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Review of Swedish emergency planning zones and distances, Appendix 1

Reference levels, dose criteria and intervention levels

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Contents

1. Introduction

As part of the report “Review of Swedish emergency planning zones and distances”, this appendix presents the reference levels, dose criteria and intervention levels used in the project. These parameters constitute the main basis for dimensioning of the proposed emergency planning zones and distances. Another area covered is development of the shielding factors for sheltering.

Emergency planning zones and distances are geographical areas in Sweden that surround facilities belonging to emergency preparedness categories I and II. Within these zones and distances, pre-planned protective actions for the public are required. Here, a protective action refers to a measure taken to reduce ongoing or potential human exposure to radiation. The main protective actions, for which planning should be in place within the proposed emergency planning zones and distances, are evacuation, sheltering, iodine thyroid blocking and relocation. Pre-planned protective actions have the purpose of keeping residual doses below the selected reference level for the event or events serving as the basis of the emergency planning zones and distances.

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

2. Reference levels

2.1. Background

One of the biggest changes brought about through the EU's new radiation safety directive [1] is that radiation protection will now be based on exposure situations instead of activities and intervention, as was previously the case. This change is in line with recommendations issued by the International Commission on Radiological Protection (ICRP) in 2007 in ICRP 103 [2]. The radiation safety directive, Council Directive 2013/59/Euratom of 5 December 2013, defines three types of exposure situation: planned exposure situations, existing exposure situations, and emergency exposure situations. The intent is to have all situations which imply, or which might imply, exposure to ionising radiation classified into one of these exposure situations.

Planned exposure situations are circumstances in which protective actions may be pre-planned before cases of exposure, and where the magnitude and extent of the exposure may be predicted with reasonable accuracy. Examples of planned exposure situations include operations that take place at nuclear power plants, and radiation treatment at hospitals. Existing exposure situations are circumstances that already exist when a decision on controlling them needs to be made. Examples of existing exposure situations include public exposure to radon and public exposure to radioactive materials spread into the surroundings in connection with a nuclear power accident, after the nuclear emergency has been terminated. A nuclear or radiological emergency refers to a sudden event involving a source of radioactivity, which has brought about or risks resulting in detriment, thus requiring immediate action. One example of an event that resulted in a nuclear emergency is the nuclear power accident of Fukushima Daiichi, which occurred in 2011.

The rationale behind the ICRP's change of radiation protection system is that the principles regarding justification and optimisation are successful tools for reducing radiation doses in activities involving ionising radiation. Consequently, the principles should be applied to all situations in which exposure to ionising radiation might occur. First and foremost, the ICRP is of the view that an increased focus on optimisation instead of intervention can improve the protection against radiation in existing exposure situations and during nuclear or radiological emergencies.

During planned exposure situations, dose constraints should be applied as an optimisation tool. For existing exposure situations and emergency exposure situations, the ICRP has instead introduced the concept of reference levels as a tool for optimisation. The ICRP has elected to introduce this new concept instead of the existing concept of dose constraints. The purpose is to emphasise the difference between optimisation work as part of planned exposure situations on the one hand, and optimisation work in existing exposure situations and emergency exposure situations on the other hand. In planned exposure situations, individual radiation doses may be estimated with a high level of accuracy to almost always keep doses below the dose constraints. In contrast, however, in cases of existing exposure situations and emergency exposure situations, it is not possible (or feasible) to conduct planning to take into account all potentially occurring individual radiation doses. In these cases, the reference level may be viewed as a target in the planning work. The ICRP emphasises that an emergency response plan should be revised if it fails to result in keeping residual doses below the selected reference level during the planning phase for an emergency exposure situation. When an emergency exposure situation occurs, the reference level should instead be viewed as a guideline, where optimisation should initially focus on the individuals or segments of the population that risk exposure exceeding the reference level, for subsequent continuation below this reference level.

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

2.2. Proposed reference levels

SSM has used the reference level 100 mSv annual effective dose as a basis for developing the proposed new emergency planning zones and emergency planning distances for the following: the postulated event at a nuclear power plant corresponding to a severe accident involving core melt, vessel melt-through and a release, where the mitigation systems fail to function and where the reactor containment is not leak tight. In the case of all the other postulated events, SSM has instead used the reference level 20 mSv annual effective dose as a basis for developing the proposed new emergency planning zones and distances.

