyroid blocking (ITB) may be warranted at distances greater than 500 km. As it is difficult to predict the areas that might be affected at great distances, enhanced planning for ITB outside the EPD will only give a small increase in capacity in relation to the costs incurred for sustaining this kind of planning. For this reason, SSM views the proposed planning for ITB as acceptable.

In the sensitivity analysis, the event involving loss of cooling of spent fuel pools is equivalent to a conceivable worst-case scenario in terms of release magnitude, though not in terms of the period of forewarning. There are conceivable events involving releases from fuel pools that have a briefer period of forewarning. However, these events also have no impact on the design of emergency planning zones or distances, as the same protective actions must be prepared. If this kind of event should occur, this would instead require selection of a quicker protective action having a lower level of effectiveness, than compared to a slower protective action having greater effectiveness, e.g. sheltering instead of evacuation.

Conclusion

In summary, SSM considers the proposed range of the PAZ of approximately 5 km, the UPZ of approximately 25 km, and the EPD of 100 km, in addition to the preparations for sheltering and ITB, as feasible, even while taking into account the event involving loss of cooling of spent fuel pools. The rationale behind this standpoint is that the proposals already allow for the possibility of a broader scope of protective actions that might be necessary, to the extent that this is possible.

4.5.4. Events with simultaneous releases from several reactors

Introduction

The nuclear power plant accident at Fukushima Daiichi served as a reminder that it is possible for several reactors at an NPP to be simultaneously impacted by a severe accident. Consequently, in the assessment of SSM, it is warranted to perform a sensitivity analysis where the total releases from the different representative source terms are scaled depending on the number of reactors at the NPP. If the releases largely take place simultaneously from several reactors, this would affect not only the distance where protective actions might be necessary in connection with the release, but also the size of the areas where protective actions may be warranted owing to the ground deposition caused by the fallout. On the other hand, should the releases take place at different points in time, this would mainly affect the size of the areas where protective actions might be necessary owing to the ground deposition caused by the fallout.

SSM has performed dispersion and dose calculations for the three NPPs at Forsmark, Oskarshamn and Ringhals, where releases take place simultaneously from one, two or three reactors on the part of both the postulated events: with and without functioning mitigation systems. The reason why SSM has not produced outcomes for simultaneous releases from four reactors is due to the fact that when the proposed emergency planning zones and distances can at the very earliest enter into force, no nuclear power plant in Sweden will have more than three reactors in operation. Using the estimates as a starting point, SSM analysed the need for different protective actions in connection with simultaneous releases from several reactors, as well as assessed the extent to which the proposed emergency planning zones and distances can meet these needs.

Analysis of releases in connection with simultaneous events without functioning mitigation systems

In the event of simultaneous releases from three reactors without functioning mitigation systems, precautionary evacuation of just over half of the UPZ in the expected direction of the wind is sufficient for considerably reducing the risk of severe deterministic effects. Consequently, in the assessment of SSM, the evacuation planning proposed by SSM, involving likely capacity for evacuation of the UPZ in several phases, gives reasonable potential for preventing severe deterministic effects, even in the case of simultaneous releases from three reactors without functioning mitigation systems.

In the case of simultaneous releases from three reactors without functioning mitigation systems, it may be warranted to carry out evacuation in the expected direction of the wind out to a distance of just over 80 km for the purpose of avoiding doses exceeding 100 mSv effective dose. In spite of this, however, SSM considers it infeasible to conduct detailed planning for evacuation outside the UPZ. It is not only difficult to predict the areas that might be affected at greater distances, it is also difficult in practice, even under satisfactory external conditions, to carry out evacuation of areas this large. The larger the areas needing evacuation, the higher the risk of negative impacts owing to the evacuation. This makes sheltering a better option, which SSM considers feasible at large distances and in large areas. Consequently, enhanced planning for evacuation prior to a release, i.e. outside the UPZ, would only give a limited increase in capacity in relation to the costs incurred by sustaining the planning and potential to carry out this kind of evacuation.

In the event of simultaneous releases from three reactors without functioning mitigation systems, sheltering may be warranted out to a distance of 350 km. As it is difficult to predict the areas that might be affected at great distances, enhanced planning for dealing with prolonged sheltering outside the EPD would only give a small increase in capacity in relation to the costs incurred for sustaining this kind of planning. Consequently, SSM considers that the pre-existing planning for sheltering in connection with an Important Public Announcement (IPA) is acceptable outside the EPD.

Analysis of releases in connection with simultaneous events involving functioning mitigation systems

In the event of simultaneous releases from three reactors with functioning mitigation systems, precautionary evacuation of the PAZ gives a good margin of safety that is sufficient for ruling out the risk of severe deterministic effects. Precautionary evacuation of the PAZ is also sufficient for achieving a high level of probability of preventing effective doses exceeding 100 mSv. Evacuation of the UPZ will also give a good margin of safety that is sufficient for preventing effective doses exceeding 20 mSv. Sheltering in the entire UPZ affected by the release would be warranted, whereas sheltering at greater distances in the EPD is unlikely to be warranted.

Conclusion

In summary, SSM considers that the proposed range of the PAZ at approximately 5 km, and the UPZ of approximately 25 km, in addition to the preparations for sheltering, are feasible even while taking into account simultaneous releases from two or three reactors without functioning mitigation systems. The rationale behind this standpoint is that the proposals already allow for the possibility of a broader scope of protective actions that might be necessary, to the extent that this is possible given the circumstances. In the event of simultaneous releases from two or three reactors with functioning mitigation systems, the proposed ranges of the emergency planning zones and distances, as well as the preparations for sheltering, give a good margin of safety and are consequently sufficient.

4.5.5. Events with well-functioning mitigation systems

Introduction

According to analyses conducted by the licensees of Swedish NPPs, the mitigation systems perform at a substantially higher level than the requirements imposed by the Government. In the assessment of SSM, there is rationale for performing a sensitivity analysis where the mitigation systems are assumed to function well, as the estimated releases would then be smaller than those presented for the postulated event with functioning mitigation systems. SSM is of the view that it should be possible to determine at an early phase of an event whether the mitigation systems are performing well, also that this information is key input for the incident commander prior to taking a decision on appropriate protective actions.

SSM defined an event and a representative source term for the sensitivity analysis with well-functioning mitigation systems in accordance with the same method as for the postulated events. Thereafter, SSM performed dispersion and dose calculations on the part of the three NPPs at Forsmark, Oskarshamn and Ringhals. Using the estimates as a starting point, SSM analysed the need for different protective actions in relation to the event involving well-functioning mitigation systems, as well as assessed the extent to which the proposed emergency planning zones and distances can meet these needs.

Analysis

In the view of SSM, precautionary evacuation of the PAZ should be carried out even in a situation where the mitigation systems might be assumed to perform well. The rationale behind this standpoint is that emergencies are often characterised by great uncertainty, and that precautionary evacuation of the PAZ is still a feasible precautionary measure in the event that the situation quickly deteriorates. However, additional evacuation is unwarranted if the mitigation systems can be assumed to function well. In contrast, however, sheltering may be warranted in the parts of the UPZ likely to be affected by the release. ITB may also be warranted to around half the range of the UPZ in the parts expected to be affected by the release in question. No ground deposition is assumed to occur implying that the population evacuated from the PAZ is prevented from returning after the release has ceased. Outside the UPZ, it is highly unlikely that protective actions for the public would be warranted.

Conclusion

SSM's proposed range of the PAZ, at approximately 5 km, and a UPZ of approximately 25 km, give a good margin of safety and are sufficient for dealing with releases in connection with the event involving well-functioning mitigation systems.

4.6. Residual dose

SSM has calculated the highest radiation doses that members of the public may receive provided that the protective actions proposed by SSM in the emergency planning zones and emergency planning distances can be completed. The purpose of these calculations is to demonstrate whether the proposals for pre-planned protective actions enable avoidance of severe deterministic effects and keeping doses below the selected reference levels. In this section, SSM presents the outcomes on the part of the postulated events with and without functioning mitigation systems. For comparison purposes, SSM also presents the outcomes for the event of the sensitivity analysis, with well-functioning mitigation systems.

4.6.1. Calculation of residual dose

As the starting points for developing the proposed range of the emergency planning zones and distances, SSM uses the reference level 100 mSv effective dose for the postulated event without functioning mitigation systems, and the reference level 20 mSv effective dose for the postulated event with functioning mitigation systems. These reference levels define a benchmark for the highest dose that the representative person may receive given implementation of planned protective actions. The actual protective actions that can be taken in connection with a severe accident depend on the circumstances of the event. However, planning for protective actions has the aim of keeping doses below the selected reference levels.

Reference levels are not directly applicable during emergency preparedness planning. Therefore, SSM has defined dose criteria for the respective protective actions and applied them when performing dispersion and dose calculations. The dose criteria apply to an unprotected person during a period of seven days, and are defined for both reference levels at 20 mSv and 100 mSv effective dose. It is a conservative assumption to calculate dose to an unprotected person staying outdoors during the first seven days after the release commencing. However, the purpose is to include the individuals who happen to be outdoors when the radioactive cloud passes, as a considerable proportion of the dose may be received then. Distributions of distances developed using the respective dose criterion serve as the basis of SSM's rationale concerning the recommended distances at which different protective actions should be prepared.

For the purpose of checking whether the planning proposed by SSM makes it possible to keep doses below the selected reference levels, SSM performed calculations of residual doses, with the assumption that different combinations of protective actions are taken. As far as concerns evacuated areas, SSM assumes that the effective dose is zero after protective actions have been taken. This applies provided that evacuation is carried out before the release has commenced and assuming that the evacuation takes place to a site that is unaffected by the release. SSM has assumed that this applies within the PAZ, in other words, to a distance of approximately 5 km. Furthermore, SSM has assumed that this can apply to parts of the UPZ if these are evacuated, i.e. to a distance of approximately 25 km depending on the circumstances of the event. Lastly, in both the UPZ and EPD, SSM has assumed that sheltering is always feasible.

Sheltering offers protection against external exposure from the radioactive cloud and the ground deposition, as well as against internal exposure due to inhalation of radioactive materials. In a detached house, SSM assumes that sheltering reduces radiation doses by half compared to staying outdoors. SSM has also looked into the effects of sheltering in premises and spaces offering better protection, e.g. cellars of detached houses and multi-residence dwellings with filtered ventilation. Here, the purpose is to study the extent to which sheltering in these indoor locations can serve as an alternative to evacuation. SSM assesses that sheltering in premises offering better protection can reduce radiation doses to one-tenth.

SSM also proposes a number of overarching objectives to serve as the basis of the proposed emergency planning zones and distances. Of these, the highest priority objective is to avoid severe deterministic effects. Consequently, SSM has defined threshold doses for three of these effects assessed by SSM as bounding effects, i.e. effects that occur at the lowest level of exposure (see section 2.6.4). For the purpose of checking whether the planning proposed by SSM makes it possible to avoid these effects, SSM performed calculations of distances at which threshold doses are exceeded, given different combinations of protective actions being taken using the same method as described above.

