Strål
säkerhets
myndigheten

Swedish Radiation Safety Authority

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Review of Swedish emergency planning zones and distances, Appendix 3

The nuclear power plants

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1. Summary

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.

The Swedish Radiation Safety Authority (SSM) has classified the nuclear power plants as belonging to emergency preparedness category I. This signifies that there is a possibility of events occurring at the NPPs that could justify taking urgent protective actions for the population outside these plants. As a part of the emergency preparedness planning that is presupposed to enable taking such protective actions in an effective way, relevant emergency planning zones and distances must be in place around the NPPs.

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.

SSM has determined two postulated events serving as the basis of the proposed emergency planning zones and emergency planning distances to surround the NPPs. 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. Based on these distances, the final proposals for emergency planning zones and planning distances to surround the respective nuclear power plants have been produced by the county administrative boards of Uppsala, Kalmar and Halland in collaboration with SSM and MSB (Swedish Civil Contingencies Agency). Consultations with national and regional stakeholders have taken place, as arranged by SSM and the county administrative boards.

This appendix is part of the report *“Review of Swedish emergency planning zones and distances”.* For explanations of terms and concepts, please see the main report.

2. Postulated events

In this project, SSM assumed two postulated events. 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.

2.1. Postulated events

The following two events serve 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.

These events assume the postulated event for the design sequence described in the safety analysis reports (SAR) produced by the NPPs [1]. In the case of the event with functioning mitigation systems, sprinkling[1] may be credited after eight hours; at the same time, the filtered containment venting system is assumed to function as stated by the design requirements defined to enable fulfilment of the government decision of 1986 on guidelines for taking of measures to limit releases in connection with severe reactor accidents [2]. When it comes to the event with non-functioning mitigation systems, no credit is given for sprinkling; at the same time, the release is assumed to occur in connection with vessel melt-through, without passing through the filtered containment venting system.

2.2. 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

[1] Sprinkling involves activation of water sprinklers in the reactor containment for the purpose of condensing the steam and thus reducing pressure in the reactor containment should an accident occur. Sprinkling also implies “washing out“ radioactive materials in aerosol form.

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, including 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 develop 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 the 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.

3. 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 has also 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 set a briefest feasible period of forewarning at approximately four hours for the postulated events.

3.1. Released activity and duration

3.1.1. Representative source terms for different NPPs

SSM not only requested documentation on the representative source terms for the two postulated events from the licensees of Swedish nuclear power plants [3] [4], but also commissioned the German technical support organisation Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) to produce corresponding materials [5] [6].

The licensees used the MAAP computer code [7] [8] in their analyses, whereas GRS used the MELCOR computer code [9]. 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 a 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.

Analyses of reactor four at Ringhals (R4) performed using MELCOR were applied to the postulated events, as these analyses are attributed with the lowest level of ambiguity. The source terms from MELCOR have nonetheless been adjusted in terms of release fraction in the case of niobium. The same release fraction is set in MELCOR for niobium and molybdenum. This results in large-scale releases of niobium that contrast with what is stated in the guidelines issued by the U.S. NRC (Nuclear Regulatory Commission) in addition to lessons learned from the nuclear power plant accidents of both Chernobyl and Fukushima Daiichi [10]. For this reason, SSM has instead elected to set the same release fraction for niobium as for zirconium, as formulated in the guidelines from the NRC.

3.1.2. Complete representative source terms

The core inventory of R4 as reported by the licensee contains 285 nuclides. The report states the equilibrium inventory for the thermal power output at 3253 MW and a degree of burn-up for the fuel at 53 MWd/kg of uranium.

In the analysis performed using MELCOR, the outcomes were presented as releases in proportions of mass of the core inventory for each time step comprising 50 seconds throughout the release sequence, whereas the source terms used to conduct dispersion and dose calculations consist of released activity per nuclide and hour. Consequently, the outcomes from the original analysis performed using MELCOR have been translated into released activity per nuclide and hour for a release taking place over a period of 48 hours. In this calculation, released activity per unit of time was also corrected for decay and ingrowth[2] in the reactor core and reactor containment for the period of time between a scram[3] and the point in time of the release, ultimately giving representative source terms containing all 285 nuclides in the declared core inventory.

Figure 1 illustrates the released percentage of activity on the part of a quantity of nuclides in the case of the postulated event without functioning mitigation systems. Each individual curve shows the cumulative released activity (Bq) for the respective nuclide as a percentage of the core inventory (Bq) at commencement of the event (t = 0 h). Note that the noble gas Xe-133 has its own scale in the figure.

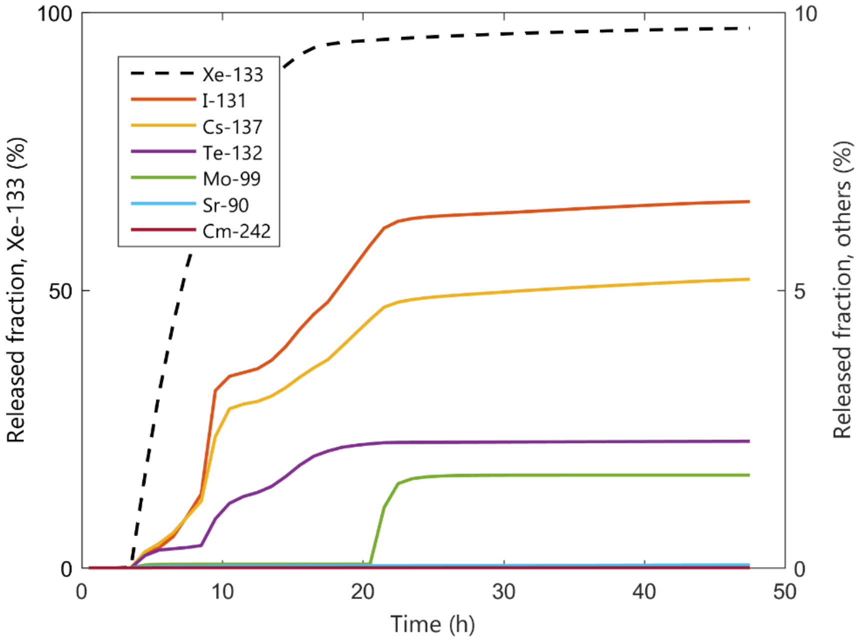

Figure 1. Released percentage of activity for a number of nuclides in the case of the postulated event without functioning mitigation systems.

[2] Ingrowth implies an increase in the quantity of radioactive materials after the fuel has been removed from operation due to the decay chains.

[3] A reactor may be quickly shut down (called a 'scram') in order to immediately interrupt nuclear fission. A scram takes place by inserting the control rods into the reactor for a duration of approximately four seconds.

3.2. 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.

3.2.1. Criteria for selecting nuclides

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.

3.2.2. Nuclides contributing to effective dose over a period of seven days

When evaluating which nuclides give a significant contribution to effective dose over a period of seven days, SSM first excluded nuclides with a brief half-life, in addition to nuclides that are only released to an insignificant extent. Nuclides with a brief half-life have already decayed by the time the release commences. Their possible contributions to daughter nuclides have thus already been taken into account when calculating the complete source terms. Additional exclusions made are a small number of nuclides that lack dose coefficients from the ICRP. The reason why these nuclides lack dose coefficients is the fact that they do not contribute to significant radiation doses.

After this point, SSM used the dispersion and dose calculation programs Lena [11] and Argos [12] in order to investigate which nuclides give significant contributions to effective dose over a period of seven days. The relative significance of different nuclides partly depends on the released quantity of the respective nuclide. Consequently, these analyses encompassed the representative source terms of both the postulated events. Rain can also have a potential impact on the nuclides giving a significant contribution to effective dose over a period of seven days. For this reason, the analyses were conducted both with and without models that simulate rain.

The study shows that relatively few nuclides contribute more than 0.1 per cent to effective dose over a period of seven days. The only nuclide that is additional for the representative source term with functioning mitigation systems, and which is not among the nuclides selected for the representative source term without functioning mitigation systems, is Xe-131. Here, the rationale is that the significance of the dose contribution from noble gases increases in relation to a lower level of volatile substances being partly captured by the filtered containment venting system. The study also shows that many of the poorly soluble nuclides contained in the release escape to such a small degree that they do not need to be included in the final source terms. Examples of poorly soluble nuclides excluded for this reason include Y-91, Zr-95, Nb-95, Ru-103, Ru-106, La-140, Ce-141, Ce-144, Np-239, Pu-238 and Pu-241.

In summary, one must take into account the following 27 nuclides (out of 285 nuclides in the original source term) when estimating effective dose over a period of seven days in the dispersion and dose calculations.