A reference level of 20 mSv effective dose for the public is in line with the level of ambition for workers in connection with emergency exposure situations. The radiation safety directive stipulates that the value of the dose limit for workers, at 20 mSv effective dose over the course of one year, should if possible not be exceeded even during emergency exposure situations. This ambition also encompasses workers, for instance within rescue, police and emergency medical services, who would in all likelihood not be exposed to ionising radiation while on duty working with the radiological emergency, either before or after the emergency exposure situation. As far as concerns the population in the proximity of the relevant facilities, SSM is of the view that the target for radiation protection in corresponding situations should at least have the same level of ambition. What's more, the reference level of 20 mSv annual effective dose is in line with the agreement of 2013 reached between the Nordic countries concerning shared guidelines for protective actions in nuclear or radiological emergencies [3]. Consequently, SSM is of the view that, to the extent that it is feasible, the reference level of 20 mSv effective dose should be applied to the postulated events serving as the basis of the proposed new emergency planning zones and distances in Sweden.

In the case of the postulated event at a nuclear power plant corresponding to a severe accident involving core melt, vessel melt-through and a release, where the mitigation systems fail to function and where the reactor containment is not leak tight, SSM applied the reference level 100 mSv annual effective dose as a basis for developing the proposed new emergency planning zones and distances. This event corresponds to a conceivable worst-case scenario in terms of release magnitude from a nuclear power reactor. This kind of event is deemed as so unlikely that it does not need to be taken into account when designing mitigation systems at nuclear power plants, according to a government decision of 1986 [4]. Consequently, as this kind of event does not presuppose additional mitigation systems, it is inappropriate to apply the reference level of 20 mSv effective dose as a basis for emergency preparedness planning. The cost of sustaining this kind of emergency preparedness would become very high at the same time as the probability is low of carrying out successful evacuation of the large areas that would then be encompassed.

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

3. Dose criteria and intervention levels

3.1. Dose criteria for protective actions

A dose criterion for a protective action is defined as the value of a dose to an individual, without taking into consideration protective actions, which when the criterion is exceeded or risks being exceeded, usually implies that the protective action is warranted. A dose criterion is defined for each separate protective action. Dose criteria are selected so that the total dose is to remain below the selected reference level provided that protective actions are taken when the respective dose criterion has been exceeded. Thus, different reference levels result in different dose criteria. Dose criteria are mainly used to define needed protective measures prior to, or in connection with, an external release of radioactive materials, in a case where radioactive materials may still be airborne and for which several different exposure pathways are possible.

Dose criteria refer to effective, equivalent or absorbed dose received by an unprotected human exposed to ionising radiation during a given period of time. Calculations of the dose contribution from external exposure include dose from the passing cloud and from ground deposition. Calculations of the dose contribution from internal exposure include committed dose from inhalation of radioactive materials contained in the cloud. Internal dose from radioactive materials that have become airborne from the ground (called 'resuspension') is not taken into account when selecting the dose criteria, as this gives a negligible contribution to total effective dose on the part of the events for which the dose criteria will be used. Nor is internal dose from intake of radioactive materials through foodstuffs taken into account when selecting the dose criteria. This is because foodstuff restrictions and inspection controls are expected to limit the dose contribution from this exposure pathway to below 1 mSv effective dose per year.

Dose criteria have been defined for the respective protective action taken on the basis of the conditions at the facility, or based on a dispersion calculation for the release. The dose criteria were produced using the integrated dose over a period of seven days, starting with the release sequence and subsequently including the dose contributions throughout the duration of the passing cloud, even during prolonged release sequences.

Dose criteria for the protective actions of evacuation, sheltering and iodine thyroid blocking are defined for both adults and children, where children are represented by the age group one-year-olds. Children are more sensitive to exposure to ionising radiation than adults, warranting separate calculation of radiation doses for adults and children. The reason why all children are represented by the age group one-year-olds is because this age group is the most sensitive age group among children[1]. When it comes to the protective action comprising iodine thyroid blocking, the dose criterion also encompasses pregnant women, with the aim of protecting the foetus.