4.6.2. Potential for avoiding severe deterministic effects

As far as concerns the event without functioning mitigation systems, severe deterministic effects are unlikely if the PAZ is evacuated before a release, at the same time as sheltering is recommended (and carried out) in the parts of the UPZ affected by the release. However, the risk of exceeding the threshold dose of 100 mGy to an embryo cannot be completely ruled out.

For the event with functioning mitigation systems, severe deterministic effects can be ruled out if the PAZ is evacuated before a release.

4.6.3. Potential for keeping doses below the selected reference levels

Analyses of cases where sheltering has reduced radiation doses by half

SSM has analysed the effect of various combinations of protective actions during a release in connection with the event without functioning mitigation systems, assuming that sheltering reduces radiation doses by half. If the PAZ is evacuated and sheltering is recommended (and carried out) before the release takes place in the parts of the UPZ and the EPD that may be affected, the population sheltered in the UPZ at a distance of approximately 5 km may receive the highest effective doses; as a maximum, their doses may be up to approximately 500 mSv if 90 per cent of all occurring weather scenarios are taken into account. If the parts of the UPZ that might be affected by the release are also evacuated to a distance of just over 15 km before the release takes place, the population sheltered in the UPZ just outside the evacuated area will receive the highest effective doses. As a maximum, these doses will be up to approximately 100 mSv if 80 per cent and 90 per cent of all occurring weather scenarios are taken into account on the part of children and adults, respectively. If all parts of the UPZ that may be affected by the release are evacuated, the population sheltered in the EPD at a distance of approximately 25 km will receive the highest effective doses. As a maximum, these doses will be up to approximately 100 mSv if 90 per cent of all occurring weather scenarios are taken into account on the part of both children and adults.

SSM has also analysed the effect of various combinations of protective actions for the event with functioning mitigation systems, assuming that sheltering reduces radiation doses by half. If the PAZ is evacuated and sheltering is recommended (and carried out before the release) in the parts of the UPZ that may be affected by such release, the population sheltered in the UPZ at a distance of approximately 5 km will receive the highest effective doses. As a maximum, these doses will be up to approximately 20 mSv if 90 per cent of all occurring weather scenarios are taken into account. If the parts of the UPZ that might be affected by the release are also evacuated to a distance of just over 15 km before the release takes place, the population sheltered just outside the evacuated area will receive the highest effective doses. As a maximum, these doses will be up to approximately 5 mSv if 90 per cent of all occurring weather scenarios are taken into account. People who are present in the parts of the EPD affected by the release at a distance of approximately 25 km may also receive effective doses of up to 5 mSv if sheltering is not recommended in this area.

Lastly, SSM has analysed the effect of various combinations of protective actions for the event in the sensitivity analysis, with well-functioning mitigation systems and assuming that sheltering reduces radiation doses by half. If the PAZ is evacuated and sheltering is recommended (and carried out before the release takes place) in the parts of the UPZ that may be affected by such release, the population sheltered in the UPZ at a distance of approximately 5 km will receive the highest effective doses. As a maximum, these doses may slightly exceed 5 mSv if 90 per cent of all occurring weather scenarios are taken into account. If the parts of the UPZ that might be affected by the release are also evacuated to a distance of just over 10 km before the release takes place, the population sheltered just outside the evacuated area will receive the highest effective doses. As a maximum, these doses will be up to approximately 2.5 mSv if 90 per cent of all occurring weather scenarios are taken into account. It is unlikely that any unprotected person who is present in the EPD at a distance of approximately 25 km will receive an effective dose exceeding 1 mSv.

For a summary account of outcomes from the different combinations of protective actions on the part of the analysed events, in which precautionary evacuation results in radiation doses of zero and sheltering reduces radiation doses by half, see Table 6.

Table 6. Maximum residual effective doses and distances at which these are received (if 90 per cent of all occurring weather scenarios are taken into account) for different combinations of possible releases and protective actions. (Evacuation is assumed to result in radiation doses of zero, and sheltering is assumed to reduce radiation doses by half.)

Protective actions	Maximum residual dose (mSv)	Distance (km)
Non-functioning mitigation systems		
Evacuation: ~5 km Sheltering: ~100 km	500	~5
Evacuation: ~15 km Sheltering: ~100 km	100[1]	~15
Evacuation: ~25 km Sheltering: ~100 km	100	~25
Functioning mitigation systems		
Evacuation: ~5 km Sheltering: ~25 km	20	~5
Evacuation: ~15 km Sheltering: ~25 km	5	~15 and ~25
Well-functioning mitigation systems		
Evacuation: ~5 km Sheltering: ~25 km	5	~5
Evacuation: ~10 km Sheltering: ~25 km	2.5	~10

[1]80 per cent and 90 per cent of the weather scenarios on the part of children and adults, respectively.

Analyses of cases in which sheltering reduces radiation doses to one-tenth

SSM has also analysed the effect of various combinations of protective actions in connection with the event without functioning mitigation systems, assuming that sheltering reduces radiation doses to one-tenth within the UPZ (e.g. at a hospital) and by half outside the UPZ. If the PAZ is evacuated and sheltering is recommended (and carried out) before the release in the parts of the UPZ and EPD that may be affected by such release, the population sheltered in the UPZ at a distance of approximately 5 km will receive the highest effective doses. As a maximum, these doses will be up to approximately 100 mSv if 90 per cent of all occurring weather scenarios are taken into account.

If the parts of the UPZ that might be affected by the release are evacuated to a distance of just over 15 km before the release takes place, the population sheltered in the EPD at a distance of approximately 25 km will receive the highest effective doses. As a maximum, these doses will be up to approximately 50 mSv if 70 per cent and 80 per cent of all occurring weather scenarios on the part of children and adults, respectively, are taken into account. However, the risk of effective doses of nearly 100 mSv to children cannot be ruled out within the EPD at a distance of approximately 25 km if 90 per cent of all occurring weather scenarios are taken into account. Thus, sheltering is a better option within the distances 15 to 25 km in the UPZ compared to sheltering within the EPD at a distance that is just over 25 km, owing to the shielding factor that is better in the UPZ.

If the parts of the UPZ that might be affected by the release are evacuated before the release takes place, the population sheltered in the EPD at a distance of approximately 25 km will receive the highest effective doses. As a maximum, these doses will be up to approximately 50 mSv if 70 per cent and 80 per cent of all occurring weather scenarios on the part of children and adults, respectively, are taken into account. However, in connection with sheltering, the risk of effective doses of nearly 100 mSv to children cannot be ruled out within the EPD at a distance of approximately 25 km.

For a summary account of outcomes for different combinations of protective actions for the analysed events, in which precautionary evacuation results in radiation doses of zero, and sheltering reduces radiation doses to one-tenth in the UPZ and by half within the EPD, see Table 7.

Table 7. Maximum residual effective doses and distances at which these are received (if 90 per cent of all occurring weather scenarios are taken into account) on the part of different combinations of possible releases and protective actions for the postulated event without functioning mitigation systems. (Evacuation is assumed to result in radiation doses of zero, and sheltering is assumed to reduce radiation doses to one-tenth in the UPZ and by half within the EPD.)

Protective actions	Maximum residual dose (mSv)	Distance (km)
Non-functioning mitigation systems		
Evacuation: ~5 km Sheltering: ~100 km	100	~5 and ~25
Evacuation: ~15 km Sheltering: ~100 km	100	~25
Evacuation: ~25 km Sheltering: ~100 km	100	~25

Conclusion

The proposed ranges of the emergency planning zones and distances, combined with the preparations in the respective zones and distances proposed by SSM, make it possible to keep doses below the selected reference levels. This applies to not only 100 mSv effective dose for the postulated event without functioning mitigation systems, but also to 20 mSv effective dose for the postulated event with functioning mitigation systems.

When it comes to the postulated event without functioning mitigation systems, this presupposes precautionary evacuation of the relevant parts of the UPZ before this release begins. An alternative to evacuating all parts of the UPZ that might be affected by the release is to evacuate the zone out to a distance of approximately 15 km, combined with sheltering in the remaining parts of the zone at a distance of between 15 and 25 km. This alternative is particularly beneficial if sheltering can take place in premises offering better protection than detached houses.

If a release in conjunction with an emergency is expected to result in protracted exposure, the reference level refers to the effective dose over the course of one year as of the initiating event. The calculations of effective dose performed, given different combinations of protective actions, refer to exposure during the first seven days after the release commenced. Exposure to ground deposition during the remaining 51 weeks, i.e. within one year as of the release commencing, could consequently warrant additional protective actions with the aim of keeping doses below the selected reference level. However, SSM considers that the release phase and phase after the release has ceased should be dealt with separately. First of all, it could lead to disproportionate consequences if relocation were carried out in order to avoid a small additional dose from ground deposition in such cases where doses close to the selected reference level were received during the release phase. Secondly, it would be impossible in practice to determine with a sufficient level of precision which doses were received by different parts of the population during the release phase, meaning that the total dose over the course of one year is very difficult to estimate. For this reason, SSM is of the opinion that after a significant release has ceased, relocation should only be decided based on potential exposure to the remaining ground deposition.

4.7. Food production

SSM has performed dispersion calculations for estimation of the distances at which measures linked to food production may need to be considered during an emergency in connection with a release from a Swedish NPP. These estimates are based on the intervention levels for food production, as shown in Appendix 1. The estimates were performed on the part of the two postulated events with and without functioning mitigation systems, as well as for the event contained in the sensitivity analysis with well-functioning mitigation systems. Using the calculation outcomes as a starting point in relation to the three events, SSM performed an analysis of needed measures for production of foodstuffs in the event of a release.

4.7.1. Outcomes from dispersion calculations

For a summary of outcomes from dispersion calculations, see Table 8. These are shown in the form of rounded average values for the three NPPs, with distances at which 90 per cent of all occurring weather scenarios are taken into account for the following events: without functioning mitigation systems, with functioning systems, and with well-functioning mitigation systems.

Table 8. Summary of the greatest distances at which intervention levels for food production might be exceeded for different events if 90 per cent of all occurring weather scenarios are taken into account (the intervention level is not exceeded: “-“).

Nuclide group	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Drinking water from surface-water sources with a low level of dilution (0.5 m deep)			
Iodine	~40	~60	>500
Caesium	~1	~15	>500
Strontium	-	-	~250
Transuranic elements	-	-	~2
Drinking water from surface-water sources with a high level of dilution (10 m deep)			
Iodine	~6	~10	>500
Caesium	-	~1	~250
Strontium	-	-	~25
Transuranic elements	-	-	-
Milk			
Iodine	~300	~350	>500
Caesium	~25	~300	>500
Strontium	-	~3	>500
Beef, lamb and reindeer			
Caesium (grazing)	~200	>500	>500
Strontium (grazing)	-	-	~250
Caesium (free-range)	~200	>500	>500
Strontium (free-range)	-	~3	>500
Pork			
Caesium	~25	~300	>500
Strontium	-	-	~30
Game (elk and venison)			
Caesium (100 kBq/m^2)	~2	~35	>500
Caesium (10 kBq/m^2)	~25	~300	>500
Grains			
Caesium	~25	~300	>500
Strontium	-	~3	>500
Leafy vegetables			
Caesium	~200	>500	>500
Strontium	-	~35	>500
Potatoes			
Caesium	-	~3	~350
Strontium	-	-	~250

4.7.2. Analysis

Intervention levels for food production are based on a series of assumptions and are therefore characterised by great uncertainty. The distances presented by SSM where the intervention levels may be exceeded should therefore only be viewed as indicative. The outcomes nevertheless help to illustrate the distances at which problems in food production might arise, the kinds of food production that are most vulnerable, in addition to the nuclides causing the biggest problems that would affect different kinds of food production. It should also be kept in mind that the outcomes refer to the largest distance in some direction at which the intervention level might be exceeded. Consequently, the distances are not a unit of measurement that conveys the size of the areas that could be affected by actual deposition.