- Noble gases: Kr-85m, Kr-87, Kr-88, Xe-133, Xe-133m, Xe-135 and Xe-135m
- Halogens: I-131, I-132, I-133 and I-135
- Alkali metals: Rb-88, Cs-134, Cs-136 and Cs-137
- Tellurium group: Sb-127, Te-127m, Te-129m, Te-131m and Te-132
- Sr and Ba: Sr-89, Sr-90 and Ba-140
- Noble metals: Mo-99, Tc-99m
- Lanthanides: Cm-242, Cm-244.

3.2.3. Iodine isotopes that contribute to thyroid dose

Core inventories reported by the licensees include the iodine isotopes shown in Table 1. Iodine isotopes with a brief half-life (second to minute scale) do not need to be taken into account in the dispersion and dose calculations, as they will have already decayed before the release commences. As the release commences after approximately four hours in the postulated events, all iodine isotopes having a half-life shorter than slightly over 20 minutes have largely decayed before the release commences. Consequently, they are excluded. The excluded isotopes are I-128, I-131m, I-136, I-136m and I-137. From these iodine isotopes, the contribution from ingrowth is nevertheless included, since it is taken into account when calculating released activity per nuclide and hour, as described previously.

Another nuclide excluded is I-129, which has a very long half-life, at the same time as the content of I-129 in the core inventory is approximately one-seventh of the content of the iodine isotopes giving the largest contributions. I-130 and I-134 only give small contributions to effective dose. However, SSM elected to include both these iodine isotopes in the calculations for the purpose of preventing underestimation of equivalent dose to the thyroid.

Consequently, the following iodine isotopes should be included in the representative source terms: I-130, I-131, I-132, I-133, I-134 and I-135.

Table 1. Iodine isotopes in the reactor (core inventory for R4). Iodine isotopes included in the dispersion and dose calculations are shaded in grey.

Iodine isotope	Half-life	Core inventory (Bq)
I-128	25.0 min	2.6E+16
I-129	1.61E+07 y	1.0E+11
I-130	12.4 h	5.8E+16
I-130m	8.84 min	3.1E+16
I-131	8.02 d	2.7E+18
I-132	2.30 h	4.0E+18
I-133	20.8 h	5.6E+18
I-134	52.5 min	6.2E+18
I-135	6.57 h	5.4E+18
I-136	1.39 min	2.5E+18
I-136m	46.9 s	1.2E+18
I-137	24.5 s	2.6E+18

3.2.4. Nuclides of significance for long-term ground deposition

Using Lena, the effective dose from ground deposition during the first year as of the release was estimated using the complete representative source term containing all nuclides of significance in the core inventory in the event without functioning mitigation systems. This was followed by ranking the nuclides by relative contribution to yearly dose from ground deposition.

Table 2 lists the nuclides contributing more than 0.1 per cent.

Table 2. Relative contribution to effective dose over the course of one year due to ground deposition.

Nuclide	Relative contribution (%)	Half-life
Cs-134	60	2.07 y
Cs-137	18	30.0 y
I-131	9	8.02 d
Te-132	7	3.20 d
I-133	2	20.8 h
Cs-136	1	13.0 d
I-135	0.6	6.57 h
Ba-140	0.5	12.8 d
Sb-125	0.5	2.76 y
I-132	0.5	2.30 h
Mo-99	0.4	2.75 d
Sb-127	0.1	3.85 d
Te-129m	0.1	33.6 d

Only six nuclides contribute more than 1 per cent to effective dose from ground deposition during the first year. Of these, Cs-134 and Cs-137 represent approximately 80 per cent of the contribution during the first year. Apart from these, I-131 and Cs-136 in particular are so long-lived that they may have a future impact on decision making concerning relocation owing to ground deposition. The contribution from Cs-136 is, however, relatively insignificant. The contribution from I-131 may approach approximately 10 per cent; however, due to its relatively brief half-life, the significance of I-131 will have reduced considerably already after a few weeks. The conclusion is that only Cs-134 and Cs-137 are of significance for estimating effective dose from ground deposition in the longer term in the case of the postulated event without functioning mitigation systems. This conclusion remains unchanged even if the deposition should take place during rain conditions.

3.2.5. Nuclides of significance for food production

The nuclides used to identify the need for measures linked to food production are Sr-89, Sr-90, I-131, Cs-134, Cs-136, Cs-137 and Cm-242.

3.2.6. Nuclides of significance for remediation

The nuclides of significance for remediation are the same nuclides that give a significant contribution to effective dose from ground deposition during the first year after the release, i.e. Cs-134 and Cs-137.

3.2.7. Summary

Table 3 provides a summary account of the nuclides selected for the representative source terms, in addition to total released activity to the atmosphere per nuclide for the two postulated events with and without functioning mitigation systems. The classification into release categories is in accordance with NUREG-1465 [10].

Figure 2 illustrates relative contributions from different groups of nuclides in relation to the postulated events: with and without functioning mitigation systems in the case of a typical weather scenario. The relative contribution from different nuclide groups may vary between weather scenarios, though the main distribution of the nuclide groups of significance still applies. In the case of releases during the postulated event without functioning mitigation systems, one conclusion that has been drawn is that the main contribution to effective dose during the first seven days will be from radioactive iodine. As far as concerns releases during the postulated event involving functioning mitigation systems, where the quantity of radioactive iodine is lower, the predominant contribution is from noble gases instead. In the case of the release due to the postulated event involving functioning mitigation systems, a contribution is stated to be from alkali metals. Nonetheless, the main source is not caesium. Instead, it is from Rb-88, which in its turn has its origin from the decay of the noble gas Kr-88.

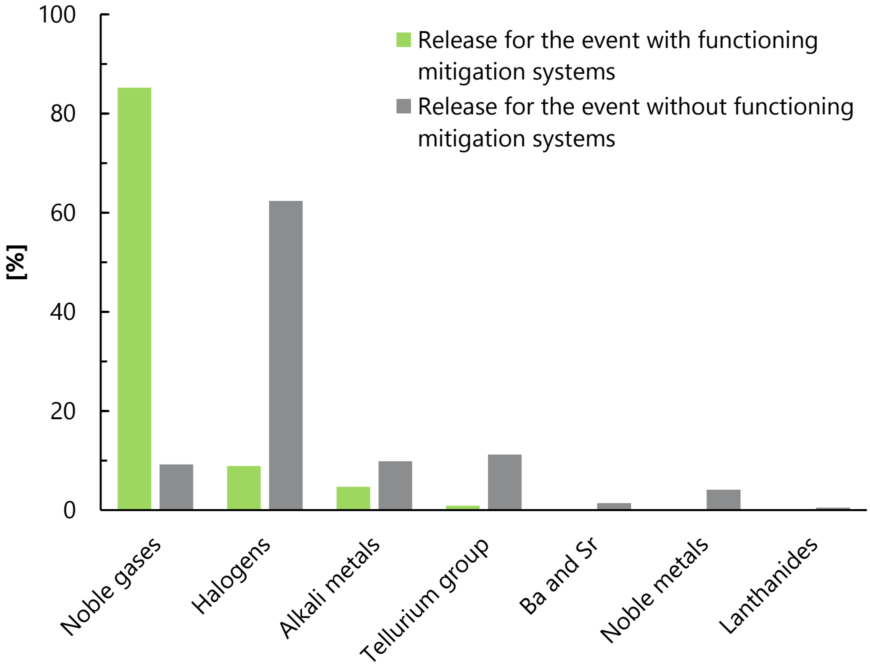

Figure 2. Relative contribution to effective dose during the first seven days in the cases of the postulated events with and without functioning mitigation systems in a typical weather scenario.

It is stated in government decisions concerning mitigation systems that the total release of Cs-134 and Cs-137 is to be kept below 0.1 per cent of the core inventory in a nuclear power reactor with an output of 1800 MWt [2]. At the degree of burn-up specified at the time, this corresponded to 150-200 TBq of Cs-137 [13]. The representative source term for the event with functioning mitigation systems gives a total release of Cs-137 at 78 TBq. The consultation version of the impending analysis regulation to be issued by SSM states a more stringent reference value for Cs-137, at 100 TBq [13]. This implies that the representative source term for the event with functioning mitigation systems is both in line with the requirements of the government decisions and with the future regulatory requirements.

Table 3. 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

3.3. Other parameters in the source terms

3.3.1. Release height

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:

- Oskarshamn and Forsmark: 27 m
- Ringhals: 48 m.

In the case of the postulated event without functioning mitigation systems, SSM has set the release height at the same height as for all the Swedish nuclear power plants:

- Oskarshamn, Forsmark and Ringhals: 27 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 for boiling water and pressurised water reactors alike.

3.3.2. Iodine forms

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.