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

3.2. Intervention levels

An intervention level is a value of a measurable quantity associated with a certain protective action which, when the level is exceeded or likely to be exceeded, implies that the protective action should in most cases be taken. Thus, intervention levels are defined for the protective actions which above all are taken based on measurement data. The intervention levels refer to deposited activity per surface unit on the ground comprising a certain nuclide, and are stated as kilobecquerels per square metre (kBq/m^2). The intervention levels only serve to provide guidance as they, in contrast to dose criteria, only take into account a particular exposure pathway. As the intervention levels relate to measured levels of ground deposition, they may require adaptation to the prevailing situation. This means that it may also be appropriate to take protective actions in connection with higher or lower levels. In some cases, it may be appropriate to take protective actions at lower intervention levels for purposes of optimisation if the protective action in itself is anticipated to give a limited negative impact. All intervention levels derived by SSM have the aim of reducing the risk of stochastic effects owing to ionising radiation.

4. Shielding factors for sheltering

The shielding factor refers to the ratio between indoor radiation dose in a protected space and outdoor radiation dose without any protection, for the same location and having the same period of exposure. This means that the lower the shielding factor, the better the protection provided. A literature study conducted by SSM has shown that the shielding factor can show great variability depending on the type of building, building materials used, the type of ventilation, and particle size in relation to the radioactive materials contained in the release [5] [6] [7] [8] [9] [10].

A multi-residence dwelling would offer good protection against external exposure to a radioactive cloud and to the ground, mainly because the building materials give a relatively high level of shielding from the radiation. Ventilation that is weak or switched off, thus giving a low level of air circulation, provides good protection against internal exposure due to inhalation since this reduces the quantity of radioactive materials entering the building. Larger particle size of the radioactive materials provides better protection against internal exposure due to inhalation since larger particles will be filtered out to a greater extent and because they have a greater tendency to settle on different surfaces.

4.1. Shielding factors while the radioactive cloud passes

SSM has used shielding factors in connection with a radioactive cloud to study radiation doses received, assuming that the protective action of sheltering has been implemented in connection with a release of radioactive materials. In connection with sheltering while the radioactive cloud passes, radiation doses are received in the form of external exposure to radioactive materials in the air and on the ground, as well as through internal exposure to radioactive materials in the indoor air. In the case of recommended sheltering in connection with accidents, it is reasonable to assume 100 per cent sheltering; thus, this applies throughout the duration of the release.

In Table 1, SSM has defined reasonably conservative values for the shielding factors in relation to the different exposure pathways. In the case of internal exposure through inhalation, the shielding factor is based on detached houses having natural ventilation with a relatively low air change rate. The corresponding shielding factor for multi-residence dwellings is defined within an interval since different types of ventilation system and any ventilation filters give substantial differences in their protection.

Table 1. Shielding factors for buildings in the case of different exposure pathways in connection with a radioactive cloud.

Exposure pathway	**Shielding factor**	
	Detached house	Multi-residence dwelling
External exposure to ground deposition	0.4	0.04
External exposure to radioactive cloud	0.7	0.1
Internal exposure from inhalation	0.5	0.1 – 0.5

Based on the values shown in Table 1, SSM has elected to apply a total shielding factor of 0.5 for sheltering in a detached house, and 0.1 for sheltering in a multi-residence dwelling or inside other premises giving broader protection in the case of the protective action of sheltering from the radioactive cloud.

When producing intervention levels and performing estimates of residual radiation dose, i.e. the dose following protective actions, SSM mainly focused on residents of detached houses due to this possibly leading to higher doses than doses received by residents of multi-residence dwellings. Thus, this is deemed to serve as a more accurate representation of the protection provided by sheltering for a more vulnerable segment of the population.

4.2. Shielding factors for ground deposition

SSM elected to use a shielding factor of 0.5 for sheltering in a detached house and 0.25 for sheltering in a multi-residence dwelling for defining the intervention levels for evacuation and remediation in the case of ground deposition of radioactive materials having a relatively long half-life.

These shielding factors apply to a long-term stay in an area having a ground deposition of radioactive materials, and were calculated assuming an 80 per cent indoor stay with the respective shielding factors 0.4 and 0.04, as shown by Table 1, and 20 per cent outdoor stay without a shielding factor.

