Strål
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Swedish Radiation Safety Authority

Report

Radiological Consequences of Fallout from Nuclear Explosions

Appendix 1 – Radiation Protection

2023:05e

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1. Introduction

In this appendix, the Swedish Radiation Safety Authority (SSM) presents the assumptions and approaches used in the report regarding radiation protection.

Presented first are the starting points for radiation protection during a heightened state of alert. The peacetime regulation of radiation protection is not fully applicable during a heightened state of alert, particularly for the general public in conjunction with the fallout from nuclear explosions. During a heightened state of alert, exposure situations and the basic principles of radiation protection in terms of justification and optimisation are also applicable. Similarly, the radiation protection objectives applicable to emergency exposure situations can also be applied during a heightened state of alert: avoid or minimise severe deterministic effects and reduce the probability of stochastic health effects as far as reasonably achievable. On the other hand, the reference levels used to plan and optimise radiation protection for peacetime radiological emergencies need to be adjusted to be applicable during a heightened state of alert. Other trade-offs may need to be made where the risks posed by the exposure must be compared with other risks that may be present during a heightened state of alert. SSM has used three reference levels in this report to evaluate the need for protective actions in connection with exposure to fallout from nuclear explosions. These aim to enable severe deterministic effects to be avoided and radiation doses to be kept as low as reasonably achievable.

This is followed by a description of how people can be exposed to ionising radiation in connection with the fallout from nuclear explosions, and the protective actions and other emergency actions that can be taken in order to reduce radiation doses and manage the consequences of the radiation doses received. In areas that may be affected by fallout from a nuclear explosion, sheltering indoors is initially the most important protective action. The degree of protection, however, varies greatly depending upon the particular premises. The ratio between the radiation dose indoors (with protection) and the radiation dose outdoors (without protection) for the same location and duration of exposure is referred to as the "protection factor". The appendix presents the protection factors for various different premises that have been used in the calculations, from houses to protective shelters in basements.

Next presented are generic criteria and dose criteria for a radiation dose to an unprotected person, which, when exceeded or at risk of being exceeded during a defined period of time, in most cases mean that it is justified to take a specific protective action or protective actions in general. Generic criteria and dose criteria are chosen so that the protective actions taken will enable the radiation dose to members of the public to be kept below the chosen reference level.

Finally, the radiation protection assessments conducted by SSM using dispersion and dose calculations are summarised along with how they relate to reference levels, generic criteria and dose criteria.

2. Starting points for radiation protection

2.1. Regulation of radiation protection during a heightened state of alert

Radiation protection in Sweden is regulated primarily via the Swedish Radiation Protection Act [1] and the Swedish Radiation Protection Ordinance [2] along with Regulations issued by SSM. The Swedish regulation of radiation protection follows the EU Radiation Protection Directive from 2013 [3], which in turn is based on recommendations published by the International Commission on Radiological Protection (ICRP) in 2007 [4].

The regulation of radiation protection in the Swedish Radiation Protection Act, the Swedish Radiation Protection Ordinance and SSM Regulations also apply in connection with a heightened state of alert, unless otherwise announced on the basis of the legislation. It is stated in the Swedish Radiation Protection Act (Chapter 2, Section 6) that the Swedish Government or the governmental authority designated by the Government may issue regulations on deviations from the act relating to the Swedish total defence. The Swedish Radiation Protection Ordinance (Chapter 7, Section 4) further states that the Swedish Armed Forces and the Swedish Radiation Safety Authority may issue regulations on deviations from the Swedish Radiation Protection Act and the Swedish Radiation Protection Ordinance for the Swedish total defence to the extent that it is necessary to strengthen defence preparedness due to prevailing special circumstances.

Defence preparedness means preparedness to withstand different types of armed attacks [5]. Swedish total defence is the activity needed to prepare Sweden for war. In order to strengthen the country's defence capability, readiness can be increased. A heightened state of alert is either *heightened readiness* or *maximum readiness*. During maximum readiness, the highest level of readiness, total defence is all the governmental activities that should then be performed. Total defence consists of military activities (military defence) and civilian activities (civil defence) [6].

The Swedish Government, the Swedish Armed Forces and the Swedish Radiation Safety Authority may thus issue regulations that deviate from current legislation regarding workers in total defence. The Swedish Armed Forces are currently working on developing regulations for their own personnel. However, no corresponding work is underway to develop regulations for workers in total defence who are not part of the Swedish Armed Forces.