In the assessment of SSM, it is feasible to have plans of action linked to food production that encompass all areas that might be affected by a release. In other words, this means taking into account distances encompassing a minimum of 90 per cent of all occurring weather scenarios. The rationale behind SSM's standpoint is that the intervention levels are linked to doses exceeding the limits imposed by the EU, which are compulsory for Sweden in the event of a nuclear power plant accident.

As regards the event without functioning mitigation systems, at least one intervention level is exceeded for all foodstuffs, with the exception of potatoes, at distances greater than the maximum distance contained in the calculations, comprising 500 km. As regards the event with functioning mitigation systems, at least one intervention level is exceeded for several foodstuffs at distances greater than the maximum distance contained in the calculations, comprising 500 km. In the case of the event with well-functioning mitigation systems, intervention levels for milk were exceeded out to distances of approximately 300 km, and the intervention levels for beef, reindeer and leafy vegetables were exceeded out to a distance of approximately 200 km.

The IAEA recommends having planning in place to enable taking of early measures linked to food production out to a distance of 300 km from an NPP. SSM's calculations demonstrate that this distance is only sufficient for the event with well-functioning mitigation systems. With the support of these calculations, SSM is of the view that planning should be in place so that measures linked to food production can be taken at an early phase throughout Sweden. Although no outcomes are presented for distances greater than 500 km, experience from nuclear power plant accidents that have occurred demonstrates that problems when producing certain foodstuffs may occur at great distances. This was particularly the case in connection with the Chernobyl accident, which impacted on industries such as reindeer and sheep farming at distances exceeding 1,000 km.

Consequently, in the assessment of SSM, the competent authorities having mandates linked to food production should review existing emergency preparedness planning in relation to the calculations presented by SSM in this report. Areas of key importance include sufficiently quick decision making concerning measures linked to food production, and protecting the population from intake of contaminated foodstuffs. In the case of certain foods, such as milk, this means taking action during the first 24 hours once an accident sequence begins. Additionally, SSM wishes to emphasise the importance of this review also taking into account the distances to nuclear power plants located abroad.

4.8. Remediation

SSM has performed dispersion calculations for estimation of the distances at which remediation may need to be considered in connection with a release from a Swedish NPP. These estimates are based on the intervention levels for remediation, as shown in Appendix 1. The estimates were performed on the part of the two postulated events, i.e. with and without functioning mitigation systems, as well as for the event contained in the sensitivity analysis, with well-functioning mitigation systems. SSM used these calculation outcomes to analyse the need for remediation in connection with releases occurring in these three events.

4.8.1. Outcomes from dispersion calculations

For a summary of outcomes from dispersion calculations, see Table 9. These are shown in the form of rounded average values for the three NPPs for these events: without functioning mitigation systems, with functioning systems, and with well-functioning mitigation systems.

Table 9. Summary of the greatest distances at which intervention levels for remediation are exceeded for different events if 70, 80 and 90 per cent of all occurring weather scenarios are taken into account ("-" signifies that the intervention level is not exceeded). The doses shown in the table refer to additional effective dose due to ground deposition during the first year.

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
A remediation plan should be produced and basic remediation measures may be warranted (higher than 1 mSv)			
70	~1	~10	>500
80	~1.5	~20	>500
90	~ 2	~30	>500
Basic remediation measures are likely to be warranted (higher than 5 mSv)			
70	-	~2	~250
80	-	~3	~350
90	-	~6	~400
Advanced remediation measures may be warranted (higher than 10 mSv)			
70	-	~1.5	~200
80	-	~2	~250
90	-	~3	~350
Advanced remediation measures are likely to be warranted (higher than 20 mSv)			
70	-	~0.5	~100
80	-	~1	~150
90	-	~1.5	~250
Advanced remediation measures are likely to be insufficient for allowing resettlement of the area for several years (higher than 50 mSv)			
70	-	-	~40
80	-	-	~70
90	-	-	~100

4.8.2. Analysis

As far as concerns the event in which the mitigation systems fail to function, a remediation plan may need to be produced encompassing the entire, or parts of, the area surrounding the NPP at a distance exceeding 500 km. Within this area, it may be warranted to take basic remediation measures to a certain extent. The distance within which basic remediation measures are likely to be warranted may extend to approximately 400 km. The distance within which advanced remediation measures may be warranted may extend approximately 350 km. The distance within which advanced remediation measures are likely to be warranted may extend approximately 250 km. Out to a distance of approximately 100 km, areas with a high level of ground deposition may occur preventing residents from returning to their homes for several years despite advanced remediation measures.

As far as concerns the event with functioning mitigation systems, a remediation plan may need to be drawn up encompassing the entire, or parts of, the area surrounding the NPP at a distance of up to approximately 30 km. Within this area, it may be warranted to carry out remediation measures to different extents. The distance within which basic remediation measures are likely to be warranted is limited to approximately 6 km. The distance within which more advanced remediation measures may be warranted is limited to approximately 3 km.

In the case of the event with well-functioning mitigation systems, it is unlikely that remediation will need to be carried out. Although the criterion for when a remediation plan will need to be produced might be exceeded out to a distance of a few kilometres from the NPP, it is uncertain whether actual remediation measures would be warranted.

In the assessment of SSM, it is likely that remediation would be applicable only after the nuclear or radiological emergency and thus, rescue services, have been terminated. For this reason, SSM does not propose any particular measures to be taken within the emergency planning zones or extended planning distance (EPD) to surround the nuclear power plants, owing to the outcomes presented. On the other hand, SSM is of the view that all county administrative boards which, according to the Civil Protection Ordinance, have mandates for remediation following a release from a nuclear facility, should review present remediation plans on the basis of the calculations presented by SSM in this report. SSM wishes to emphasise the importance of this kind of review also taking into account the distances to nuclear power plants located in other countries.

5. Westinghouse Electric Sweden AB's fuel fabrication plant

The fuel fabrication plant in Västerås manufactures nuclear fuel for different types of nuclear power reactors. The plant converts enriched uranium hexafluoride to uranium dioxide, which is then processed into fuel elements. The plant also has facilities for uranium recovery.

In this chapter, SSM presents postulated events, representative source terms, outcomes of dispersion calculations, input data for determining the range of an emergency planning zone, in addition to the proposed design of this zone to surround the fuel fabrication plant in Västerås. Other outcomes presented include those from sensitivity analyses, residual doses, as well as analyses of needed measures on the part of food production and remediation. For more information, see Appendix 4.

5.1. Postulated events

SSM has determined two postulated events serving as the basis of the proposed emergency planning zone to surround the fuel fabrication plant:

- **Criticality event**. This event is due to overfilling of a container of liquid with dissolved uranium, resulting in the system becoming over-critical. The criticality event gives rise to both direct radiation and a release of fission products (e.g. iodine). The situation is ongoing for eight hours before a sufficient quantity of liquid has vaporised so that the criticality process ends.

- **Event involving a fire and a release of uranium powder**. This event is due to a fire starting in, or spreading to, filters belonging to the process ventilation system. This scenario assumes that flame detectors and fire dampers fail to work, resulting in all the uranium powder of five bag filters, a total of 1,000 kg of uranium dioxide, being released and spread to the surroundings. The fire is assumed to burn for five hours.

In the assessment of SSM, both these events should be taken into account as part of emergency preparedness planning for the fuel fabrication plant since they give rise to different types of environmental consequences. In addition, SSM considers that these events are suitable for dimensioning of emergency preparedness planning, as different types of emergencies, such as severe earthquakes and large fires in other parts of the fuel fabrication plant, are unlikely to result in more severe radiological environmental consequences.

5.1.1. Uranium hexafluoride and chemical hazards

Events involving uranium hexafluoride did not serve as the basis of the proposed emergency planning zone to surround the fuel fabrication plant. This is because the radiological consequences from potential releases of uranium hexafluoride are assessed as smaller than those from releases of uranium powder. However, the chemical hazards attributed to uranium hexafluoride are substantial. This is why it is important to have the overall emergency preparedness planning for the fuel fabrication plant also take into account events giving rise to chemical hazards.

5.2. Representative source terms

5.2.1. Criticality

The postulated criticality event gives rise to 1E+19 nuclear fissions, of which 10 per cent occur instantaneously. This is followed by additional nuclear fission reactions with 1.9E+17 fissions every ten minutes over a period of eight hours. The nuclear fission reactions give rise to pulses of direct radiation with subsequent releases of fission products. SSM has postulated a period of forewarning of five minutes, starting from the occurring criticality up until the commencing release of fission products to the surroundings. The source term for this criticality event is shown by Table 10. Note: there is no period of forewarning for direct radiation.

Table 10. Nuclides and levels of activity of the representative source term for criticality at the fuel fabrication plant in Västerås. The table presents the total release of activity, the activity generated by the first pulse (0-10 min.), and activity from subsequent pulses (10-480 min.). The levels of activity are corrected for decay and ingrowth over a period of 10 minutes.

Release group	Nuclide	Activity (Bq)		
		Total	0-10 min.	10-480 min.
Noble gases[1]	Kr-83m	5.6E+12	5.6E+11	5.0E+12
	Kr-85	6.1E+07	6.1E+06	5.5E+07
	Kr-85m	5.4E+12	5.4E+11	4.9E+12
	Kr-87	3.3E+13	3.3E+12	3.0E+13
	Kr-88	2.3E+13	2.3E+12	2.1E+13
	Rb-88	7.6E+12	7.6E+11	6.8E+12
	Kr-89	1.7E+14	1.7E+13	1.5E+14
	Rb-89	2.1E+14	2.1E+13	1.9E+14
	Sr-89	1.6E+10	1.6E+09	1.4E+10
	Xe-131m	3.0E+09	3.0E+08	2.7E+09
	Xe-133	6.7E+10	6.7E+09	6.0E+10
	Xe-133m	1.0E+12	1.0E+11	9.0E+11
	Xe-135	5.3E+13	5.3E+12	4.7E+13
	Xe-135m	1.4E+13	1.4E+12	1.3E+13
	Xe-137	3.0E+14	3.0E+13	2.7E+14
	Xe-138	2.9E+14	2.9E+13	2.6E+14
	Cs-138	7.1E+13	7.1E+12	6.4E+13
Halogens	I-131	3.2E+11	3.2E+10	2.9E+11
	I-132	3.9E+13	3.9E+12	3.5E+13
	I-133	5.9E+12	5.9E+11	5.3E+12
	I-134	1.5E+14	1.5E+13	1.3E+14
	I-135	1.7E+13	1.7E+12	1.5E+13

[1] Including decay products from noble gases.