A study conducted in Japan [11], based on data collected between 5 and 51 months after the nuclear power accident of Fukushima Daiichi, shows that 0.5 is a reasonably conservative value for the shielding factor in connection with a ground deposition of caesium. The study, conducted in Date City, north-west of Fukushima Daiichi, showed that the average value of the shielding factor was 0.15 and that the shielding factor was below 0.5 for approximately 95 per cent of the population.

5. Dose criteria and intervention levels for evacuation and relocation

This chapter describes selection of dose criteria and intervention levels for the protective actions of evacuation and relocation. The dose criteria and intervention levels are presented in the three subsections below, categorised by the purpose and area of application.

5.1. Dose criteria for precautionary evacuation

The highest priority objective for radiation protection during an emergency exposure situation is to avoid severe deterministic effects. To meet this objective, SSM suggests establishment of a PAZ to surround facilities belonging to emergency preparedness category I. It is only at these facilities where severe deterministic effects can occur outside the respective site. Within the PAZ, evacuation should be possible to implement as a precaution, based on the conditions at the facility, and before an external release of radioactive materials has occurred.

Dose criteria for precautionary evacuation are based on threshold doses for severe deterministic effects, as defined by the ICRP [2]. Threshold doses, which refer to absorbed dose to an organ, imply an increased incidence of severe deterministic effects among those receiving radiation doses exceeding this level. For both adults and children, the limiting organ dose is absorbed dose to red bone marrow. Embryos and foetuses are particularly sensitive to exposure to ionising radiation during certain periods of development, for which reason separate dose criteria are needed for embryos and foetuses. The limiting doses are absorbed dose to an embryo during the period of organ development, in addition to absorbed dose to the brain of a foetus during this critical development period. Table 2 illustrates dose criteria in the form of threshold doses for the protective action of precautionary evacuation. The PAZ is dimensioned based on the defined threshold doses, which comprise total absorbed dose from external exposure and committed absorbed dose from inhalation.

Table 2. Threshold doses defined by the ICRP [2] for protective actions to avoid severe deterministic effects.

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

5.2. Dose criteria for evacuation

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

The dose criteria applying to the protective action of evacuation refer to total effective dose from external exposure and committed effective dose from internal exposure. An evacuation carried out as planned would halt human exposure to ionising radiation. Consequently, the dose criteria for evacuation are set at the same level as the reference levels. Thus, the dose criterion for the protective action of evacuation is 20 mSv effective dose to both adults and children for all events, with the exception of the postulated event without functioning mitigation systems, as described in more detail in the main report. For this event, the dose criterion is 100 mSv effective dose. These dose criteria are the main basis for determining the approximate range of the UPZ to surround Swedish nuclear power plants.

5.3. Intervention levels for relocation due to ground deposition

Intervention levels for the protective action of relocation due to ground deposition have been developed for the purpose of limiting the effective dose from external exposure due to ground deposition over the longer term. They were developed for nuclides with a relatively long half-life and are set in order to limit the effective dose to 20 mSv from these nuclides during the first year. Based on radiation measurement outcomes from areas where the intervention level has been exceeded, relocation should be considered. Intervention levels for the protective action of relocation have been used for determining the range of the EPDs within which it should be possible to perform radiation measurements within one week.

When rescue services are terminated following an emergency, this is also when the emergency exposure situation ceases. If the event has led to a release of radioactive materials giving rise to long-term exposure, the emergency exposure situation transitions into an existing exposure situation. Under the radiation safety directive, the reference level for an existing exposure situation is not allowed to be set higher than 20 mSv effective dose over the course of one year. Consequently, identification of affected areas and carrying out relocation of people in the areas in which ground deposition can give an effective dose exceeding 20 mSv during the first year are requisite actions for terminating the nuclear or radiological emergency.

Table 3shows the intervention levels that indicate when relocation may need to be considered due to ground deposition. Each intervention level has been calculated using the shielding factor 0.5, which is based on an assumption of residency in a detached house in combination with an assumption of the population staying indoors 80 per cent of the time. Another assumption is that the radioactive materials are evenly distributed on the ground in the uppermost centimetre of a layer of soil having a density of 1.6 g/cm^3.