It is unclear whether current legislation provides support for the Swedish Government or any other governmental body to issue regulations that deviate from current radiation protection legislation for the general public or workers in general. For the general public, this should be investigated further, as it is clear *i.a.* from this report that the rules and regulations that apply to the general public in peacetime are not suitable for all situations that may arise during a heightened state of alert. For employees who are not part of total defence, it should first be investigated whether situations may arise during a heightened state of alert where the rules applicable to workers in peacetime are not appropriate. If it turns out that there are such situations, the mandate to issue regulations that deviate from the regulations in peacetime for workers who are not part of the total defence also needs to be investigated.

2.2. Exposure situations

The regulation of radiation protection is based on three exposure situations that are intended to cover the entire range of possible exposure situations: *planned exposure situations, emergency exposure situations,* and *existing exposure situations.*

A *planned exposure situation* is an exposure situation where radiation protection can be planned in advance and where the exposure can be predicted with a reasonable degree of certainty. Examples of planned exposure situations include the operation of nuclear power plants and radiotherapy in hospitals.

An *emergency exposure situation* is defined in the Swedish Radiation Protection Act as a sudden event that involves a radiation source, has entailed or may entail severe adverse consequences and necessitates prompt actions [1]. An emergency exposure situation is an exposure situation that requires the implementation or preparation of urgent protective actions. The accident at the Japanese Fukushima Daiichi nuclear power plant in 2011 is an example of an event giving rise to an emergency exposure situation. Radioactive fallout from a nuclear explosion could give rise to an emergency exposure situation.

An *existing exposure situation* is an exposure situation that already exists when a decision on control needs to be made and the situation does not (or no longer) requires urgent protective actions to be taken or be prepared. Examples of existing exposure situations include those that exist naturally, such as radon or cosmic radiation, and those that may arise as a result of an emergency exposure situation, such as radioactive fallout from a nuclear explosion, after the emergency exposure situation is terminated.

There is a clear link between rescue services under the Swedish Civil Protection Act [7] and emergency exposure situations under the Swedish Radiation Protection Act [1]. Rescue services are defined as the rescue operations that the state or the municipalities are responsible for in case of accidents or imminent danger of accidents in order to prevent or limit damage to people's lives and health, property or the environment, if this is justified given the need for prompt actions, the importance of what is being threatened, the cost of the operation, and the circumstances in general. The term “accident” is defined as a sudden event that has entailed or may entail severe adverse consequences and necessitates prompt actions [8]. If the criteria for rescue services are fulfilled and the severe adverse consequences have been or can be caused by a radiation source, the criteria for an emergency exposure situation are also met in almost all conceivable situations [9]. Rescue services in response to fallout from a nuclear explosion is an example of a situation that is also an emergency exposure situation.

An emergency exposure situation can transition to an existing exposure situation or to a planned exposure situation. For such a transition to be possible, the general preconditions specified in the legislation for an existing exposure situation or planned exposure situation must be met [1] [2]. In addition, the specific preconditions for the transition from an emergency exposure situation to an existing exposure situation specified in the Swedish Radiation Protection Ordinance must be met [2].

2.3. Principles of radiation protection

Radiation protection is based on three principles: *justification, optimisation* and *application of dose limits*. *Justification* means that any decision modifying an exposure situation must do more good than harm. *Optimisation* means that the probability of exposure, the number of people exposed and the amount of radiation dose to each individual is to be kept as low as reasonably achievable, taking financial and societal factors into consideration. It is the overall radiation protection that should be optimised, and not individual protective actions. In an emergency exposure situation, for example as a result of radioactive fallout from a nuclear explosion, what this means in practice is that each individual protective action must be justified. It is then the combination of protective actions that needs to be both justified and optimised, taking into consideration that the combination of protective actions resulting in the lowest total dose is not necessarily the best in all possible circumstances. This may be the case, if for example the combination of protective actions that would result in the lowest total dose would result in an unreasonable distribution of radiation doses between different groups, or if the combination of protective actions resulting in the lowest dose would result in excessive negative consequences for the groups concerned. Optimisation is a forward-looking iterative process aimed at preventing or reducing future doses. The third principle, the application of *dose limits*, is only used in planned exposure situations and therefore is not further discussed in this report.

2.4. Radiation protection objectives in the event of an emergency exposure situation

In the context of emergency exposure situations, there are two overall objectives for radiation protection: firstly to prevent or minimise severe deterministic effects and secondly to reduce the likelihood of stochastic effects to the extent reasonably achievable [10]. Protective actions to avoid or minimise severe deterministic effects are almost always justified, even though some considerations of overriding risks may be necessary in the context of fallout from a nuclear explosion. Careful consideration is required for protective actions taken to reduce the likelihood of stochastic effects. In a heightened state of alert, higher radiation doses may be justified compared to in peacetime, but the extent to which this is justified must be determined based on the particular event and the prevailing circumstances.