5.2.2. Fire with a release of uranium powder

The postulated event involving a fire and a release of uranium powder has a source term encompassing 1,000 kg of uranium dioxide (equivalent to approximately 880 kg of uranium) with a degree of enrichment of U-235 of 3.9 per cent. The assumed duration of the fire and release is five hours. Nuclide and activity content are summarised in Table 11.

Table 11. Nuclides and levels of activity of the representative source term for a fire with a release of uranium powder.

Nuclide	Mass (kg)	Activity (Bq)
U-234	0.29	6.8E+10
U-235	34	2.7E+09
U-238	850	1.0E+10
Th-234	1.2E-08	1.0E+10
Th-231	1.4E-10	2.7E+09
Pa-234m	4.1E-13	1.0E+10

5.2.3. Sensitivity analyses

The fuel fabrication plant's stack has a height of approximately 20 m. However, during serious events, the possibility cannot be ruled out that a release does not pass via the stack. As a lower release height gives a higher air concentration in the vicinity of the facility, and thus higher inhalation doses and more ground deposition, SSM conducted dispersion and dose calculations using release heights of both 10 m and 20 m on the part of the postulated events.

In the case of the release of uranium powder, SSM also chose to investigate the impact of assumed particle size, density and release duration. The dispersion and dose calculations used particle sizes varying between 1, 5 and 10 µm, densities between 1, 5 and 10 g/cm^3, and release durations between 60 and 300 minutes.

5.3. The basis for an emergency planning zone

SSM performed dispersion and dose calculations based on historical weather data for the purpose of estimating the greatest distances at which dose criteria and intervention levels are exceeded. Calculations were performed for the period 2013-2015, with a total of around 950 dispersion and dose calculations per representative source term, thus giving a sufficient statistical basis for taking into account variations in weather conditions around the fuel fabrication plant.

5.3.1. Criticality

The outcomes of dispersion and dose calculations pertaining to releases of fission products during the criticality event demonstrate that no dose criteria are exceeded for evacuation or sheltering off-site. The greatest distance at which the dose criterion for sheltering, 10 mSv effective dose, is exceeded for children is shorter than 100 m in 90 per cent of the weather scenarios, even if the release is assumed to occur at a height of 10 m.

Resulting doses due to exposure to direct radiation during the criticality event are illustrated by Figure 7 below. Due to direct radiation, the dose criteria for evacuation and sheltering are exceeded out to respective distances of approximately 250 m and 300 m. However, it should be noted that only one-tenth of the total dose from direct radiation is generated by the initial pulse: 90 per cent of the dose is distributed evenly over the eight hours during which the process is ongoing (in one pulse every 10 minutes). This gives good potential to reduce exposure by taking relevant protective actions.

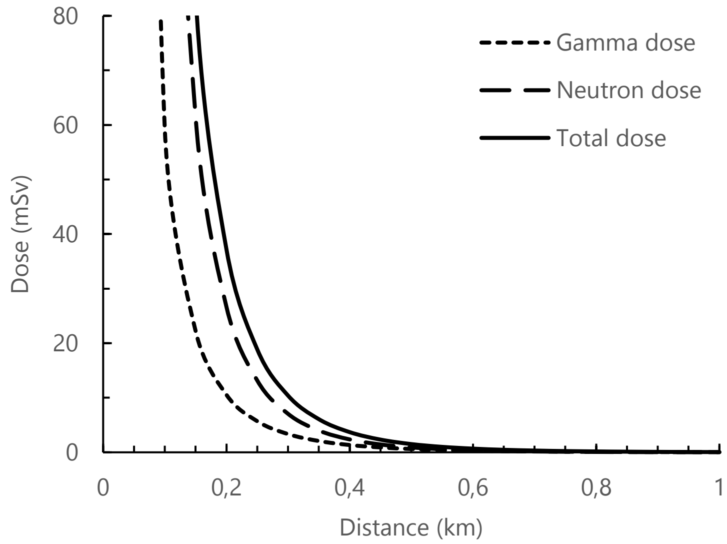

Figure 7. Effective dose from direct radiation due to a criticality event in the case of an unprotected person who is standing outdoors throughout the event. Shielding equivalent to 20 cm of concrete is assumed.

Dispersion and dose calculations performed for a release of fission products from the fuel fabrication plant due to the criticality event demonstrate that the greatest distance at which predistribution of ITB may be warranted for children (dose criterion of 50 mSv equivalent dose to the thyroid) is shorter than 300 m in 90 per cent of the weather scenarios for the release height of 10 m. The dose criterion for ITB for adults (50 mSv equivalent dose to the thyroid) is not exceeded outside the facility.

SSM has also studied the distances at which equivalent dose to the thyroid on the part of children might be up to 10 mSv. In this context, the results indicate the distances at which it would be warranted to recommend sheltering for the purpose of reducing doses to the thyroid, even in a case where predistribution of ITB is unwarranted. In the case of the release height 10 m, the greatest distance at which this level is exceeded is shorter than 900 m in 80 per cent of the occurring weather scenarios. If 90 per cent of all weather scenarios are taken into account, the corresponding distance is 1,300 m.

A release of fission products that might warrant evacuation for the purpose of avoiding external exposure due to ground deposition in the longer term does not occur as part of the postulated criticality event.

5.3.2. Fire with a release of uranium powder

Outcomes of dispersion and dose calculations for the event involving a fire and a release of uranium powder are presented below. The emphasis of the results presented is on adults, as adults receive higher doses than children in connection with this event. Events involving fire and releases of uranium powder are predominated by the dose contribution from inhalation. Adults receive a higher intake of uranium, and thus higher doses, owing to their higher rate of inhalation compared to children.

Dispersion and dose calculations performed for the event involving a fire and a release of uranium demonstrate that the greatest distance at which the dose criterion for evacuation, 20 mSv effective dose, is exceeded for adults is shorter than approximately 300 m in 80 per cent of the occurring weather scenarios. The distance depends on the values set for the parameters belonging to the sensitivity analysis, though in no cases does it exceed 400 m for the 80th percentile.

The largest distance at which the dose criterion for sheltering, 10 mSv effective dose, is exceeded for adults is shorter than 700 m in 80 per cent of the occurring weather scenarios, regardless of the selected parameter values belonging to the sensitivity analyses. If 90 per cent of all weather scenarios are taken into account, the corresponding distance is 1,300 m.

Personal contamination by uranium may occur in connection with a release of uranium powder. However, the calculations performed by SSM show that this only gives rise to marginal dose contributions. Thus, SSM considers it unwarranted to carry out large-scale checks for personal contamination of members of the public who were present outside the facility in connection with a release from the fuel fabrication plant. As a precaution, affected individuals may be advised to shower and to wash their hair once they are home, as well as change and launder their clothing.

5.4. Emergency planning zone

The dispersion and dose calculations show that it may be warranted in connection with events at the fuel fabrication plant to carry out evacuation in the vicinity of the facility, out to a distance of approximately 300-400 m from the outlet point. As the postulated events at the fuel fabrication plant are of relatively short durations, and because sheltering in industrial buildings in the area may be assumed to provide satisfactory protection, SSM is of the view that sheltering is a better option. Moreover, in the case of the event involving a fire and a release of uranium powder, the dispersion and dose calculations show that sheltering is warranted out to a distance of approximately 700 m, or slightly further, depending on the percentage of weather scenarios taken into account.

SSM’s proposals:

1. A UPZ should be established to surround the fuel fabrication plant. Within this zone, sheltering is to be recommended in connection with a declared general emergency.
2. The range of the UPZ should be approximately 700 m.
3. The trade school ABB Industrigymnasium should belong to the UPZ.
4. It is not warranted to carry out contamination checks of members of the public who were present in the UPZ during the emergency.

The county administrative board of Västmanland proposes designing the UPZ to surround the fuel fabrication plant as illustrated by Figure 8. In the proposed zone, sheltering should be recommended in connection with criticality events as well as during suspected or observed releases of uranium due to a fire.

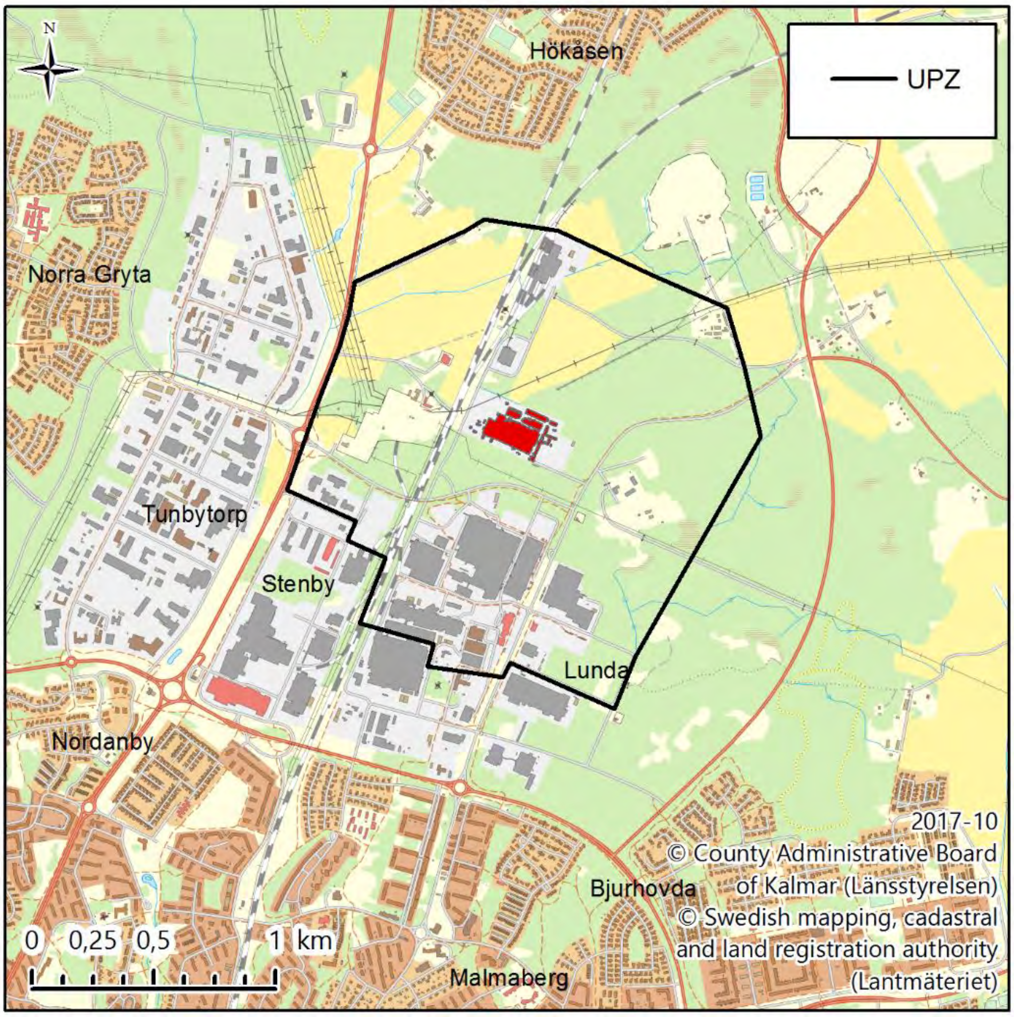

Figure 8. Proposed emergency planning zone (UPZ) to surround the fuel fabrication plant in Västerås.