In the case of events involving releases from nuclear power plants, radiation doses in the longer term (after one month or more) will mainly be received from decay of the nuclides Cs-134 and Cs-137. The intervention level for releases from the nuclear power plants shown in Table 3 refers to total activity for these nuclides, where the activity relation between these nuclides is the same as in the representative source terms for events at nuclear power plants.

The postulated events at Clab, the central interim storage facility for spent nuclear fuel, may give rise to ground deposition of Cs-134 and Cs-137, though also significant ground deposition of Co-60. The intervention levels for Cs-134 + Cs-137 differ between releases from a nuclear power plant and from Clab. Here, the root cause is that Clab's nuclear fuel is assumed as older in the analysed events, which gives differences in the activity relation between these nuclides. As Cs-134 and Cs-137 have different dose conversion factors, the intervention levels also differ. More details on this topic are presented in the facility-specific accounts contained in the main report.

Events at the fuel fabrication plant in Västerås cannot give rise to a significant ground deposition of long-lived, gamma-emitting nuclides which warrants relocation due to hazards of external exposure. Thus, for this facility, no intervention levels are provided for relocation.

Table 3. Intervention levels for relocation where external exposure from ground deposition comprising selected nuclides could give rise to an effective dose of 20 mSv during the first year.

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

6. Dose criteria for sheltering

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

According to the Nordic agreement from 2013 regarding shared Nordic guidelines for protective actions in early and intermediate phases of a nuclear or radiological emergency [3], also in accordance with the principles for optimisation in emergency exposure situations, protective actions should be considered even in cases where the event is not anticipated to lead to radiation doses exceeding the selected reference level. Nordic radiation safety authorities are in agreement on the general suitability of taking protective actions if the projected effective dose is expected to exceed 10 mSv. For this reason, SSM has set the dose criterion for sheltering at 10 mSv effective dose.

The dose criterion applying to sheltering refers to total effective dose from external exposure and committed effective dose from inhalation on the part of both adults and children. The aim is to reduce the risk of stochastic effects owing to ionising radiation.

7. Dose criteria for iodine thyroid blocking (ITB)

The thyroid gland is sensitive to radiation and accumulates radioactive iodine in connection with inhalation while the radioactive cloud passes. Intake of stable iodine prevents uptake of radioactive iodine in the thyroid. Intake of ITB is advisable before a radioactive release occurs. Consequently, this is a protective action that requires considerable planning to enable its implementation in practice, either in the form of predistributed ITB, or through urgent distribution of ITB during the nuclear or radiological emergency. The basis of planning for ITB is the dose criterion 50 mSv committed equivalent dose to the thyroid on the part of adults, children and pregnant women. This dose criterion has the aim of reducing the risk of stochastic effects owing to ionising radiation.

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

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

8. Intervention levels for food production

This chapter discusses intervention levels above which different protective actions in the food industry should be considered. In this context, the protective actions that may become applicable include measurement programmes and inspection controls, limiting intake by banning sale or by providing dietary advice, in addition to various kinds of countermeasures in the animal breeding and agricultural sectors in order to reduce plant and animal uptake of radioactive substances. Intervention levels are presented for the categories of drinking water, milk, meats, grains, leafy vegetables and potatoes. The levels' purpose is to limit committed effective dose from consumption of these foodstuffs. The intervention levels refer to a ground deposition (kBq/m^2) of selected nuclides and should be viewed as indicative as to when the activity concentration (Bq/kg) in foodstuffs might exceed the EU's maximum permitted levels of radioactive contamination of food and feed [12]. These limits, which are presented in Table 4, have the purpose of keeping the effective dose from intake of foodstuffs below 1 mSv during the first year.

Intervention levels for food production are subject to great uncertainty. The transfer factors from ground deposition to foodstuffs may be quite variable (for example, depending on the time of year), and are in several instances not fully known. Consequently, these intervention levels are indicated by an estimated value and are conservatively rounded down to the nearest tenth power. The values presented here apply to the initial period of time following radioactive fallout if this should occur during the growing season. The intervention levels for foodstuffs are both sourced from *Livsmedelsproduktion vid nedfall av radioaktiva ämnen* (Food production in the case of fallout of radioactive substances) [13] as well as estimates carried out by the Swedish Defence Research Agency [14].