During an accident sequence, the iodine chemistry is complex, influenced by many parameters including pressure, temperature, pH, radiation levels and interaction with surfaces in the facility in question. Thus, no general answer can be given to the question of how the distribution of iodine forms is manifested in either a reactor vessel or reactor containment, or in a release to the surroundings in the event of an accident. Having this rationale, SSM commissioned Vattenfall AB to produce distributions of iodine forms in the reactor containment as part of a realistic and a conservative scenario [14]. Both scenarios are based on a minimum pH level of 7 in the reactor containment, which could be the case if some form of pH regulation is available during an accident, or if there is some other way to demonstrate that the pH level is outside the acidic range during the accident sequence. For the postulated events, SSM applies the composition of iodine forms in the reactor containment from the conservative scenario.

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. Compared to the filtered containment venting systems of boiling water reactors, the filtered containment venting systems of pressurised water reactors are more effective at reducing iodine contamination. Consequently, the composition of iodine forms in a release will differ between these reactor types, although the filtering significantly reduces the total release of iodine in both cases.

To enable an estimate of iodine form composition in a release, SSM hypothetically assumes that particulate and elemental iodine are filtered out to the same extent by the filtered containment venting system, and that organic iodine is not filtered out at all. This means that the relative composition of iodine forms in the representative source terms can be postulated as shown in Table 4.

Table 4. Relative composition of volatile iodine forms in the atmosphere of a reactor containment and in a release in the cases of the postulated events with and without functioning mitigation systems ('DF' denotes decontamination factor).

Iodine form	Reactor containment (%)	Releases (%)
Functioning mitigation systems (Oskarshamn and Forsmark, DF100)		
Organic	0.15	13.1
Elemental	4.85	4.2
Particulate	95	82.7
Functioning mitigation systems (Ringhals, DF500)		
Organic	0.15	42.9
Elemental	4.85	2.8
Particulate	95	54.3
Without functioning mitigation systems (all NPPs, DF1)		
Organic	0.15	0.15
Elemental	4.85	4.85
Particulate	95	95

3.3.3. Heat energy

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 movement 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.

3.3.4. Period of forewarning

SSM has based its estimate of the briefest feasible period of forewarning on outcomes of calculated release sequences using MELCOR in the case of the nuclear power reactor Ringhals 4. In the case of the event without functioning mitigation systems, the release commences after 3.5 hours. In the case of the event with functioning mitigation systems, the release commences after 4.6 hours. Given the uncertainties associated with the analyses involving source term codes, SSM views it as reasonable to set an average briefest feasible period of forewarning at approximately four hours for the postulated events.

3.4. Comparison with Chernobyl and Fukushima Daiichi

The total release to the atmosphere per nuclide in the representative source term for the postulated event without functioning mitigation systems has been compared with the estimated total release to the atmosphere of corresponding nuclides in connection with the nuclear power accidents of Fukushima Daiichi [15] and Chernobyl [16], see Table 5.

The 11 nuclides contributing more than 1% to effective dose during the first seven days in the case of the event without functioning mitigation systems are shown shaded in grey in Table 5. In the case of the postulated event without functioning mitigation systems, the release to the atmosphere is on a par with the total atmospheric release from reactors 1 to 3 at Fukushima Daiichi, though of a smaller magnitude than the atmospheric release from Chernobyl.

Table 5. Comparison between atmospheric releases in the case of the postulated event without functioning mitigation systems (denoted below as 'SSM') and estimated releases from the nuclear power plant accidents of Chernobyl and Fukushima Daiichi.

Nuclide	SSM	Fukushima Daiichi	Chernobyl
Kr-85m	2.1E+17		
Kr-87	3.9E+16		
Kr-88	3.2E+17		
Xe-133	5.3E+18	6.0E+18 – 1.2E+19	6.5E+18
Xe-133m	1.7E+17		
Xe-135	2.2E+18		
Xe-135m	3.9E+17		
I-130	1.9E+15		
I-131	1.8E+17	1.0E+17 – 4.0E+17	1.8E+18
I-132	2.5E+17		
I-133	2.6E+17	6.8E+14 – 3.0E+17	2.5E+18
I-134	2.4E+15		
I-135	1.0E+17		
Rb-88	9.2E+15		
Cs-134	2.6E+16	8.3E+15 – 5.0E+16	4.7E+16
Cs-136	5.8E+15		3.6E+16
Cs-137	1.9E+16	7.0E+15 – 2.0E+16	8.5E+16
Sb-127	5.9E+15		
Te-127m	9.3E+14		
Te-129m	4.2E+15	3.3E+15 – 1.2E+16	2.4E+17
Te-131m	1.0E+16		
Te-132	9.0E+16	7.6E+14 – 1.6E+17	1.2E+18
Sr-89	1.4E+15	4.3E+13 – 1.3E+16	1.2E+17
Sr-90	1.3E+14	3.3E+12 – 1.4E+14	1.0E+16
Ba-140	2.5E+15	1.1E+15 – 2.0E+16	2.4E+17
Mo-99	8.5E+16	8.8E+07	7.2E+16
Tc-99m	8.2E+16		
Cm-242	8.3E+11	9.8E+09 – 9.8E+11	4.0E+14
Cm-244	1.1E+11		

4. Dispersion and dose calculations

SSM has performed dispersion and dose calculations based on historical weather data for the three NPPs of Forsmark, Oskarshamn and Ringhals on the part of both the postulated events: with and without functioning mitigation systems. Calculations were performed using weather data for the period 2006-2015. In total, the data material encompasses approximately 4,240 dispersion and dose calculations per postulated event and NPP. This gives a sufficient statistical basis for taking into account variations in weather conditions around the nuclear power plants. For more information about dispersion and dose calculations, refer to the main report and Appendix 2.

This chapter presents tables illustrating the greatest distances at which threshold doses for severe deterministic effects, in addition to dose criteria and intervention levels for different protective actions, are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account. The tables also indicate an average value for the outcomes from the three NPPs for the respective percentile. All the outcomes are presented with two significant figures. For more information about threshold doses, dose criteria and intervention levels, refer to the main report and Appendix 1.

4.1. Event without functioning mitigation systems

4.1.1. Precautionary evacuation

SSM has assumed threshold doses for severe deterministic effects for the purpose of defining approximate distances at which precautionary evacuation should be pre-planned in the case of the postulated event without functioning mitigation systems, see Table 6 to 8.

Table 6. The greatest distances at which 1,000 mGy absorbed dose to red bone marrow on the part of adults and children is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	1.4	1.4	1.4	1.4
80	1.9	1.6	1.6	1.7
90	2.7	2.2	2.3	2.4
		Children		
70	1.0	1.1	1.2	1.1
80	1.4	1.2	1.4	1.3
90	2.1	1.6	1.7	1.8

Table 7. The greatest distances at which 100 mGy absorbed dose to an embryo 2 to 7 weeks post conception is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	7.2	5.1	5.6	6.0
80	9.8	6.1	7.5	7.8
90	11	9.7	11	10

Table 8. The greatest distances at which the threshold dose 300 mGy absorbed dose to the brain of a foetus 8 to 15 weeks post conception is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	2.6	2.6	2.4	2.5
80	3.9	3.2	3.1	3.4
90	6.3	4.6	5.0	5.3

4.1.2. Evacuation

SSM has assumed the higher dose criterion for evacuation at 100 mSv effective dose for the purpose of defining approximate distances at which evacuation should be pre-planned in the case of the postulated event without functioning mitigation systems, see Table 9. For comparison purposes, SSM also presents outcomes for the lower dose criterion for evacuation, at 20 mSv effective dose, see Table 10.

Table 9. The greatest distances at which the dose criterion 100 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	16	13	20	17
80	23	18	26	22
90	31	29	36	32
		Children		
70	22	17	27	22
80	27	26	33	29
90	39	36	44	40

Table 10. The greatest distances at which the dose criterion 20 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	49	53	61	54
80	70	75	80	75
90	99	100	100	100
		Children		
70	65	80	79	75
80	88	100	92	94
90	110	130	120	120

4.1.3. Relocation due to ground deposition

SSM has assumed the intervention level 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 for the purpose of defining approximate distances at which relocation due to ground deposition should be pre-planned in the case of the postulated event without functioning mitigation systems, see Table 11.

Table 11. The greatest distances at which the intervention level 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	110	100	130	120
80	180	150	170	170
90	300	240	250	260

4.1.4. Sheltering

SSM has assumed the dose criterion 10 mSv effective dose for the purpose of defining approximate distances at which sheltering should be pre-planned for the event without functioning mitigation systems, see Table 12.

Table 12. The greatest distances at which the dose criterion 10 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	90	110	100	100
80	120	130	130	130
90	180	180	170	180
		Children		
70	110	130	130	120
80	140	160	150	150
90	210	200	190	200

4.1.5. Iodine thyroid blocking

SSM has assumed the dose criterion 50 mSv equivalent dose to the thyroid for the purpose of defining approximate distances at which ITB may be warranted for the event without functioning mitigation systems, see Table 13.