Compared to the present zone, the proposed UPZ has been extended somewhat towards the south. This is in order to include the ABB Industrigymnasium trade school and the adjacent restaurant. This zone has road 56 as its western boundary; however, this road is not encompassed by the UPZ because it needs to be used to facilitate management of an event that might take place at the fuel fabrication plant. Similarly, the design of this zone towards the south-west has been adapted to facilitate traffic to and from this area.

5.5. Residual dose

SSM performed calculations of possible radiation doses brought about by the postulated events, based on the assumption that the protective actions proposed by SSM are carried out. The purpose of these calculations is to demonstrate whether the proposal for pre-planned protective actions will make it possible to keep residual doses below the selected reference levels.

The closest buildings located outside the site of the fuel fabrication plant, where the public may be assumed to be present following a declared general emergency, are at a distance of approximately 300 m. For this reason, SSM performed calculations of possible radiation doses that might be received at this distance during sheltering. SSM also performed calculations of the radiation dose that might be received by an unprotected individual located just outside the UPZ.

These calculations assumed that sheltering in different indoor locations provides differing degrees of protection (shielding factors). Most of the buildings in the area are industrial buildings which may be assumed to provide satisfactory protection against radiation, including filtered ventilation (for example). Consequently, SSM's assumption was that sheltering reduces radiation doses to one-tenth (shielding factor 0.1). Representing a more conservative assumption, SSM also performed calculations in which doses were reduced by half, corresponding to the protection offered by a detached house (shielding factor 0.5). In the case of direct radiation, only the shielding factor of 0.5 was applied, as the dose contribution here was largely due to neutrons. Neutrons are not shielded out as well by building materials.

5.5.1. Criticality

In the case of sheltering in the UPZ, the highest effective doses from direct radiation may amount to approximately 5 mSv at a distance of 300 m. Outcomes of dispersion and dose calculations demonstrate that the additional effective dose from the release of fission products at this distance will be in the interval of 0.5-2.5 mSv if 90 per cent of the weather scenarios are taken into account. This depends on the assumed shielding factor represented by the buildings. Consequently, at this distance, the total effective dose in connection with sheltering is a maximum of 7.5 mSv in 90 per cent of the weather scenarios.

An individual who is present outside the UPZ, and thus might be outdoors during the accident sequence, may receive effective doses amounting to a maximum of 3 mSv if 90 per cent of the weather scenarios are taken into account. The dose contribution from a release of fission products predominates at this distance, exceeding doses from direct radiation.

5.5.2. A fire and a release of uranium powder

The dispersion and dose calculations show that a person located indoors 300 m from the release point may receive a maximum effective dose of approximately 4 mSv, if 90 per cent of the weather scenarios are taken into account and assuming a shielding factor of 0.1. With a shielding factor of 0.5, the corresponding level is 20 mSv effective dose.

Individuals who are present outside the UPZ, and thus might be outdoors during the accident sequence, may receive effective doses from the release of uranium powder amounting to a maximum of 20 mSv if 90 per cent of the weather scenarios are taken into account.

The above calculations are based on the possible doses which, in accordance with the sensitivity analyses, might be received in connection with worst-case scenario conditions (height 10 m, particle size 1 µm, release duration 60 min.). Given all other parameter values, the radiation doses will be lower. Consequently, in the assessment of SSM, the proposed UPZ is sufficient for keeping doses below the reference level of 20 mSv effective dose in connection with events involving a fire and a release of uranium powder.

5.6. Food production and remediation

Around the fuel fabrication plant, it is unwarranted to take further urgent protective actions outside the UPZ. For this reason, SSM has not proposed any EPD of the type that should surround the nuclear power plants. On the other hand, there is a need to perform separate planning for radiation monitoring and sampling for assessment of possible ground deposition following a fire and a release of uranium. Pre-planned advice and recommendations for the public should also be in place for the purpose of reducing intake of radioactive materials.

SSM's proposals:

1. Planning should be in place for protection against intake of uranium following a release from the fuel fabrication plant.
2. Such planning should cover radiation monitoring and sampling, and be dimensioned for quantification of ground deposition within a distance up to 3 km from this plant.
3. This planning should also encompass pre-planned advice and recommendations for the purpose of reducing intake of radioactive materials.

Data from radiation monitoring and sampling is a prerequisite not only for possible remediation, but also to enable the responsible body to provide recommendations to the public regarding needed restrictions to reduce intake of radioactive materials. All county administrative boards are subject to the Civil Protection Ordinance, which requires planning to be in place for radiation measurements for events involving a release of radioactive materials from nuclear facilities. As a release of uranium (which is an alpha emitter) from the fuel fabrication plant would differ substantially from a release from the NPPs, both in terms of relevant protective actions and methods of measurement, this presupposes separate planning for the fuel fabrication plant, beyond pre-existing planning in place in other parts of the country.

Advice and recommendations to the public concerning possible measures to reduce intake of radioactive materials may for example relate to own food crops, work that gives rise to dust, or general recommendations for behaviours that can reduce exposure. It is also important to have capability to communicate which areas are unaffected by possible deposition. The advice to be provided in an early phase of a nuclear or radiological emergency at the fuel fabrication plant must be established in advance. After a release of radioactive materials has ceased, advice and recommendations should be based on data on ground deposition by means of radiation monitoring and sampling.

Following an event at the fuel fabrication plant, SSM views it as reasonable that any ground deposition of uranium should be analysed to a level of detail corresponding to clearance levels for rooms and buildings in accordance with SSM's clearance regulations. In the case of the postulated event involving a fire and a release of uranium powder, the greatest distance where the intervention level (10 kBq/m^2 for the sum of U-234, U-235 and U-238) is exceeded is shorter than approximately 3 km if 90 per cent of the occurring weather scenarios are taken into account. The remediation procedures that may be warranted owing to detected levels constitute an area that should be decided on when this kind of situation arises, while taking prevailing circumstances into account.

After criticality events, a ground deposition of I-131 may occur in the area around the fuel fabrication plant. This may have an impact on food production. Due to the relatively brief half-life of the nuclide (approximately eight days), this does not give rise to any problems in the longer term. Nor are these levels higher than those that could affect the area following a release from a Swedish NPP. Consequently, for this event, no separate planning is needed for food supply management beyond the required national strategy.

Ground deposition of uranium that may occur in connection with a fire and a release of uranium powder also presupposes separate and targeted planning to protect the food chain. It is probable that the impact on food production may arise at levels that are lower than the intervention level of 10 kBq/m^2 for the sum of U-234, U-235 and U-238. Nevertheless, SSM is of the view that the distances at which the intervention level might be exceeded are a reasonable basis for dimensioning the capability for carrying out radiation measurements and sampling. It is unlikely that the entire area defined by this distance will be affected by a fallout giving a high level of ground deposition. If the capability for radiation measurements and sampling is dimensioned to cover this area, then the resources should also be adequate for use at greater distances. An additional perspective is that mapping of alpha-emitting nuclides in the environment requires a great deal more resources and time than compared with gamma-emitting nuclides. Consequently, at greater distances, it may be necessary to instead focus on measurements on produced foodstuffs.

6. The central interim storage facility for spent nuclear fuel

Established in 1985, Clab, the central interim storage facility for spent nuclear fuel, is located north-east of Oskarshamn on the peninsula of Simpevarp. Clab is used for interim storage of all spent nuclear fuel from the Swedish nuclear power industry. At the present time, around 6,500 tonnes of spent fuel are stored here pending final disposal. The installations at this facility include storage pools located 40 m below the ground surface and reception pools at ground level. Clab is operated by SKB, the Swedish Nuclear Fuel and Waste Management Company.

In this chapter, SSM presents postulated events, representative source terms, outcomes of dispersion and dose calculations, and input data for determining the range of an emergency planning distance to surround Clab. Other outcomes presented include those from sensitivity analyses, residual doses, as well as analyses of needed measures on the part of food production and remediation. For more detailed information, see Appendix 5.

6.1. Postulated events

SSM has determined three postulated events serving as the basis of the proposed emergency planning distance to surround Clab:

- **Criticality event.** This is an event resulting in criticality with an immediate release of fission products. The criticality event in question is based on an event in which the bottom plate of a compact fuel element cassette loosens, whereupon the fuel becomes exposed in a disadvantageous geometry without the neutron-absorbing boron plates present in the cassette.
- **Event involving the reception pool.** This is an event corresponding to leakage in the reception pool owing to a severe earthquake. The total residual effect for the fuel assembly stored in the reception pool is assumed to be at the maximum level that is allowed for management (400 kW). The fuel assembly in the reception pool is exposed to the air and becomes overheated owing to a lack of cooling, which results in fuel damage and a release of fission products.
- **Event involving a transport container.** This is an event in which a transport container filled with water, with its cooling mantle mounted, remains hanging from an overhead crane with no cooling due to a loss of electrical power. The water in the transport container contains fission and activation products that boil off. No additional damage to the fuel assembly occurs.

In the assessment of SSM, these three events should be taken into account as part of emergency preparedness planning for Clab as they affect the dimensioning differently in terms of the period of forewarning and releases of long-lived radioactive substances. All the postulated events occur above ground in the reception building. SSM has also taken into account events in the storage pools below ground level, but these have no impact on the design basis in terms of either the period of forewarning or the magnitude of the release.

6.2. Representative source terms

6.2.1. Criticality

SSM has developed a representative source term for the postulated criticality event at Clab. As mentioned previously, the event is due to a loose bottom plate of a compact fuel cassette. It is assumed that the fuel assembly is unirradiated and has a degree of enrichment of 4.2 per cent U-235. The criticality sequence leads to a strong pulse of energy (1 MW) lasting one second. This ceases immediately as the fuel becomes fragmented owing to the pulse of energy. The release is expected to have a duration of one hour and pass via the stack. Only noble gases are part of this release because the other fission products remain in the pool water. No heat content has been assumed; in other words, SSM does not anticipate the heat energy of the release to result in plume rise. Table 12 illustrates total released activity to the atmosphere in the representative source term for the criticality event.

Table 12. Nuclides and activity in the representative source term for criticality at Clab. The table presents total released activity to the atmosphere.