Deterministic effects: Early health effects arising as a direct result of exposure to ionising radiation. Deterministic health effects are characterised by a threshold dose, and the severity of the health effect increases with an increased radiation dose.

Severe deterministic effects: Deterministic effects that are so severe that they are fatal, life-threatening, or results in permanent injury that reduces quality of life.

Stochastic effects: Random health effects that may arise in the long term as a consequence of exposure to ionising radiation. The probability of their occurrence increases with an increased radiation dose, but the severity of the health impact, if it does occur, is independent of the amount of the radiation dose. Cancer is one example of a stochastic effect.

2.5. Reference levels

Reference levels are used in optimisation to limit individual radiation doses in the context of both emergency exposure situations and existing exposure situations. Reference levels represent a level of dose above which it is inappropriate to plan for exposure to occur and below which optimisation of radiation protection should continue. The value chosen for the reference level depends on the circumstances of the particular situation under consideration. A strategy for protective actions during an emergency exposure situation must both allow doses to be kept below pre-determined reference levels and radiation protection to be optimised. An example of the practical implementation of a strategy could be emergency response plans for fallout from nuclear explosions.

In the evaluation of whether a strategy enables doses to be kept below selected reference levels, radiation doses to a *representative per*son are calculated. A representative person is a hypothetical individual receiving a radiation dose that is representative of the radiation doses to more highly exposed individuals in the population, with the exception of people with extreme or rare habits [11]. In the event of radioactive fallout from a nuclear explosion, a one-year-old child is normally a representative person. The reason for this is that children are more sensitive than adults to exposure from ionising radiation. Younger children are represented by the group of 1-year-olds [11]. The conclusions on protective actions presented in this report are therefore based on a one-year-old child. Since in many situations it may be relevant and of interest to see differences between children and adults, calculation results for adults are also presented in the report.

Reference levels for emergency exposure situations are regulated in the Swedish Radiation Protection Ordinance. The reference level for exposure of members of the public in an emergency exposure situation is 100 mSv annual effective dose for events at a nuclear power plant not taken into account in the design of the nuclear reactor, and 20 mSv annual effective dose for all other events [2]. See the fact box below for information on radiation doses. For an emergency exposure situation to transition to an existing exposure situation, the Swedish Radiation Protection Ordinance also requires that it is possible to establish a reference level of no more than 20 mSv annual effective dose [2]. Thus, unless regulation is otherwise amended, the reference level of 20 mSv annual effective dose applies to an emergency exposure situation related to radioactive fallout from a nuclear explosion. In addition, it must be possible to establish a reference level of 20 mSv annual effective dose or lower to enable a transition from an emergency exposure situation to an existing exposure situation.

The reference levels in Swedish legislation follow the ICRP recommendations from 2007 [4]. The ICRP provides effective dose ranges for selecting reference levels that are appropriate in different exposure situations. For emergency exposure situations, this range is 20 to 100 mSv effective dose, incurred either acutely or in a year. The rationale given by the ICRP for the upper level of 100 mSv is that effective doses above this level increase the risk of deterministic effects as well as the risk of developing cancer later in life. Therefore according to the ICRP, exposure above 100 mSv would only justified in extreme cases, such as in life-saving interventions or to prevent a disaster. No other individual or societal factor would compensate for such a high exposure.

The ICRP reasoning works well in peacetime. However, other considerations may need to be made during a heightened state of alert. The risks entailed by the exposure, *e.g.* in an area affected by radioactive fallout from a nuclear explosion, must be weighed against other risks that may exist during a heightened state of alert.

However, the overall objectives for radiation protection in nuclear and radiological emergencies are still applicable. Severe deterministic effects should be avoided or minimised. To evaluate possible severe deterministic effects, RBE-weighted absorbed dose to individual bodily organs should be used [4]. However, the ICRP provides guidance that effective doses below 1000 mSv should avoid severe deterministic effects; below 500 mSv should avoid other deterministic effects [12]. In the event of radioactive fallout from a nuclear explosion, radiation doses are dominated by external exposure from the radioactive material deposited on the ground. Individuals who are thus exposed receive a whole-body dose, which means that the above benchmarks should work relatively well. A reference level expressed in effective dose should therefore not be set higher than 1,000 mSv.