Table 13. The greatest distances at which the dose criterion 50 mSv equivalent dose to the thyroid is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	88	110	97	99
80	110	130	120	120
90	150	160	150	160
		Children		
70	150	150	150	150
80	200	180	190	190
90	290	230	240	260

4.2. Event with functioning mitigation systems

4.2.1. Precautionary evacuation

SSM has assumed threshold doses for severe deterministic effects for the purpose of defining approximate distances at which precautionary evacuation should be pre-planned in the case of the postulated event with functioning mitigation systems. The threshold dose 1,000 mGy absorbed dose to red bone marrow is not exceeded outside the sites of the NPPs, neither on the part of adults or children, even if 90 per cent of all occurring weather scenarios are taken into account. For other outcomes, see Table 14 and 15.

Table 14. The greatest distances at which 100 mGy absorbed dose to an embryo 2 to 7 weeks post conception is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	1.1	1.3	1.2	1.2
80	1.4	1.4	1.3	1.4
90	2.0	1.8	1.6	1.8

Table 15. The greatest distances at which 300 mGy absorbed dose to the brain of a foetus 8 to 15 weeks post conception is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	0.5	0.5	0.3	0.4
80	0.6	0.5	0.5	0.5
90	0.7	0.7	0.6	0.6

4.2.2. Evacuation

SSM has assumed the lower dose criterion for evacuation at 20 mSv effective dose for the purpose of defining approximate distances at which evacuation should be pre-planned for the postulated event with functioning mitigation systems, see Table 16. For comparison purposes, SSM also presents outcomes for the higher dose criterion for evacuation, at 100 mSv effective dose; see Table 17.

Table 16. The greatest distances at which the dose criterion 20 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	4.5	4.1	4.3	4.3
80	6.1	4.8	5.3	5.4
90	9.1	6.3	8.3	7.9
		Children		
70	4.8	4.3	4.3	4.5
80	6.4	5.0	5.4	5.6
90	9.5	6.7	9.2	8.5

Table 17. The greatest distances at which the dose criterion 100 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
Adults				
70	1.8	1.2	1.2	1.4
80	2.3	1.3	1.4	1.7
90	2.6	1.8	1.9	2.1
Children				
70	2.0	1.2	1.3	1.5
80	2.4	1.5	1.5	1.8
90	2.7	2.0	2.0	2.2

4.2.3. Relocation due to ground deposition

SSM has assumed the intervention level 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 for the purpose of defining approximate distances at which relocation due to ground deposition should be pre-planned in the case of the postulated event with functioning mitigation systems, see Table 18.

Table 18. The greatest distances at which the intervention level 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	0.8	0.7	0.5	0.7
80	1.3	0.8	0.8	1.0
90	2.1	1.2	1.4	1.6

4.2.4. Sheltering

SSM has assumed the dose criterion 10 mSv effective dose for the purpose of defining approximate distances at which sheltering should be pre-planned for the event with functioning mitigation systems, see Table 19.

Table 19. The greatest distances at which the dose criterion 10 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	6.7	5.1	8.3	6.7
80	10	7.6	10	9.2
90	16	12	15	15
		Children		
70	7.2	6.3	8.3	7.3
80	10	8.3	11	9.6
90	17	13	16	16

4.2.5. Iodine thyroid blocking

SSM has assumed the dose criterion 50 mSv equivalent dose to the thyroid for the purpose of defining approximate distances at which intake of iodine tablets may be warranted for the event involving functioning mitigation systems, see Table 20. SSM also presents outcomes for the dose criterion 10 mSv equivalent dose to the thyroid on the part of children and pregnant women, as this may indicate the distances within which intake of predistributed iodine tablets is advisable, see Table 21.

Table 20. The greatest distances at which the dose criterion 50 mSv equivalent dose to the thyroid is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	2.7	2.3	2.3	2.4
80	3.4	2.8	3.0	3.1
90	5.7	4.1	4.4	4.7
		Children		
70	5.0	3.3	5.0	4.4
80	6.7	5.0	6.3	6.0
90	10	6.7	11	9.5

Table 21. The greatest distances at which the dose criterion 10 mSv equivalent dose to the thyroid is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
Children				
70	17	13	20	17
80	23	19	29	24
90	35	32	43	37

5. Emergency planning zones and distances

In this chapter, 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.

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.

5.1. The basis for emergency planning zones and distances

5.1.1. 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 evacuating the nearest 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 of the approximate distance of 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 of the approximate distance of 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 [17].

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.

5.1.2. 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 of just over 20 km is adequate for keeping effective doses to children and adults below 100 mSv in the case of the postulated 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 on 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 relocation 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 of 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 km and 30 km [18].

Moreover, SSM assesses that a large proportion of northern Öland should belong to the UPZ surrounding the Oskarshamn NPP, 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 [19]. 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 5.1.4.

The postulated event with functioning mitigation systems does not affect the range of the UPZ. The lower dose criterion for evacuation, at 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.

5.1.3. 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 to be performed promptly. 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 for 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 [18].

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.

5.1.4. 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, i.e. 10 mSv effective dose, to both the events: with and without functioning mitigation systems.

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 a zone between 20 km and 30 km from the NPP, and which was in effect for 10 days before a decision was taken concerning voluntary evacuation, resulted in major hardships 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 slightly exceeding 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.

5.1.5. 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 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. For adults, the calculations demonstrate that the corresponding distances are approximately 100, 120 and 160 km, respectively.

In the assessment of SSM, it is feasible to predistribute ITB within the PAZ and UPZ, in line with the recommendations from the IAEA [18]. 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 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 [18]. 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, even if 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 considers it advisable to investigate the potential to supply ITB to children and pregnant women throughout Sweden.

5.1.6. Warnings and predistributed information

SSM's proposals:

1. Warning announcements 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[4] 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 [20]. A general emergency is declared if an event or abnormal operation has occurred at the NPP where a release is taking place warranting protective actions for the public, or such release cannot be ruled out within a duration of 12 hours [20]. 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.

5.2. Emergency planning zones and distances surrounding NPPs in Sweden

The respective county administrative boards of Uppsala, Kalmar and Halland have proposed designs 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. One key change is that only the determined 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 around the NPPs.

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

The proposed designs of the emergency planning zones utilise 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 designs of the emergency planning zones. In some cases, this means that 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.

5.2.1. The Forsmark NPP

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 3.

Figure 3. The proposed PAZ and UPZ to surround the Forsmark NPP.

5.2.2. The Oskarshamn NPP

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 on 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 4.

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

5.2.3. The Ringhals NPP

The boundary of the PAZ mainly runs along Västkustbanan (West Coast Railway) past the Ringhals plant, meaning that the entire peninsula of Värö is encompassed. 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 5.

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

5.3. EPDs surrounding Swedish nuclear power plants

SSM considers it advisable to establish an EPD extending 100 km to surround the NPPs of Forsmark, Oskarshamn and Ringhals. The counties affected by the Forsmark NPP 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 Ringhals NPP are Halland, Västra Götaland, Jönköping and Kronoberg. The NPPs of 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.

5.4. 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.

6. 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 chapter, 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.

6.1. Events having other release sequences

6.1.1. 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.

6.1.2. 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.

In the event of a release of radioactive materials due to a nuclear power plant accident, the dose to individuals in surrounding areas depends on the period of time until the radioactive materials are released into the environment (containment time) and on the release sequence, primarily the duration of the release. Three different mechanisms help to reduce doses received: the decay of the radioactive materials before they are released into the environment; decay during a protracted release sequence; and the distribution of released radioactive materials across large areas owing to variations in wind direction. The latter mechanism may nevertheless result in a larger number of people being affected by a release.

A release from a nuclear power reactor contains a mixture of a large number of different nuclides, whose half-life range from under one minute to many decades, or even longer periods of time. A considerable proportion of the most short-lived nuclides decay before the release reaches the surroundings, even during relatively brief containment periods of a few hours or less. The longer containment periods that are achievable, the smaller the release of the more long-lived nuclides as well. However, the benefits of this diminish in pace with longer containment periods, though the advantages may be substantial for up to several weeks if this is technically feasible.

If the release is of a short duration, the radioactive materials contained in the release will move in a relatively cohesive way. In contrast, if the release should instead take place over a longer duration, the radioactive materials will be dispersed over an area depending on variability in wind direction and wind speed during this given period of time. Generally, it is not possible to perform calculations of reduced doses due to wind variability in relation to a certain release duration. However, it is evident that longer release duration on average gives broader dispersion owing to wind variability in the cases of releases that are ongoing for up to several weeks. When the durations exceed this, the differences are insignificant.