Release group	Nuclide	Activity (Bq)
Noble gases	Kr-85	1.2E+14
	Kr-87	2.5E+14
	Kr-88	3.5E+14
	Kr-89	2.1E+15
	Xe-137	2.5E+15
	Xe-138	3.2E+15

6.2.2. Reception pool

SSM has developed a representative source term for the postulated event involving a release of fission products from the reception pool at Clab. This event is postulated to occur owing to a severe earthquake, which results in water leakage from the reception pool. In turn, the loss of water results in overheating of the spent nuclear fuel stored in the pool. This is due to the loss of cooling. This event is of slow duration. After nine days, this overheating results in fuel damage with a consequential release of fission products. The release is assumed to take place via an outlet point corresponding to the height of the reception building, 20 m, due to the failed ventilation system as a consequence of the earthquake. No heat content has been assumed; in other words, SSM does not anticipate the heat energy of the release to result in plume rise. This release takes place over a period of 48 hours. Table 13 illustrates total released activity to the atmosphere in the representative source term for the reception pond.

Table 13. Nuclides and activity in the representative source term for a release from the reception pool at Clab. The table presents total released activity to the atmosphere.

Release group	Nuclide	Activity (Bq)
Noble gases	Kr-85	3.3E+15
Halogens	I-129	2.4E+08
Alkali metals	Cs-134	3.4E+13
	Cs-137	1.6E+14

6.2.3. Transport container

SSM has developed a representative source term for the postulated event involving a release of activation and fission products from a transport container. Spent nuclear fuel is transported inside Clab using a transport container that cools the fuel assembly with water. The transport container is postulated to be subjected to a loss of cooling, whereupon the heated coolant vaporises. The coolant contains radioactive materials that dissolve in the water as it boils. Here as well, an earthquake is assumed to be the root cause of this event, for which reason the release is assumed to take place via an outlet point corresponding to the height of the reception building, 20 m. This release takes place over a period of 40 hours. No heat content has been assumed; in other words, SSM does not anticipate the heat energy of the release to result in plume rise. Table 14 illustrates total released activity to the atmosphere in the representative source term for the transport container at Clab.

Table 14. Nuclides and activity in the representative source term for a release from the transport container at Clab. The table presents total released activity to the atmosphere.

Release group	Nuclide	Activity (Bq)
Noble gases	Kr-85	2.1E+08
Halogens	I-129	1.8E+03
Alkali metals	Cs-134	4.8E+09
	Cs-137	6.2E+09
Tellurium group	Sb-125	2.5E+07
Noble metals	Co-58	3.0E+12
	Co-60	1.2E+14
Cerium group	Pu-238	9.4E+08
	Pu-239	1.3E+08
	Pu-240	2.2E+08
	Pu-241	1.8E+10
Lanthanides	Am-241	1.0E+07
	Am-243	1.3E+08
	Cm-244	7.3E+08
Other nuclides	H-3	2.5E+06
	Mn-54	7.9E+12
	Fe-55	1.2E+14
	Ni-59	3.9E+10
	Ni-63	5.8E+12
	Sr-90	4.2E+07
	Ag-108m	5.5E+07
	Ag-110m	2.2E+08

6.2.4. Sensitivity analysis

SSM has performed a sensitivity analysis using dispersion and dose calculations in order to study the impact of an expanded source term for the criticality event in which additional noble gases are released. The sensitivity analysis also takes into account the dose contribution from iodine generated by the criticality event.

As the height of the release is of great significance for the air concentration of radioactive materials in the vicinity, and thereby for not only inhalation doses but also levels of ground deposition, SSM carried out a sensitivity analysis using additional dispersion and dose calculations assuming higher and lower release heights. In the cases of the postulated events occurring in the reception pool and transport container, both 10 m and 36 m were assumed in these analyses. SSM also studied the impacts of a more rapid release sequence on the event involving the transport container.

6.3. The basis for an emergency planning distance

SSM performed dispersion and dose calculations based on historical weather data for the purpose of estimating the greatest distances at which dose criteria and intervention levels are exceeded. Weather data from the period 2006-2015 was used in the dispersion calculations. In total, the data material contains approximately 2,350 dispersion and dose calculations per representative source term. The sensitivity analyses used weather data for the period 2012-2015, which encompasses approximately 1,100 dispersion and dose calculations per representative source term. This gives a sufficient statistical basis for taking into account variations in weather conditions around Clab.

6.3.1. Criticality

No dose criteria were exceeded outside the site of the facility on the part of the postulated criticality event, neither for adults nor children. The greatest distance at which the dose criterion for sheltering, 10 mSv effective dose, is exceeded is shorter than 100 m if 90 per cent of the occurring weather scenarios are taken into account. The distances are the same for children and adults.

The results from the sensitivity analysis, where additional nuclides were included in the source term, give the same distances as for the representative source term, for children and adults alike. According to the sensitivity analysis of the postulated criticality event at Clab, radiation doses from iodine and additional noble gases are negligible.

In the assessment of SSM, direct radiation from the criticality fission pulse has no impact on the population outside the facility, as this event can only occur if water is present in the reception pool; also, the water itself constitutes an effective radiation shield.

6.3.2. Reception pool

The outcomes of the dispersion and dose calculations show that no dose criteria are exceeded outside the restricted area around the facility on the part of the postulated event involving a release from the reception pool. The greatest distance at which the dose criterion for sheltering, 10 mSv effective dose, is exceeded is shorter than 200 m if 90 per cent of the occurring weather scenarios are taken into account. The sensitivity analysis shows that the corresponding distance is somewhat longer (300 m) if the release is assumed to occur at a height of 10 m.

However, significant ground deposition of caesium, which may warrant protective actions outside the restricted area, may occur on the part of the postulated event involving a release from the reception pond. The dispersion and dose calculations show that the greatest distance at which the intervention level for relocation owing to high ground deposition of caesium (sum of Cs-134 and Cs-137), 3,000 kBq/m^2, is exceeded is shorter than 600 m if 90 per cent of the occurring weather scenarios are taken into account. The sensitivity analysis shows that the corresponding distance is 900 m if the release instead occurs at a height of 10 m.

On the whole for this event, the dispersion and dose calculations show that sheltering is unwarranted outside the restricted area, though ground deposition may occur warranting relocation.

6.3.3. Transport container

The outcomes of the dispersion and dose calculations for the postulated event involving a release from a transport container show that the dose criterion for sheltering, 10 mSv effective dose, is exceeded at a distance corresponding to that of the restricted area. For this event, the greatest distance at which the dose criterion for sheltering is exceeded is shorter than 300 m if 90 per cent of the occurring weather scenarios are taken into account. The sensitivity analyses show that the corresponding distance is somewhat longer (400 m) if the release is assumed to occur at a height of 10 m. In addition, assuming a more rapid release sequence, the distance where sheltering is warranted would be shorter than 500 m if 90 per cent of the occurring weather scenarios are taken into account.

Significant ground deposition, which may warrant protective actions outside the restricted area, might occur on the part of the postulated event involving the transport container at Clab. The greatest distance at which the intervention level for relocation owing to ground deposition of cobalt (Co-60), 1,000 kBq/m^2, is exceeded for releases from the transport container is shorter than 1.3 km if 90 percent of the occurring weather scenarios are taken into account. The sensitivity analysis shows that the corresponding distance is somewhat longer (1.6 km) if the release is assumed to occur at a height of 10 m. In addition, assuming a more rapid release sequence, the distance at which relocation is warranted due to high ground deposition of cobalt would be shorter than 2.1 km if 90 per cent of the occurring weather scenarios are taken into account.

6.3.4. Warnings and predistributed information

The emergency class of general emergency is to be declared at Clab if an event or abnormal operation has occurred which jeopardises safety, and a release to the surroundings, warranting protective actions for the public, is ongoing or cannot be ruled out. SSM considers it advisable to review whether the emergency class is appropriate for alerting of public authorities, warning the public, and as input for decision making concerning measures to protect the public.

Based on the outcomes of dispersion and dose calculations, SSM is of the view that it is not automatically warranted to warn the public in connection with a general emergency, because it is unwarranted to implement sheltering and other urgent protective actions. Nor is it, according to the same line of reasoning, warranted to have information predistributed to residents in the vicinity of Clab. However, should an event or abnormal operation occur at Clab, communication should be directed at the public. Consequently, it is important to alert the county administrative board and other competent authorities. In the assessment of SSM, the pre-existing basic capability for providing information to the public is sufficient.

6.4. Emergency planning distance

The dispersion and dose calculations show that in connection with releases on the part of the postulated events, it is unwarranted to take any urgent protective actions outside the area with restricted access surrounding Clab, even if 90 per cent of the weather scenarios are taken into account. On the other hand, planning is needed for radiation measurements, mainly for the purpose of giving decision-making input regarding relocation based on exposure from ground deposition. In order to dimension these emergency response measures, SSM suggests establishment of an EPD surrounding Clab.

SSM's proposals:

1. Discontinuation of the present emergency planning zone.
2. Establishment of an EPD with a range of 2 km surrounding Clab.
3. The capability to carry out radiation measurements in the EPD should be dimensioned to facilitate decision-making input regarding relocation due to ground deposition within one week of the release ceasing.
4. It is advisable to have the emergency class of general emergency reviewed.
5. The authorities should be alerted in connection with events or abnormal operation having safety significance.
6. Information should be provided to the public in connection with abnormal operation and events having an impact on safety.

6.4.1. Conclusion concerning an emergency planning zone

The area with restricted access surrounding Clab is delineated by fencing and signage, and extends approximately 200-350 m from the centre of the reception building. The public is closed off from this area, which is designated as a protected installation under the Protection Act (2010:305). The outcomes of the dispersion and dose calculations show that it is unwarranted to carry out planning for sheltering outside the area with restricted access. Thus, in the assessment of SSM, the range of the area with restricted access offers sufficient public safety.

The IAEA recommends that facilities belonging to emergency preparedness category II should have an emergency planning zone with a range of at least 500 m, in other words, somewhat larger than the area with restricted access surrounding Clab. SSM and the Kalmar county administrative board are nevertheless of the opinion that clear delineation is more important in this case for the purpose of facilitating effective emergency management. Consequently, SSM suggests discontinuation of the present emergency planning zone for protection of the public in the vicinity of Clab.

6.4.2. Proposed EPD

The outcomes of the dispersion and dose calculations show that radiation measurement planning should be in place for mapping of potential ground deposition following an event occurring at Clab. This mainly applies to the county administrative board's planning and capability for radiation measurements to enable relocation due to high levels of ground deposition of long-lived gamma-emitting nuclides (caesium or cobalt). This may occur at distances of approximately 1-2 km, as shown by the outcomes of dispersion calculations that take into account 90 per cent of the weather scenarios. Consequently, for the purpose of dimensioning the capability to conduct radiation measurements, SSM proposes establishment of an EPD with a range of 2 km.

6.5. Residual dose

SSM performed calculations on residual doses, assuming that the protective actions proposed by SSM can be carried out. The purpose of these calculations is to demonstrate whether the pre-planned protective actions proposed by SSM will make it possible to keep doses below the selected reference levels. As SSM has not proposed an emergency planning zone to surround Clab, no urgent protective actions need to be taken on the part of the public outside the area of restricted access surrounding the facility. Thus, the distances at which a certain dose is received during the first week will, as a maximum, reach the estimated distributions across the largest distances, as presented in Appendix 5.