Furthermore, the probability of stochastic effects, mainly cancer, should be reduced as far as reasonably achievable. The ICRP radiation protection system is based on the linear non-threshold (LNT) model where the risk of stochastic effects is assumed to increase in direct proportion to the radiation dose. According to this model, each increase in radiation dose results in a non-zero risk of stochastic effects [4]. The ICRP provides an overall risk coefficient for fatal cancer of 5 percent per Sv for a population [4]. This risk coefficient should only be used in radiation protection planning and cannot be used to estimate the individual risk of dying from cancer after a given exposure. Looking at a large group of people, this means that average effective radiation doses of 100, 500 and 1,000 mSv give a risk of fatal cancer of 0.5 percent, 2.5 percent and 5 percent in that group. The risk increases with increasing radiation dose, but must be weighed against other (non-radiological) risks that may occur in connection with radioactive fallout from a nuclear explosion. Based on what applies in peacetime, a minimum reference level should be set at 100 mSv effective dose. A suitable step between 100 mSv and 1,000 mSv could be to set a reference level at 500 mSv. At this level, deterministic effects, even those that are not severe, could probably be avoided. In this report, three possible reference levels associated with the fallout from nuclear explosions have therefore been used in the evaluation: 100, 500 and 1,000 mSv annual effective dose.

Reference levels that are applicable to emergency exposure situations and existing exposure situations during a heightened state of alert need further investigation, including the reference levels used in this report. Different situations may justify the application of different reference levels, *e.g.* depending upon the type of event and whether there is a heightened state of alert, heightened readiness or maximum readiness in force.

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

RBE weighting: A measure of the relative effectiveness of different types of radiation in causing a specific health effect.

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

Effective dose: A protective quantity that is a measure of the overall risk of stochastic health effects. The effective dose is calculated as the total of all equivalent doses from the tissues and organs of the body, weighted by a factor that takes into consideration the fact that different tissues and organs have different sensitivities to exposure from ionising radiation. The effective dose is indicated in sievert (Sv).

3. Protective actions and other response actions

3.1. Exposure pathways

As a result of fallout from a nuclear explosion, people can be externally and internally exposed to ionising radiation. External exposure involves exposure to ionising radiation from radioactive material outside the body. Internal exposure involves exposure to ionising radiation from radioactive material that have entered the body. External and internal exposure can occur via a variety of exposure pathways:

- External exposure from radioactive material in the air
- External exposure from radioactive material on the ground
- External exposure from radioactive material on the skin, hair or clothing
- Internal exposure from inhalation of radioactive material
- Internal exposure via the consumption of food and drinking water affected by the fallout and thus containing radioactive material
- Internal exposure from inadvertent ingestion of radioactive material, for example material that has deposited on the skin.

In this report, external exposure from radioactive material in the air, on the ground and (partly) radioactive material deposited on the skin has been studied, as well as internal exposure from radioactive material entering the body via inhalation. Internal exposure from radioactive material entering the body via consumption of food, drinking water or inadvertent ingestion has not been studied. However, it is reasonable to assume that these exposure pathways are also of considerable importance in connection with the fallout from nuclear explosions. The Swedish Radiation Safety Authority therefore intends to investigate these exposure pathways more closely in future studies.

The dispersion and dose calculations take external exposure into account, both from radioactive material in the air and from radioactive material deposited on the ground. These contributions to the total radiation dose are respectively referred to here as "cloud dose" and "ground dose". The calculations also take internal exposure from inhaled radioactive material into account. This contribution to the total dose is referred to as the inhalation dose. External exposure from radioactive material on the skin may give rise to a skin dose. Internal exposure from inhaled radioactive iodine can result in a thyroid dose. Both external and internal exposures can give rise to an absorbed dose to red bone marrow, but as the contribution from radioactive material on the ground is entirely dominant, only this contribution has been considered.

3.2. Protective actions and other response actions

Protective actions aim to avoid or minimise future exposure and are based on the fundamental principles of radiation protection, see the text box below. In the event of a large-scale accident involving the release of radioactive material, protective actions such as precautionary evacuation, evacuation prior to and during the release, sheltering indoors, administration of iodine tablets, actions to avoid or reduce inadvertent ingestion, decontamination of persons, actions regarding food and drinking water for human consumption, actions for goods, relocation (*i.e.* evacuation due to ground contamination, after the release of radioactive material and dispersion of fallout have ceased) and remediation may be relevant [13]. In the context of fallout from a nuclear explosion, several of these protective actions may also be relevant.