If the release should take place over a longer period of time, both wind variability and decay over the release duration contribute to reducing doses to humans in the surroundings. Doses are reduced further over a longer release duration, though the benefits of extending the release duration beyond two or three weeks are relatively small.

6.2. Events affecting spent fuel pools

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.

SSM has performed dispersion and dose calculations for a postulated event involving a loss of cooling that results in releases from the spent fuel pools 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.

6.2.1. Event

One event was taken into account as part of the sensitivity analysis, which involves releases from spent fuel pools:

- **An event involving a loss of cooling of spent fuel pools.** This event is caused by failed cooling of water in the spent fuel pools, resulting in the water heating up and vaporising in pace with the rising heat of the fuel assembly.

During normal operation, and to deal with abnormal operation for which the spent fuel pools are designed, several systems are in place for cooling of this fuel. Should cooling fail, and no further preventive or mitigation measures are available, the fuel's residual heat unavoidably leads to overheating of the fuel, and its subsequent damage and melting.

Here, SSM excluded other events accounted for in the licensees' safety analysis reports. The design basis events, for example, a mishap involving fuel handling, which is accounted for in a safety analysis report, result in insignificant releases and are irrelevant for consideration from an emergency preparedness perspective.

6.2.2. Representative source term

SSM based the representative source term on details relating to reactor 3 of the Oskarshamn nuclear power plant. This nuclear power reactor was selected because it has the highest level of thermal power output among all Swedish reactors. SSM has assumed a maximum quantity of fuel elements that can be kept in a spent fuel pool (several pools in fact), corresponding to a situation involving vessel inspection. This is comparable to ordinary refuelling, when only around one-third of the maximum capacity of the spent fuel pools is used. SSM also defined the event as commencing immediately after completed unloading of all fuel elements in connection with vessel inspection, just over six days after reactor shutdown.

Table 22 shows nuclides and total released activity to the atmosphere after approximately three days, and Table 23 shows a summary of the course of time as of the beginning of fuel damage to the release of radioactive materials.

Table 22. Nuclides and total released activity to the atmosphere after approximately three days in an event involving loss of cooling of spent fuel pools.

Release group	Nuclide	Total release (Bq)
Noble gases	Kr-85	3.0E+16
	Xe-131m	3.0E+16
	Xe-133	2.0E+18
	Xe-133m	1.5E+16
	Xe-135	6.1E+11
Halogens	I-129	1.0E+11
	I-130	2.0E+11
	I-131	1.3E+18
	I-132	5.5E+17
	I-133	3.3E+15
Alkali metals	Rb-86	3.3E+15
	Cs-134	5.1E+17
	Cs-136	7.9E+16
	Cs-137	3.7E+17
Tellurium group	Te-125m	4.2E+15
	Te-127	6.1E+16
	Te-127m	2.9E+16
	Te-129	7.3E+16
	Te-129m	1.1E+17
	Te-131	5.4E+14
	Te-131m	2.4E+15
	Te-132	4.4E+17
Ruthenium	Mo-99	5.0E+17
	Rh-103m	4.6E+12
	Rh-105	4.4E+10
	Ru-103	4.6E+12
	Ru-106	1.9E+12
	Tc-99m	4.9E+17

Table 23. Time course from the beginning of fuel damage to the release of radioactive materials in an event involving loss of cooling of spent fuel pools

Event	Time (hours)
Beginning of dryout of the fuel assembly	~42
Initial production of hydrogen	~55
Commencement of release	~56

6.2.3. Dispersion and dose calculations

This section presents tables illustrating the greatest distances at which dose criteria and intervention levels for different protective actions are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account. The tables also show an average value for the outcomes from the three NPPs for the respective percentile. All the outcomes are presented with two significant figures.

In the case of the events involving releases from spent fuel pools, SSM has not calculated distances at which threshold doses for severe deterministic effects were exceeded. However, calculations were performed for distances at which 1,000 mSv effective dose is exceeded. SSM wishes to emphasise that the distances calculated in this way can both overestimate and underestimate the distances where different severe deterministic effects may occur. Consequently, these calculation outcomes can only provide an indication of the distances within which severe deterministic effects might occur [21]. Table 24 shows the outcomes for the event involving loss of cooling.

Table 24. The greatest distances at which 1,000 mSv effective dose is exceeded for the event involving loss of cooling of spent fuel pools if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	6.3	3.3	12	7.1
80	14	6.1	17	12
90	22	17	24	21
		Children		
70	13	3.3	15	11
80	17	12	20	16
90	24	20	29	24

SSM used the respective dose criterion of 20 mSv and 100 mSv effective dose in order to define the approximate distances at which evacuation should be pre-planned. Table 25 shows the outcomes in the case of loss of cooling in relation to the dose criterion 100 mSv effective dose. The dose criterion 20 mSv effective dose is exceeded at distances greater than 500 km, i.e. the maximum distance in these calculations, even if only 70 per cent of all occurring weather scenarios are taken into account. For this reason, no outcomes are presented for this dose criterion.

Table 25. The greatest distances at which the dose criterion of 100 mSv effective dose is exceeded in the event involving loss of cooling of spent fuel pools if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	85	100	100	100
80	120	130	130	130
90	200	190	170	190
		Children		
70	100	120	120	110
80	140	150	140	140
90	220	200	190	200

SSM used the dose criterion 10 mSv effective dose in order to define the approximate distances at which sheltering should be pre-planned. The dose criterion is exceeded at distances greater than 500 km, i.e. the maximum distance in these calculations, even if only 70 per cent of all occurring weather scenarios are taken into account. For this reason, no outcomes are presented for this dose criterion.

SSM used the dose criterion 50 mSv equivalent dose to the thyroid for the purpose of defining approximate distances at which intake of iodine tablets may be warranted. The dose criterion is exceeded at distances greater than 500 km, in other words the maximum distance in these calculations, even if only 70 per cent of all occurring weather scenarios are taken into account. For this reason, no outcomes are presented for this dose criterion.

SSM used the intervention level 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 for the purpose of defining approximate distances at which relocation due to ground deposition should be pre-planned. The intervention level is exceeded at distances greater than 500 km, i.e. the maximum distance in these calculations, even if only 70 per cent of all occurring weather scenarios are taken into account. For this reason, no outcomes are presented for this dose criterion.

In the analysed releases from the spent fuel pools, an additional intervention level of 10,000 kBq/m^2 was added for the total of Cs-134 and Cs-137. This is equivalent to an additional dose of 100 mSv effective dose over the course of one year due to ground deposition. Table 26 shows the greatest distances at which the intervention level for the event involving a loss of cooling to the spent fuel pools is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Table 26. The greatest distances at which the intervention level 10,000 kBq/m^2 for the total of Cs-134 and Cs-137 is exceeded for the event involving a loss of cooling if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
70	360	130	290	260
80	440	230	370	350
90	>500	350	463	-[1]

[1] No average value can be computed since the geographical domain of the calculation is surpassed in the case of the Forsmark NPP.

6.2.4. Analysis

For the event loss of cooling of spent fuel pools, precautionary evacuation in the expected direction of the wind of the nearest 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 implementing the emergency preparedness planning proposed by SSM.

In the event loss of cooling of spent fuel pools, evacuating distances beyond 100 km in the expected direction of the wind 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 capacity 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, relocation due to ground deposition may be warranted at distances greater than 500 km. SSM’s proposals would imply pre-planning of relocation 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.

In the event involving loss of cooling of spent fuel pools, sheltering 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 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.

In 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.

6.3. Events involving simultaneous releases from several reactors

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 of Forsmark, Oskarshamn and Ringhals, where the releases take place simultaneously from one, two or three reactors on the part of these 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.

6.3.1. Events and representative source terms

SSM performed the sensitivity study regarding simultaneous releases from several reactors at an NPP. In this study, the dose criteria for different protective actions were divided by two and three, respectively. The greatest distances for different protective actions, which are calculated this way, will apply to releases of magnitudes two to three times greater than compared with a release from one nuclear power reactor. This is because the radiation dose at a particular point is proportional in relation to release magnitude. Consequently, there was no need to define new events or produce new representative source terms in order to perform the sensitivity analysis.

6.3.2. Dispersion and dose calculations

This section presents tables illustrating the greatest distances at which dose criteria and intervention levels for different protective actions are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account. The tables also show an average value for the outcomes for the three NPPs for the respective percentile. All the outcomes are presented with two significant figures.