Table 4. Maximum permitted levels of radioactive contamination of food under the Council Regulation [12].

Nuclide group/ foodstuff category	**Foodstuff (Bq/kg)**			
	Infant food	Dairy produce	Other food except minor food	Liquid food
Isotopes of strontium, notably Sr-90	75	125	750	125
Isotopes of iodine, notably I-131	150	500	2,000	500
Alpha-emitting isotopes of plutonium and transplutonium elements, notably Pu-239 and Am-241	1	20	80	20
All other nuclides of half-life greater than 10 days, notably Cs-134 and Cs-137	400	1,000	1,250	1,000

8.1. Intervention levels for drinking water

Intervention levels for drinking water refer to a level of ground deposition over, or in close proximity to, surface water recipients which might lead to excessive levels of radioactivity in drinking water. Groundwater resources are initially impacted to a very limited extent by radioactive fallout; consequently, this topic is not discussed here.

Table 5 shows indicative intervention levels for protective actions in production of drinking water by using a marker nuclide. If the ground deposition of the marker nuclide exceeds the intervention level, the activity from the total of all isotopes within the nuclide group risks exceeding the EU's maximum permitted levels for liquid food. Having been calculated on the part of two cases of vertical dilution, these intervention levels are subject to great uncertainty. Here, dilution refers to the depth in the surface water recipient at which the radioactive substances are diluted before the point in time at which the drinking water is produced.

Table 5. Intervention levels for radioactivity in drinking water from surface water recipients, computed assuming respective dilution depth of 0.5 m and 10 m vertical dilution above the raw water intake.

Marker nuclide*	**Nuclide group**	**Intervention level** (kBq/m^2)
Cs-137	Nuclides with a half-life of more than 10 days	100 (0.5 m dilution) 1,000 (10 m dilution)
I-131	I-131, Te-132, I-132, I-133	100 (0.5 m dilution) 1,000 (10 m dilution)
Sr-90	Sr-89, Sr-90, Y-90	10 (0.5 m dilution) 100 (10 m dilution)
Cm-242	Pu-238, Pu-239, Pu-240, Cm-242, Cm-244	10 (0.5 m dilution) 100 (10 m dilution)

*A ground deposition of the marker nuclide in accordance with the levels in the table might lead to exceeding the EU's maximum permitted levels for the sale of liquid food on the part of the entire nuclide group.

8.2. Intervention levels for milk production

Table **6** shows intervention levels for milk production. These intervention levels refer to a level of ground deposition on pasture land that might lead to exceeding the EU's maximum permitted levels for foodstuffs in the case of milk. During the early phase following a nuclear power plant accident (from the first few days to weeks), the iodine isotope I-131 is limiting for these interventions. One measure that may be considered is to keep cows in stalls.

Table 6. Intervention levels for milk production.

Nuclides	**Intervention level** (kBq/m^2)
Cs-134 + Cs-136 + Cs-137	10
Sr-89 + Sr-90	10
I-131	5

8.3. Intervention levels for meat production

Table 7 shows intervention levels for meat production. These intervention levels refer to a level of ground deposition on pasture land or arable land which might lead to exceeding the EU's maximum permitted levels for foodstuffs in the case of meat. The table shows values for grazing and free-range grazing, as well as for grain-fed pork. When it comes to game meats, the variability may be substantial. Consequently, the intervention level is stated as an interval.

Table 7. Intervention levels for grazing or production of grain for meat production.

Type of meat	**Nuclide group**	**Intervention level** (kBq/m^2)
Beef/lamb/reindeer	Cs-134 + Cs-136 + Cs-137 Sr-89 + Sr-90	1/1 (free-range grazing/grazing) 10/100 (free-range grazing/grazing)
Pork	Cs-134 + Cs-136 + Cs-137 Sr-89 + Sr-90	10 (grain) 1,000 (grain)
Game* (elk and venison)	Cs-134 + Cs-136 + Cs-137	10-100 (free-range grazing)

* An interval is given as there may be considerable variability between types of animal and, for instance, depending on the supply of mushrooms in forests.