In the case of radiation dose from possible remaining ground deposition in the proposed EPD, however, the line of reasoning is different. Relocation may be necessary after the initial few days based on the outcomes of radiation measurements. This is for the purpose of keeping doses below the reference level of 20 mSv effective dose during the first year. This means that the dose received is linked to the points in time for a decision on relocation and implementing this relocation. In the opinion of SSM, it is feasible to have adequate decision-making input ready within one week for implementing a relocation. This would imply a residual effective dose of, at most, a few mSv to the individuals affected by the release. If e.g. relocation is carried out within one month after the emergency, the residual effective dose would be below 5 mSv for the nearest residents encompassed by the relocation.

6.6. Food production

A compilation of outcomes having an impact on food production as a consequence of the postulated events at Clab is shown by Table 15. Intervention levels for food production are based on a set of assumptions and are therefore characterised by great uncertainty. The distances presented by SSM at which the intervention levels may be exceeded should therefore only be viewed as indicative. The outcomes nevertheless help to illustrate the distances at which difficulties in food production might arise, the kinds of food production that are most vulnerable, in addition to the nuclides leading to the biggest problems that would affect different kinds of food production.

The dispersion calculations for Clab underpin the proposal recommending national planning for measurements throughout Sweden in the areas of food production and other commodities. However, not all the postulated events at Clab signify an impact on food production across county boundaries. In the assessment of SSM, the competent authorities having mandates linked to food production should review existing emergency preparedness planning in relation to the calculations presented in this report. An area of key importance is sufficiently quick decision making concerning measures linked to food production and protection of the population from intake of contaminated foodstuffs.

Table 15. Summary compilation of approximate distances at which intervention levels for food production are exceeded on the part of the postulated event in Clab's reception pond, if 90 per cent of all occurring weather scenarios are taken into account.

Nuclide group	Foodstuff (km)
	Drinking water from surface-water sources with a low level of dilution (0.5 m deep)
Caesium	~ 15
	Drinking water from surface-water sources with a high level of dilution (10 m deep)
Caesium	~ 2
	Milk
Caesium	~ 120
	Beef (plus reindeer)
Caesium (grazing)	>500
Caesium (free-range)	>500
	Pork
Caesium	~ 120
	Game (elk and venison)
Caesium (100 kBq/m^2)	~ 15
Caesium (10 kBq/m^2)	~ 120
	Grains
Caesium	~ 120
	Leafy vegetables
Caesium	>500
Strontium	~ 1
	Potatoes
Caesium	~ 2

6.7. Remediation

Usually, when it comes to events involving a release of hazardous substances from non-nuclear facilities, the party conducting the activities bears the responsibility for potential remediation work. However, under the Civil Protection Ordinance, county administrative boards have a designated mandate in the case of an event involving a release of radioactive materials from nuclear facilities. When looking into the need for remediation, the outcomes of dispersion and dose calculations show whether remediation is warranted as a consequence of the postulated events in the reception pool and transport container at Clab.

A compilation of the greatest distances at which different remediation procedures may be considered owing to a release in the case of the postulated events at Clab is presented by Table 16.

In the assessment of SSM, it is likely that remediation would be applicable only after the nuclear or radiological emergency, and thus rescue services, have been terminated. For this reason, SSM does not propose any particular measures to be taken within the EPD for Clab owing to the outcomes presented. On the other hand, SSM is of the view that all county administrative boards should review the present remediation plans on the basis of the estimates and calculations presented by SSM in this report.

Table 16. Summary of the greatest distances at which intervention levels for remediation are exceeded for different events if 70, 80 and 90 per cent of all occurring weather scenarios are taken into account ("-" signifies that the intervention level is not exceeded). The doses shown in the table refer to additional effective dose due to ground deposition during the first year.

Percentile	Reception pool (km)	Transport container (km)
A remediation plan should be produced and basic remediation measures may be warranted (higher than 1 mSv)		
70	~ 6	~ 8
80	~ 7	~ 12
90	~ 11	~ 20
Basic remediation measures are likely to be warranted (higher than 5 mSv)		
70	~ 1.5	~ 3.0
80	~ 2	~ 3.5
90	~ 2.5	~ 4.5
Advanced remediation measures may be warranted (higher than 10 mSv)		
70	~ 1	~ 1.5
80	~ 1	~ 2
90	~ 1.5	~ 2.5
Advanced remediation measures are likely to be warranted (higher than 20 mSv)		
70	~ 0.5	~ 1
80	~ 0.5	~ 1
90	~ 0.5	~ 1.5
Advanced remediation measures are likely to be insufficient for allowing resettlement of the area for several years (higher than 50 mSv)		
70	-	~ 0.5
80	-	~ 0.5
90	-	~ 0.5

7. Impacts of new emergency planning zones and distances

7.1. Requisite amendments to Swedish legislation

The assignment to review emergency planning zones and emergency planning distances includes suggesting requisite amendments to Swedish legislation. Emergency planning zones and distances surrounding nuclear power plants are currently regulated by the *Civil Protection Ordinance (2003:789)*. Consequently, SSM has carried out consultations and a review together with MSB (Swedish Civil Contingencies Agency) in order to identify required amendments to this Ordinance to enable implementation of the new emergency planning zones and distances proposed by SSM in this report. It is the shared opinion of SSM and MSB that amendments are needed to Chapter 4, Section 21, under the heading *Programme for rescue services*, as well as to Chapter 4, Sections 23 to 28, under the heading *Emergency planning zones and emergency planning distances*.

7.1.1. Programme for rescue services

The proposal of SSM is to have the list of items to be dealt with by the programme for rescue services in the case of a nuclear emergency supplemented with an item regulating protective actions. The rationale behind this proposal is to emphasise the importance of having the planning of county administrative boards take into account potentially required protective actions. If the proposed new emergency planning zones and distances are implemented, an additional number of county administrative boards compared to today will need to conduct planning for emergency response. Thus, this area is a key aspect of the programme for rescue services.

7.1.2. Emergency planning zones and distances

The sections regulating today's emergency planning zones and distances should be removed and replaced by new sections with wording that imposes requirements for dimensioning of new emergency planning zones and distances, and stipulates requisite preparations within the respective zone and distance.

SSM suggests having the Ordinance impose a requirement for a UPZ with a range of approximately 25 km, in addition to a PAZ with a range of approximately 5 km from the nuclear power plants. Furthermore, SSM suggests that this requirement should state that the relevant county administrative boards are to design the UPZ and PAZ in adaptation to the prevailing circumstances of the respective nuclear power plant. These proposals represent more stringent regulation of existing requirements due to the larger area than today to be encompassed. Another consequence of the proposals is that a greater number of county administrative boards compared to today will be subject to this requirement. In the assessment of SSM, it is of crucial importance to have the dimensions of emergency planning zones and distances regulated by the Ordinance due to the high cost of sustaining the required emergency preparedness within these zones and distances. At the same time, however, SSM is of the view that the de facto design of the zones need not be regulated in detail by the Ordinance. Instead, this responsibility should rest with the relevant county administrative boards, since this facilitates keeping the design of the zones up to date. As a consequence of this, it is the suggestion of SSM to have the appendix of the Ordinance, which stipulates the design of today's emergency planning zones and distances, removed from the Ordinance.

The Ordinance should also regulate distribution of ITB to the public, in addition to predistributed information to residents in the PAZ and UPZ about the content of the programme for rescue services that is applicable in the event of a release of radioactive materials from the NPPs. SSM also suggests regulating arrangements in the following areas: warnings to the public, evacuation and relocation, sheltering, and supplementary distribution of ITB within the PAZ and UPZ. An additional proposal by SSM is to have the requirements state that pre-planning for evacuation should make it possible to give priority to evacuation of the PAZ. The proposed pre-planning for sheltering and the possibility to give priority to evacuation of the PAZ signify more stringent requirements compared to today. The rationale behind the proposed requirement for pre-planning for sheltering is that this measure, particularly if combined with intake of ITB, serves as an alternative to evacuation if the time is insufficient for evacuating the area in the vicinity of the nuclear facilities, or if evacuating greater distances will have an overly negative impact. The rationale behind the proposed requirement to have capability to prioritise evacuation of the PAZ is both: a) to ensure that severe deterministic effects do not occur regardless of the situation at a nuclear power plant, and b) to create potential for implementing a limited precautionary evacuation around an NPP at an early phase of an event.

SSM suggests that the Ordinance impose requirements for having an EPD in place with a range of 100 km from the nuclear power plant. This suggestion represents more stringent regulation of existing requirements due to the larger area than today to be encompassed. A consequence of this suggestion is that a greater number of county administrative boards compared to today will be subject to this requirement.

Furthermore, SSM suggests having the Ordinance regulate pre-planning for radiation measurements, relocation based on data from such measurements, sheltering, and limited distribution of ITB in new areas within the EPD. The proposed pre-planning for relocation, based on data from radiation measurements, and for sheltering and limited distribution of ITB in new areas of the EPD, represents more stringent regulation of the requirements compared to today. The rationale behind the proposed requirement for pre-planning for relocation based on data from radiation measurements is to ensure that a decision to relocate can be taken quickly, as it is a key aspect for dealing with the nuclear or radiological emergency, and thus for termination of rescue services. The rationale behind the proposed requirement for pre-planning for implementation of sheltering is not only that this measure may also be applicable to greater distances outside the UPZ, but also that this would presuppose action plans in a case of prolonged sheltering. The rationale behind the proposed pre-planning for limited distribution of ITB in new areas is that such distribution presupposes specific planning in place regarding its actual implementation.

The current requirement in the Ordinance, stating that certain county administrative boards must prepare an emergency response plan for nuclear facilities in emergency category II, should be changed as follows: removing the requirements for the county administrative board of Södermanland, while at the same time adding the requirements for the county administrative boards of Kalmar and Västmanland. In the assessment of SSM, the rationale behind this proposal is that there is no longer any need for targeted emergency response planning relating to the nuclear facilities located at the Studsvik site of Södermanland County. On the other hand, in the assessment of SSM, targeted emergency response planning is required relating to the nuclear facilities comprising the fuel fabrication plant in Västerås, located in Västmanland County, and the central interim storage facility for spent nuclear fuel (Clab), located in Oskarshamn, Kalmar County.

Lastly, SSM suggests an amendment to the Ordinance's requirement, which stipulates that municipal authorities must assist county administrative boards with emergency response planning, so that the requirement applies to both the PAZ and UPZ. SSM also suggests changing the requirement for municipal authorities to assist county administrative boards, by making human resources and property available for performing radiation measurements and reporting of measurement outcomes, so that the requirement encompasses the entire EPD. This suggestion represents more stringent regulation of existing requirements, as a greater number of municipal authorities compared to today will be subject to these requirements.