In the cases involving simultaneous releases from one, two or three reactors, SSM did not calculate distances at which threshold doses for severe deterministic effects are exceeded. However, calculations were performed for distances at which 1,000 mSv effective dose is exceeded. SSM wishes to emphasise that the distances calculated in this way can both overestimate and underestimate the distances where different severe deterministic effects may occur. Consequently, these calculation outcomes can only provide an indication of the distances within which severe deterministic effects might occur [21]. Table 27 shows outcomes in connection with releases from one, two or three reactors in the case of the postulated event without functioning mitigation systems, and in Table 28, the corresponding outcomes are shown in the case of the postulated event with functioning mitigation systems.

Table 27. The greatest distances at which 1,000 mSv effective dose is exceeded in the case of the postulated event without functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1 reactor (km)	2 reactors (km)	3 reactors (km)
	Adults		
70	2.0	3.3	4.6
80	2.6	4.4	7.0
90	4.0	7.3	11
	Children		
70	3.1	4.8	7.4
80	4.2	6.7	10
90	6.0	11	16

Table 28. The greatest distances at which 1,000 mSv effective dose is exceeded in the case of the postulated event with functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1 reactor (km)	2 reactors (km)	3 reactors (km)
	Adults		
70	0.1	0.3	0.6
80	0.2	0.4	0.6
90	0.3	0.5	0.8
	Children		
70	0.1	0.4	0.6
80	0.2	0.4	0.6
90	0.3	0.6	0.8

SSM used the respective dose criterion of 20 mSv and 100 mSv effective dose in order to define the approximate distances at which evacuation should be pre-planned. Table 29 and Table 30 show the respective outcomes in connection with releases from one, two and three reactors in the case of the postulated event without functioning mitigation systems in relation to the respective dose criterion of 100 mSv and 20 mSv effective dose. Table 31 and Table 32 show the corresponding outcomes in the case of the postulated event with functioning mitigation systems.

Table 29. The greatest distances at which the dose criterion 100 mSv effective dose is exceeded in the case of the postulated event without functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	**1 reactor (km)**	**2 reactors (km)**	**3 reactors (km)**
		Adults	
70	17	23	33
80	22	33	43
90	32	45	67
		Children	
70	22	33	45
80	29	43	59
90	40	60	84

Table 30. The greatest distances at which the dose criterion 20 mSv effective dose is exceeded in the case of the postulated event without functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	**1 reactor (km)**	**2 reactors (km)**	**3 reactors (km)**
		Adults	
70	54	100	130
80	75	130	160
90	100	180	240
		Children	
70	75	120	150
80	94	150	190
90	120	200	270

Table 31. The greatest distances at which the dose criterion 100 mSv effective dose is exceeded in the case of the postulated event with functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1 reactor (km)	2 reactors (km)	3 reactors (km)
	Adults		
70	1.4	2.3	2.7
80	1.7	2.7	3.5
90	2.1	3.9	4.9
	Children		
70	1.5	2.4	2.9
80	1.8	2.9	3.7
90	2.2	4.1	5.3

Table 32. The greatest distances at which the dose criterion 20 mSv effective dose is exceeded in the case of the postulated event with functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1 reactor (km)	2 reactors (km)	3 reactors (km)
	Adults		
70	4.3	6.7	10
80	5.4	9.2	13
90	7.9	15	20
	Children		
70	4.5	7.3	10
80	5.6	9.6	14
90	8.5	16	21

SSM used the dose criterion 10 mSv effective dose in order to define the approximate distances at which sheltering should be pre-planned. Table 33 and Table 34 show the respective outcomes in connection with releases from one, two and three reactors in the case of these postulated events: without, and with, functioning mitigation systems.

Table 33. The greatest distances at which the dose criterion 10 mSv effective dose is exceeded in the case of the postulated event without functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1 reactor (km)	2 reactors (km)	3 reactors (km)
Adults			
70	100	150	200
80	130	200	260
90	180	280	340
Children			
70	120	180	230
80	150	240	290
90	200	310	360

Table 34. The greatest distances at which the dose criterion 10 mSv effective dose is exceeded in the case of the postulated event with functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1 reactor (km)	2 reactors (km)	3 reactors (km)
Adults			
70	6.7	13	18
80	9.2	17	22
90	15	24	32
Children			
70	7.3	13	18
80	9.6	18	24
90	16	25	33

6.3.3. Analysis

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 located 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.

6.4. Event involving well-functioning mitigation systems

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 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: the Forsmark, Oskarshamn and Ringhals plants. 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.

6.4.1. Event

One event with mitigation systems that perform well was taken into account in the sensitivity analysis:

- **An event with well-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 completely.

Not only this event, but also the postulated events, are based on the postulated event in the case of the design sequence described in the safety analysis report (SAR) produced by the NPPs [1]. However, sprinkling may be credited following a realistic period of time, while at the same time, the filtered containment venting system is assumed to function as demonstrated by validated experiments. Other realistic assumptions have also been credited, for instance relating to residual heat.

6.4.2. Representative source term

The representative source term for the event involving well-functioning mitigation systems was developed in accordance with the same method as for the representative source terms for the two postulated events, see Chapter 3. Using the same approach as for the postulated events, SSM assumes that the release is ongoing over a period of 48 hours in the event with well-functioning mitigation systems. Table 35 illustrates total released activity to the atmosphere per nuclide for the event involving well-functioning mitigation systems. For the sake of comparison, one column shows total released activity to the atmosphere per nuclide for the postulated event with functioning mitigation systems.

SSM applied the same line of reasoning to the composition of iodine forms contained in the release defined in the event with well-functioning mitigation systems, as taken into account for the two postulated events, see section 3.3.2. For this event, SSM nevertheless made the assumption that the composition of iodine forms in the reactor containment corresponds to the realistic scenario accounted for in a report from Vattenfall AB [14]. This means that the composition of iodine forms in the representative source terms is postulated as shown in Table 36.

SSM has assumed in its calculations for the sensitivity analysis involving well-functioning mitigation systems that the release height corresponds to the height of the stack for the filtered containment venting system, i.e. 27 m in the case of the NPPs of Oskarshamn and Forsmark, in addition to 48 m in the case of the Ringhals NPP. Furthermore, using the same approach as for both the postulated events, SSM has set the heat content of the release at zero. Lastly, SSM set the briefest feasible period of forewarning at 27 hours, based on outcomes of calculated release sequences using MELCOR in the case of reactor 4 at the Ringhals NPP.

Table 35. Total released activity to the atmosphere per nuclide for the events involving well-functioning and functioning mitigation systems.

Release group	Nuclide	Well-functioning mitigation systems (Bq)	Functioning mitigation systems (Bq)
Noble gases	Kr-85m	6.6E+15	1.7E+17
	Kr-87	2.0E+11	2.2E+16
	Kr-88	1.4E+15	2.4E+17
	Xe-133	5.1E+18	5.4E+18
	Xe-133m	1.5E+17	1.7E+17
	Xe-135	9.5E+17	2.2E+18
	Xe-135m	3.8E+16	3.4E+17
Halogens	I-130	1.8E+12	1.2E+13
	I-131	4.4E+14	1.2E+15
	I-132	5.4E+14	1.6E+15
	I-133	3.6E+14	1.6E+15
	I-134	6.5E+05	5.7E+12
	I-135	3.7E+13	6.1E+14
Alkali metals	Rb-88	1.1E+09	2.9E+13
	Cs-134	7.8E+12	1.1E+14
	Cs-136	1.7E+12	2.4E+13
	Cs-137	5.6E+12	7.8E+13
Tellurium group	Sb-127	1.3E+09	1.4E+12
	Te-127m	1.0E+10	5.5E+12
	Te-129m	4.6E+10	2.5E+13
	Te-131m	7.0E+10	6.2E+13
	Te-132	8.2E+11	5.3E+14
Ba and Sr	Sr-89	2.2E+09	1.9E+12
	Sr-90	2.2E+08	1.8E+11
	Ba-140	3.9E+09	3.4E+12
Noble metals	Mo-99	9.6E+03	4.2E+12
	Tc-99m	9.3E+03	4.0E+12
Lanthanides	Cm-242	2.0E+05	3.5E+08
	Cm-244	2.6E+04	4.6E+07

Table 36. Composition of iodine forms in the reactor containment and a release in the event with well-functioning mitigation systems ('DF' denotes decontamination factor).

Iodine forms	Reactor containment (%)	Release (%)
Well-functioning mitigation systems (Oskarshamn and Forsmark, DF500)		
Organic	0.01	4.76
Elemental	4.99	4.76
Particulate	95	90.48
Well-functioning mitigation systems (Ringhals, DF1500)		
Organic	0.01	13.04
Elemental	4.99	4.34
Particulate	95	82.62

6.4.3. Dispersion and dose calculations

This section presents tables illustrating the greatest distances at which dose criteria and intervention levels for different protective actions are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account. The tables also show an average value for the outcomes from the three NPPs for the respective percentile. All the outcomes are presented with two significant figures.