8.4. Intervention levels for grains, leafy vegetables and potatoes

Table 8 shows intervention levels for production of grains (e.g. bread grains), leafy vegetables and potatoes. These intervention levels refer to a level of ground deposition on arable land which might lead to exceeding the EU's maximum permitted levels in the foods produced. In the case of leafy vegetables, the intervention level is quite low since these vegetables have a large leaf surface in relation to their weight. As potatoes are a root vegetable, their intervention level is relatively high. This crop is nevertheless included since potatoes are an important staple food.

Table 8. Intervention levels for grains, leafy vegetables and potatoes.

Crop	Nuclide group	Intervention level (kBq/m^2)
Grains*	Cs-134 + Cs-136 + Cs-137	10
	Sr-89 + Sr-90	10
Leafy vegetables*	Cs-134 + Cs-136 + Cs-137	1
	Sr-89 + Sr-90	1
Potatoes	Cs-134 + Cs-136 + Cs-137	1,000
	Sr-89 + Sr-90	100

*In the case of standing vegetation, the assumption is that the activity in the aboveground parts of the plants reduces by a biological half-life of approximately 10 to 15 days. As a consequence, even at the same level of ground deposition, the activity in the plant will reduce over time, meaning that the intervention level can subsequently be raised. Root uptake during future growing seasons is not considered. This also applies to pasture ground.

9. Intervention levels for remediation

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

Large-scale remediation of outdoor surfaces by removing the uppermost soil layer may result in considerable reduction of potential radiation doses. However, this action is very time-consuming and costly. It also generates large quantities of waste. Another outcome is substantial environmental damage. Cleaning of surfaces does not reduce radiation doses to the same extent, but is less harmful to the environment and easier to carry out.

Table 9 shows potential remedial actions at different levels of additional doses received from ground deposition during the first year. These actions may serve as a point of departure when considering the need for remediation that may arise on the part of the events analysed by SSM. In the table, basic remediation measures for example refer to clearing of ditches and removing soil under downspouts. Advanced remediation measures for example refer to large-scale projects for the purpose of cleaning up buildings and land. To serve as input for consideration of the relevant remedial actions for different levels of additional dose, SSM has taken into account aspects such as decision-making relating to remediation that took place in Japan following the nuclear power accident at Fukushima Daiichi [15] [16] [17].

Table 9. Additional dose and potential remedial actions in the case of ground deposition of radioactive substances.

Additional dose (mSv/year)	**Remedial actions**
>1	A remediation plan should be produced and basic remediation measures may be warranted
>5	Basic remediation measures are likely to be warranted
>10	Advanced remediation measures may be warranted
>20	Advanced remediation measures are likely to be warranted
>50	Advanced remediation measures are likely to be insufficient for allowing resettlement of the area for several years

With one exception, intervention levels for remediation are calculated for the same nuclides and using the same calculation presumptions as the intervention levels for relocation (see section 5.3). This is for the purpose of limiting effective dose from external exposure due to ground deposition over the longer term. The intervention levels for remediation are set at levels that give estimated additional doses from these nuclides, as shown in Table 9, during the first year. There are other nuclides in the releases that contribute to the additional dose from ground deposition, but their half-life is so short that SSM advises their exclusion from consideration when deciding on remediation.

Table 10 shows intervention levels for remediation in the case of an additional dose of 1 mSv during the first year. Other intervention levels for remediation are obtained through multiplication with the annual additional dose. This for example makes the intervention levels for an additional dose of 20 mSv identical to the intervention levels for relocation.

Table 10. Intervention levels for remediation in the case of an additional dose of 1 mSv during the first year.

Facility	**Nuclides**	**Intervention level** (kBq/m^2)
Nuclear power plants	Cs-134 + Cs-137	100
Clab	Co-60 Cs-134 + Cs-137	50 150

In the case of events at the fuel fabrication plant in Västerås, SSM has elected to apply a different criterion to intervention levels for remediation. This intervention level has been set at 10 kBq/m^2 for the total of the uranium isotopes U-234, U-235 and U-238. Uranium results in a very limited dose from external exposure. However, a ground deposition of uranium risks leading to internal doses from involuntary intake of activity from the ground or due to resuspension followed by inhalation. Estimates show that only delimited areas are subject to ground deposition exceeding this level. For this reason, SSM is of the opinion that considering remediation is feasible down to the level for site release as defined by SSM's clearance regulations [18].

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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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