7.2. Economic impacts

Part of this assignment to review emergency planning zones and distances is to present potential cost increases for central, regional and local government, and businesses and individuals. Consequently, SSM, MSB and the county administrative boards of Uppsala, Kalmar, Halland and Västmanland have performed estimates of likely economic impacts of the proposed new emergency planning zones and distances. These estimates only include costs related to rescue services that fall under the responsibility of the state, as regulated by the Civil Protection Ordinance.

The proposals are estimated to result in increased administrative expenditure annually totalling approximately SEK 24 million, in addition to today's appropriation of SEK 48 million. Costs are also incurred in the form of development expenditure when implementing the proposals; these amount to approximately SEK 5.5 million per year over a three-year period. SSM wishes to emphasise the possibility that some of the costs may be lower than estimated, mainly depending on the choice of technical solution for warning the population in the new emergency planning zones.

The cost of emergency preparedness work, relating to the NPPs affected by the proposed emergency planning zones and distances, has been allocated between these three areas:

- Likely development expenditure of county administrative boards during a limited period of time, in addition to the boards' administrative expenditure for maintaining emergency preparedness in accordance with the proposal.
- The administrative expenditure of MSB and SSM for maintaining emergency preparedness in accordance with the proposal.
- The costs for investments made on a national level.

All the numbers presented in this section are rounded to two significant figures. A large proportion of these costs relates directly to the number of households affected by the emergency planning zones and distances. Estimates of the number of households, which were used as the basis for the cost estimates, are shown in Table 17.

Table 17. Number of households within the emergency planning zone and emergency planning distance to surround the respective NPP. Numbers in brackets represent households in today's corresponding zones. Holiday dwellings are excluded.

	Number of households		
Area	**Forsmark**	**Oskarshamn**	**Ringhals**
PAZ	27	80	1,500
UPZ	8,700 (900)	13,000 (1,100)	53,000 (10,000)
EPD	280,000 (29,000)	160,000 (33,000)	600,000 (250,000)

Costs for facilities belonging to emergency preparedness category II are presented separately in section 7.2.4.

7.2.1. Development expenditure and administrative expenditure of county administrative boards

If the proposed new emergency planning zones and distances are implemented, this will result in substantial development work taking place at the county administrative boards. For the most part, the development expenditure will consist of personnel costs, including areas such as updates of existing plans and programmes, designing new evacuation sites, as well as developing systems for alerts and warnings. In the presentation, the estimated costs are allocated over a three-year period.

In order to estimate the county administrative boards' future administrative expenditure if the proposed new emergency planning zones and distances are implemented, costs have been calculated as per the structure currently used for these boards' reporting to MSB. Here, these costs are broken down into three areas: administration; technology and telecommunications; and training and exercises.

- **Administration**
  A large proportion of the county administrative boards' costs for preparedness for nuclear energy emergencies relates to emergency response planning and ongoing cooperation with relevant stakeholders. This area includes aspects such as evacuation planning, communication to parts of the population that might be affected by an emergency at a nuclear power plant, in addition to administration and management of ITB and technical warning systems.
- **Technology and telecommunications**
  This cost item includes areas such as technical equipment, telephony and mobile phone subscriptions.
- **Training and exercises**
  A key part of maintaining capacity for dealing with nuclear power accidents is carrying out recurring training sessions and exercises involving all personnel having tasks as defined by the respective county administrative board's emergency response plan. This planning not only encompasses a board's workforce, but also the human resources of other relevant stakeholders. Also, every other year, a large-scale exercise takes place in one of the counties in Sweden in which a nuclear

power plant is situated. This exercise involves a large number of relevant stakeholders.

The proposed EPD also presupposes a certain level of emergency response planning in surrounding counties.[4] Costs incurred by this were included in the estimate of future administrative expenditure.

A breakdown of development expenditure and administrative expenditure of county administrative boards is shown in Table 18. The table also presents current administrative expenditure of administrative boards of the counties in which a nuclear power plant is situated. The county administrative boards of these ‘nuclear power counties’ have previously announced that the allocated funds are insufficient for meeting the requirements of the Civil Protection Ordinance.[5] Consequently, the entire difference between new and pre-existing administrative expenditure is not due to the proposed new emergency planning zones and distances.

Table 18. Development expenditure and administrative expenditure per county with a nuclear power plant and surrounding counties in the case of implementation of the proposed new emergency planning zones and distances.

	Annual expenditure (SEK thousands)		
Cost item	**Forsmark**	**Oskarshamn**	**Ringhals**
Development, years 1-3	1,700	1,700	2,100
Administration, NPP counties	7,800	7,800	9,000
Administration, surrounding counties	1,200	1,600	1,200
Total, years 1-3	**10,700**	**11,100**	**12,300**
Total, thereafter	**9,000**	**9,400**	**10,200**
Current appropriations, NPP counties	4,880	4,800	5,070

7.2.2. Administrative expenditure of MSB and SSM

The proposed new emergency planning zones and distances will also result in increased costs for MSB and SSM in areas including training, exercises and supervisory work. In the assessment of MSB and SSM, there is a corresponding need for two additional full-time positions at MSB plus one additional full-time position at SSM. The total annual administrative expenditure for these full-time positions is estimated at SEK 2.4 million.

[4]This affects the counties of Jönköping, Kronoberg, Gotland, Östergötland, Västra Götaland, Gävleborg, Västmanland and Stockholm. Skåne and Dalarna counties have been excluded as they are only affected slightly by the EPD. The counties of Kronoberg and Jönköping share boundaries with both Kalmar and Halland counties, and are included in the cost estimates for emergency preparedness work relating to the NPPs of both Oskarshamn and Ringhals.

[5] E.g. accounted for by means of MSB’s budget documentation for the period 2017-2019, MSB ref. no. 2016-975.

7.2.3. National investments

Major investments and procurement processes shared by the counties in which a nuclear power plant is situated are coordinated on a national level. These costs are borne by MSB or SSM. Some of these costs are directly proportional to the number of residents in the respective emergency planning zones and distances. The costs presented in this section only encompass direct expenditure for acquisitions and, when relevant, for distribution. Costs for ongoing administration (e.g. supplementary distribution and questions from the public regarding ITB and RDS receivers) are included in the administrative expenditure discussed in section 7.2.1. In order to accurately illustrate the level of costs over time, acquisition costs have been allocated over a number of years based on the expected lifetime. Table 19 shows average annual expenditure.

These costs include the following:

- **Outdoor warning systems**
  There is currently a higher concentration of sirens for outdoor warning of the population in areas out to a distance of approximately 12 to 15 km from the NPPs. The estimated cost is based on an assumption of twice the number of supplementary sirens compared to today, when the warning system is expanded to cover the proposed UPZ.
- **Indoor warning systems**
  Indoor warnings are communicated by means of RDS receivers, which are distributed to residents of areas out to a distance of approximately 12 to 15 km from the NPPs. The estimated cost for the warning system is based on expansion of the existing system to encompass both the PAZ and UPZ.
- **ITB and providing information**
  This cost item includes predistributed ITB as well as maintaining stocks of the iodine tablets (regionally and nationally) for limited distribution in new areas. This cost item includes printing of information leaflets, co-packing and distribution.
- **Radiation monitoring instruments**
  Around the nuclear power plants, planning is in place for radiation monitoring and radiation measurements, both at fixed points for continuous monitoring of radiation levels (stationary gamma stations), and in the form of mobile radiation measurements for mapping of ground deposition following a release of radioactive materials.

Costs incurred for distributing RDS receivers to residents in the PAZ and UPZ represent a significant proportion of the total cost. However, prior to a new procurement process for RDS receivers, SSM recommends reviewing the systems for warning the population in the PAZ and UPZ in the light of new technical possibilities.

The estimated cost of mobile radiation measurements is based on assumed implementation of a new system for radiation measurements, where this capability is to be maintained by the county administrative boards of the nuclear power counties. The feasibility of this kind of system needs to be investigated further by the relevant stakeholders.

Table 19. Estimated annual expenditure for national investments.

Cost item	Annual expenditure (SEK thousands)			
	Forsmark	**Oskarshamn**	**Ringhals**	**Total**
Outdoor warning systems (sirens)				
New expenditure	180	410	410	1,000
Current expenditure	88	210	210	500
Indoor warning systems (RDS)				
New expenditure	660	960	4,100	5,700
Current expenditure	130	140	870	1,100
ITB (predistribution and limited distribution in new areas) plus information				
New expenditure	820	530	2,000	3,300
Current expenditure	210	160	850	1,200
Instruments				
New expenditure	510	510	510	1,500
Current expenditure	430	430	430	1,300
Total costs				
New expenditure	2,200	2,400	7,000	12,000
Current expenditure	850	930	2,300	4,100

7.2.4. Costs relating to facilities belonging to emergency preparedness category II

County administrative board expenditure for emergency response planning for facilities belonging to emergency preparedness category II is shown in Table 20.

As far as concerns emergency preparedness work relating to the fuel fabrication plant in Västerås, this expenditure mostly comprises personnel costs for the emergency response planning of the Västmanland county administrative board. Costs are also incurred when providing information to the public, maintaining warning systems, and maintaining a certain capability for performing radiation measurements.

As emergency preparedness work relating to Clab can mainly be managed as part of the emergency response planning of the Kalmar county administrative board for the Oskarshamn NPP, no additional costs are incurred by the emergency response planning for Clab. However, a certain level of efforts are required in order to update existing emergency response plans in accordance with SSM's proposed EPD.

Table 20. Development expenditure and administrative expenditure for facilities belonging to emergency preparedness category II in the case of implementation of the proposed new emergency planning zones and distances.

Cost item	Annual expenditure (SEK thousands)	
	Fuel fabrication plant in Västerås	Clab
Development, year 1	-	200
Administration	580	-

7.3. Other socioeconomic impacts

The proposed emergency planning zones and distances will, in the assessment of SSM, imply minimal socioeconomic impacts. Today's emergency planning zones and distances imply virtually no socioeconomic impacts whatsoever, beyond the direct expenditure linked to maintaining the zones and distances. Consequently, SSM assesses that there is no rationale for expecting changed circumstances if new emergency planning zones and distances are implemented.

However, if an emergency were to occur, SSM is of the opinion that the proposed new emergency planning zones and distances could contribute to substantially reduced socioeconomic impacts due to the emergency, particularly around the NPPs. Improved potential for reducing radiation doses to those affected by an emergency may be of crucial significance for enabling not only individuals, but also society as a whole, to return to manageable living conditions.

7.4. Financing increased expenditure on the part of the state

Central government expenditure for nuclear emergency preparedness is currently funded through the emergency planning fee regulated by the *Ordinance concerning certain fees imposed by the Swedish Radiation Safety Authority (2008:463)*. Consequently, SSM suggests that the higher level of costs for the state, brought about by the proposed new emergency planning zones and distances, should be financed by raising this emergency planning fee. This suggestion is in line with the 2016 energy production agreement reached between Swedish political parties, which share the same view that the nuclear power industry must bear its own costs.

Appendices

1. Reference levels, dose criteria and intervention levels
2. Dispersion and dose calculations
3. The nuclear power plants
4. The fuel fabrication plant in Västerås
5. The central interim storage facility for spent nuclear fuel

2017:27e

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 300 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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