In the case of the event with well-functioning mitigation systems, SSM did not calculate distances at which threshold doses for severe deterministic effects are exceeded. However, SSM has calculated distances at which 1,000 mSv effective dose is exceeded. SSM wishes to emphasise that the distances calculated in this way can both overestimate and underestimate distances where different severe deterministic effects may occur. Consequently, these calculation outcomes can only provide an indication of the distances within which severe deterministic effects might occur [21]. The outcomes show that 1,000 mSv effective dose is not exceeded outside the fenced off areas surrounding the NPPs (i.e. 500 m from the outlet point) on the part of neither adults or children, even if 90 per cent of all occurring weather scenarios are taken into account.

SSM used the respective dose criterion of 20 mSv and 100 mSv effective dose in order to define approximate distances at which evacuation should be pre-planned. Table 37 and Table 38 show outcomes for these dose criteria for the event with well-functioning mitigation systems.

Table 37. The greatest distances at which the dose criterion 20 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	2.5	1.9	1.8	2.1
80	2.8	2.3	2.2	2.4
90	3.8	3.2	2.9	3.3
		Children		
70	2.5	2.0	1.8	2.1
80	2.9	2.5	2.3	2.6
90	4.0	3.5	3.1	3.5

Table 38. The greatest distances at which the dose criterion 100 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	0.7	0.5	0.5	0.6
80	0.8	0.7	0.7	0.7
90	1.1	0.7	0.8	0.9
		Children		
70	0.8	0.5	0.6	0.6
80	0.8	0.7	0.7	0.7
90	1.2	0.7	0.8	0.9

SSM used the intervention level of 2,000 kBq/m^2 for the total of Cs-134 and Cs-137 for the purpose of defining approximate distances at which relocation due to ground deposition should be pre-planned. In the event with well-functioning mitigation systems, this intervention level is not exceeded, even if 90 per cent of all occurring weather scenarios are taken into account.

SSM used the dose criterion 10 mSv effective dose in order to define approximate distances at which sheltering should be pre-planned. Table 39 shows the outcomes for this dose criterion in relation to the event with well-functioning mitigation systems.

Table 39. The greatest distances at which the dose criterion 10 mSv effective dose is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	3.2	3.0	2.7	3.0
80	4.2	3.7	3.5	3.8
90	6.4	4.9	5.1	5.5
		Children		
70	3.3	3.3	2.9	3.2
80	4.4	4.0	3.7	4.0
90	6.8	5.0	5.3	5.7

SSM used the dose criterion 50 mSv equivalent dose to the thyroid for the purpose of defining approximate distances at which intake of iodine tablets may be warranted. Table 40 shows the outcomes for this dose criterion in relation to the event with well-functioning mitigation systems. SSM also presents outcomes for the dose criterion 10 mSv equivalent dose to the thyroid on the part of children and pregnant women, as this can indicate the distances within which intake of predistributed iodine tablets is advisable, see Table 41.

Table 40. The greatest distances at which the dose criterion 50 mSv equivalent dose to the thyroid is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	1.7	1.0	1.0	1.2
80	2.3	1.2	1.2	1.6
90	2.5	1.6	1.3	1.8
		Children		
70	2.5	2.0	1.8	2.1
80	3.0	2.5	2.2	2.6
90	4.5	3.8	2.9	3.7

Table 41. The greatest distances at which the dose criterion 10 mSv equivalent dose to the thyroid on the part of children is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Children		
70	6.7	5.0	6.7	6.1
80	8.6	6.7	9.8	8.4
90	17	12	15	15

For the event with well-functioning mitigation systems, SSM also calculated the greatest distances at which the dose limit for the public, at 1 mSv effective dose, is exceeded; see Table 42.

Table 42. The greatest distances at which the dose limit for the public, at 1 mSv effective dose, is exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
		Adults		
70	19	15	20	18
80	24	22	25	23
90	34	34	38	35
		Children		
70	20	17	21	19
80	25	23	26	25
90	36	36	40	37

6.4.4. 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 relocated 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.

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 the event involving well-functioning mitigation systems.

7. 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 keep doses below the selected reference levels. In this chapter, SSM presents outcomes for 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.

7.1. Calculation of residual dose

As the starting points for developing the proposed ranges 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 nuclear or radiological emergency 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 response 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. out 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. 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.

7.2. Dispersion and dose calculations

In this section, SSM presents tables illustrating the greatest distances at which threshold doses for severe deterministic effects, in addition to dose criteria for protective actions, are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account, assuming sheltering in indoor locations offering various degrees of protection (shielding factors). These outcomes are presented in the form of average values for the three NPPs of Forsmark, Oskarshamn and Ringhals. All the outcomes are presented with two significant figures.

7.2.1. Severe deterministic effects

Table 43 shows distances at which threshold doses for severe deterministic effects are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event without functioning mitigation systems. Table 44 shows corresponding outcomes for the event with functioning mitigation systems. Threshold doses are not exceeded in the event involving well-functioning mitigation systems. Consequently, no outcomes are presented for this event.

Table 43. The greatest distances at which threshold doses for severe deterministic effects are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event without functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1,000 mGy red bone marrow, adults (km)	1,000 mGy red bone marrow children (km)	100 mGy, embryo (km)	300 mGy foetus (brain) (km)
70	0.9	0.7	3.8	1.5
80	1.1	0.8	5.0	1.9
90	1.4	1.1	7.4	2.9

Table 44. The greatest distances at which threshold doses for severe deterministic effects are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event with functioning mitigation systems if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	1,000 mGy red bone marrow, adults (km)	1,000 mGy red bone marrow children (km)	100 mGy, embryo (km)	300 mGy foetus (brain) (km)
70	-	-	0.6	-
80	-	-	0.7	0.3
90	-	-	1.0	0.4

7.2.2. Stochastic effects

Table 45 shows distances at which a selection of different effective doses are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event without functioning mitigation systems. Table 46 shows corresponding outcomes for the event with functioning mitigation systems. Table 47 illustrates outcomes for the event involving well-functioning mitigation systems. Table 48 also shows distances at which different effective doses are exceeded after seven days in connection with sheltering, using the shielding factor 0.1 for the event without functioning mitigation systems. SSM elected to only perform these calculations on the part of the postulated event without functioning mitigation systems, with the rationale that sheltering in premises offering better protection than a detached house is of main significance for this event.

Table 45. The greatest distances at which different effective doses are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event without functioning mitigation systems, if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	500 mSv (km)	100 mSv (km)	50 mSv (km)
	Adults		
70	2.0	8.6	17
80	2.6	12	22
90	4.0	17	32
	Children		
70	3.1	12	22
80	4.2	16	29
90	6.0	23	40

Table 46. The greatest distances at which different effective doses are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event with functioning mitigation systems, if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	20 mSv (km)	5 mSv (km)	2.5 mSv (km)
		Adults	
70	2.4	6.7	13
80	2.9	9.2	17
90	4.1	15	24
		Children	
70	2.5	7.3	13
80	3.1	9.6	18
90	4.3	16	25

Table 47. The greatest distances at which different effective doses are exceeded after seven days in connection with sheltering, using the shielding factor 0.5 for the event of the sensitivity analysis, with well-functioning mitigation systems, if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	5 mSv (km)	2.5 mSv (km)	0.5 mSv (km)
		Adults	
70	3.0	4.9	18
80	3.8	6.1	23
90	5.5	10	35
		Children	
70	3.2	5.0	19
80	4.0	6.1	25
90	5.7	11	37

Table 48. The greatest distances at which different effective doses are exceeded after seven days in connection with sheltering, using the shielding factor 0.1 for the event without functioning mitigation systems, if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account.

Percentile	100 mSv (km)	20 mSv (km)	10 mSv (km)
Adults			
70	2.0	8.6	17
80	2.6	12	22
90	4.0	17	32
Children			
70	3.1	12	22
80	4.2	16	29
90	6.0	23	40

7.3. Analysis

7.3.1. 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.

7.3.2. 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 in relation to 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 out 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 (to a distance of just over 15 km) that might be affected by the release are also evacuated 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 (to a distance of just over 10 km) that might be affected by the release are also evacuated 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 49.

Table 49. 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 (to a distance of just over 15 km) 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, 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 km 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 (to a distance of approximately 25 km) 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 50.

Table 50. 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 km 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.

8. 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 of the main report. 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. In this chapter, SSM presents tables illustrating the greatest distances at which different intervention levels for food production are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account. The tables show an average value of the outcomes from the three NPPs for the respective percentile. All the outcomes are presented with two significant figures. 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.

8.1. Dispersion calculations

Outcomes from dispersion calculations for intervention levels linked to drinking water from surface-water sources with a low level of dilution (depth of 0.5 metre) and high level of dilution (depth of 10 m), respectively, are shown in Table 51 and 52.

Table 51. The greatest distances at which intervention levels linked to drinking water from surface-water sources with a low level of dilution (depth of 0.5 m) are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
I-131: 100 kBq/m^2			
70	21	17	>500
80	30	33	>500
90	44	60	>500
Cs-137: 100 kBq/m^2			
70	0.5	3.3	>500
80	0.6	6.9	>500
90	0.8	14	>500
Sr-90: 10 kBq/m^2			
70	-	-	84
80	-	-	130
90	-	-	230
Cm-242: 10 kBq/m^2			
70	-	-	0.4
80	-	-	0.9
90	-	-	1.6

Table 52. The greatest distances at which intervention levels linked to drinking water from surface-water sources with a high level of dilution (depth of 10 m) are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
I-131: 1,000 kBq/m^2			
70	2.0	3.7	>500
80	3.1	6.0	>500
90	5.6	11	>500
Cs-137: 1,000 kBq/m^2			
70	-	0.6	100
80	-	0.8	140
90	-	1.3	230
Sr-90: 100 kBq/m^2			
70	-	-	7.6
80	-	-	13
90	-	-	25
Cm-242: 100 kBq/m^2			
70	-	-	0.4
80	-	-	0.9
90	-	-	1.6

Outcomes from the dispersion calculations for intervention levels linked to milk production are presented in Table 53.

Table 53. The greatest distances at which intervention levels linked to milk production are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
I-131: 5 kBq/m^2			
70	180	220	>500
80	240	290	>500
90	320	360	>500
Cs-134+Cs-136+Cs-137: 10 kBq/m^2			
70	7.4	110	>500
80	13	180	>500
90	24	280	>500
Sr-89+Sr-90: 10 kBq/m^2			
70	-	1.6	>500
80	-	2.0	>500
90	-	3.0	>500

Outcomes from dispersion calculations for intervention levels linked to production of the following meats: beef, lamb and reindeer; pork; and game (i.e. elk and venison); respectively, are presented in Table 54 to 56.

Table 54. The greatest distances at which intervention levels linked to production of beef, lamb and reindeer are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Cs-134+Cs-136+Cs-137: 1 kBq/m^2 (grazing and free-range grazing)			
70	80	>500	>500
80	120	>500	>500
90	210	>500	>500
Sr-89+Sr-90: 100 kBq/m^2 (grazing)			
70	-	-	91
80	-	-	150
90	-	-	250
Sr-89+Sr-90: 10 kBq/m^2 (free-range grazing)			
70	-	1.6	>500
80	-	2.0	>500
90	-	3.0	>500

Table 55. The greatest distances at which intervention levels linked to production of pork are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Cs-134+Cs-136+Cs-137: 10 kBq/m^2			
70	7.4	110	>500
80	13	180	>500
90	24	280	>500
Sr-89+Sr-90: 1,000 kBq/m^2			
70	-	-	8.2
80	-	-	15
90	-	-	28

Table 56. The greatest distances at which intervention levels linked to game (elk and venison) are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Cs-134+Cs-136+Cs-137: 10 kBq/m^2			
70	7.4	110	>500
80	13	180	>500
90	24	280	>500
Cs-134+Cs-136+Cs-137: 100 kBq/m^2			
70	1.1	12	>500
80	1.4	21	>500
90	2.2	36	>500

Table 57 to 59 show outcomes from dispersion calculations for intervention levels linked to grains, leafy vegetables and potatoes.

Table 57. The greatest distances at which intervention levels linked to grains are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Cs-134+Cs-136+Cs-137: 10 kBq/m^2			
70	7.4	110	>500
80	13	180	>500
90	24	280	>500
Sr-89+Sr-90: 10 kBq/m^2			
70	-	1.6	>500
80	-	2.0	>500
90	-	3.0	>500

Table 58. The greatest distances at which intervention levels linked to leafy vegetables are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Cs-134+Cs-136+Cs-137: 1 kBq/m^2			
70	80	>500	>500
80	120	>500	>500
90	210	>500	>500
Sr-89+Sr-90: 1 kBq/m^2			
70	-	12	>500
80	-	21	>500
90	-	35	>500

Table 59. The greatest distances at which intervention levels linked to potatoes are exceeded if 70, 80 and 90 per cent, respectively, of all occurring weather scenarios are taken into account (the intervention level is not exceeded when indicated by "-").

Percentile	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Cs-134+Cs-137: 1,000 kBq/m^2			
70	-	1.5	190
80	-	1.8	270
90	-	2.8	360
Sr-89+Sr-90: 100 kBq/m^2			
70	-	-	91
80	-	-	150
90	-	-	250

For a summary of outcomes from dispersion calculations, see Table 60. The distances are shown in the form of rounded average values for the three NPPs, on the part of these events: without functioning mitigation systems, with functioning systems, and with well-functioning mitigation systems. The respective distances take into account 90 per cent of all occurring weather scenarios.

Table 60. 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 when indicated by “-”).

Nuclide group	Well-functioning (km)	Functioning (km)	Non-functioning (km)
Drinking water from surface-water sources with a low level of dilution (depth of 0.5 m)			
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 (depth of 10 m)			
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

8.2. 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.

9. 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 of the main report. 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. In this chapter, SSM presents tables illustrating the greatest distances at which different intervention levels for remediation are exceeded if the respective 70, 80 and 90 per cent of all occurring weather scenarios are taken into account. The tables also show an average value of the outcomes from the three NPPs for the respective percentile. All the outcomes are presented with two significant figures. SSM used these calculation outcomes to analyse the need for remediation in connection with releases occurring in these three events.

9.1. Dispersion calculations

The outcomes from dispersion calculations for the postulated event without functioning mitigation systems are shown in Table 61. Table 62 represents the postulated event involving functioning mitigation systems. Table 63 represents the event of the sensitivity analysis, involving well-functioning mitigation systems.

Table 61. The greatest distances at which intervention levels for remediation are exceeded in the case of the postulated event without functioning mitigation systems if 70, 80 and 90 per cent, respectively, 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	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
100 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 1 mSv)				
70	>500	>500	>500	>500
80	>500	>500	>500	>500
90	>500	>500	>500	>500
500 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 5 mSv)				
70	350	150	280	260
80	430	240	350	340
90	470	350	450	420
1,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 10 mSv)				
70	240	140	200	190
80	330	210	260	270
90	430	300	350	360
2,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 20 mSv)				
70	110	100	130	120
80	180	150	170	170
90	300	240	250	260
5,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 50 mSv)				
70	33	33	53	39
80	60	61	83	68
90	110	110	120	110

Table 62. The greatest distances at which intervention levels for remediation are exceeded in the case of the postulated event with functioning mitigation systems if 70, 80 and 90 per cent, respectively, 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	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
100 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 1 mSv)				
70	9.6	6.6	15	10
80	19	13	25	19
90	30	27	41	33
500 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 5 mSv)				
70	2.5	1.9	1.8	2.1
80	3.4	3.0	2.7	3.0
90	6.2	4.8	7.9	6.3
1,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 10 mSv)				
70	2.0	1.2	1.2	1.5
80	2.4	1.6	1.5	1.8
90	3.4	2.6	2.5	2.8
2,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 20 mSv)				
70	0.8	0.7	0.5	0.7
80	1.3	0.8	0.8	1.0
90	2.1	1.2	1.4	1.6
5,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 50 mSv)				
70	-	-	-	-
80	-	-	-	-
90	-	-	-	-

Table 63. The greatest distances at which intervention levels for remediation are exceeded in the case of the event contained in the sensitivity analysis involving well-functioning mitigation systems if 70, 80 and 90 per cent, respectively, 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	Forsmark (km)	Oskarshamn (km)	Ringhals (km)	Average value (km)
100 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 1 mSv)				
70	1.2	0.8	0.8	0.9
80	1.6	1.1	1.2	1.3
90	2.5	1.6	1.8	2.0
500 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 5 mSv)				
70	-	-	-	-
80	-	-	-	-
90	-	-	-	-
1,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 10 mSv)				
70	-	-	-	-
80	-	-	-	-
90	-	-	-	-
2,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 20 mSv)				
70	-	-	-	-
80	-	-	-	-
90	-	-	-	-
5,000 kBq/m^2 for the total of Cs-134 and Cs-137 (additional dose 50 mSv)				
70	-	-	-	-
80	-	-	-	-
90	-	-	-	-

For a summary of outcomes from dispersion calculations, see Table 64. The distances 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 64. Summary of the greatest distances at which intervention levels for remediation are exceeded for different events if 70, 80 and 90 per cent, respectively, 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

9.2. 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 to approximately 350 km. The distance within which advanced remediation measures are likely to be warranted may extend to 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.

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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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