Sheltering indoors reduces external exposure from radioactive material on the ground and in the air, as well as internal exposure via inhalation of radioactive material or inadvertent ingestion of radioactive material. The degree of protection for each exposure pathway differs between different premises (for further information, see also Section 3.3). With the administration of iodine tablets, the absorption of radioactive iodine to the thyroid gland is reduced. Iodine thyroid blocking provides some protection against severe deterministic effects resulting from exposure to the thyroid gland for all age groups as well as reduces the risk of developing thyroid cancer for people under 40 years of age, especially children and foetuses. Relocation has the effect of the cessation or reduction of exposure to radioactive material deposited on the ground after the fallout has ceased accumulating, provided that relocation is to an area unaffected or only slightly affected by the fallout.

The protective actions of personal decontamination, actions to avoid or reduce inadvertent ingestion, actions regarding food and drinking water for human consumption, actions for goods and remediation may also be relevant in the context of nuclear explosions, however these are not considered in this report. Evaluating the need for these protective actions requires the development of criteria for when these actions may be justified in the context of fallout from nuclear explosions.

A precautionary evacuation is conducted at an early stage of an incident with the purpose of facilitating subsequent crisis management and improving the capability to implement protective actions if the situation deteriorates. Precautionary evacuation cannot be excluded, but it is based on information about the threat of the use of nuclear weapons or early warning of an impending nuclear strike. Precautionary evacuation is therefore not further considered in this report. Evacuation prior to and during fallout is not an appropriate protective action in the event of a nuclear explosion. The reasons for this are varied. Firstly, the time from explosion to exposure is quite brief. This means that in many cases there is not enough time to evacuate to a safe distance, which may result in people being unprotected, *e.g*. outdoors or in a car, during the fallout. Secondly, it cannot be expected to be possible to determine in time and with sufficient certainty which areas may be affected, which means that it is difficult to determine whether evacuation to another area ultimately will lead to a lower risk of exposure.

In addition to protective actions, there are other response actions aimed at mitigating the consequences of an emergency exposure situation. In the context of fallout from nuclear explosions, management of severe deterministic effects, personal monitoring and estimation of individual radiation doses may be relevant. Management of severe deterministic effects involves medical treatment in the health care system. The report addresses the need for management of severe deterministic effects for children and adults due to red bone marrow and skin exposure. The need for management of severe deterministic effects on the thyroid gland has also been evaluated, but no such need arises at the distances covered by the calculations, *i.e.* distances greater than 8 km. For foetuses, there are some additional possible health effects that are not addressed in the report. Personal monitoring and estimation of individual radiation dose are also not addressed.

Basic rules for protection against radiation:

- Avoid being close to a source of radiation for any period longer than essential
- Maintain as much distance as possible between you and the source of the radiation
- Have as much shielding material as possible between you and the source of the radiation.
- Avoid ingesting or inhaling radioactive material
- Avoid having radioactive material coming into contact your skin

3.3. Protection factors

The protection factor when sheltering indoors refers to the ratio between the radiation dose indoors (with protection) and the radiation dose one would receive outdoors (without protection) for the identical location and the duration of the exposure. This means that the lower the protection factor is, the more effective the protection obtained. The protection factor can vary greatly, depending on *i.a.* the type of building, the building material, the type of ventilation, and the particle size of the radioactive material in the fallout.

In general, the greater volume and the denser the material between the source of the radiation (in this case radioactive material in the air or deposited on the ground) and an individual sheltering indoors, the more effective the shielding against external exposure will be. This means that concrete buildings and basements[1] provide good protection against exposure from radioactive material outside the building. As a general rule, filtered ventilation or switched-off ventilation with a low airflow rate also provides good protection against internal exposure from inhalation, as it reduces the amount of radioactive material entering the premises. Table 1 shows the protection factors used in the report for sheltering indoors in varying premises.

The effect of taking iodine tablets can also be described by a protection factor. In this context, the protection factor refers to the ratio between the radiation dose with the administration of iodine tablets and the radiation dose without the intake of iodine tablets, for the identical location and duration of the exposure. In the report, the protection factor for the administration of iodine tablets is set at 0.1 [14]. Sheltering indoors also leads to lower thyroid doses, as the concentration of radioactive iodine in the air is lower indoors than in the air outdoors. The protection factors for sheltering indoors that are applied for internal exposure from inhalation of radioactive material in the air are shown in Table 1.

Normal residency over time in an area affected by fallout from a nuclear explosion also provides protection against exposure from radioactive material deposited on the ground, since the vast majority of people spend most of their time indoors. Protection factors for long-term normal residency in an area with a ground deposition of radioactive material are calculated assuming 80 percent staying indoors in a single-family house (referred to here as “house”) or multifamily residential building or similar (referred to here as “large building”) with protection factors of 0.4 and 0.1, respectively, and 20 percent outdoor presence without protection. Table 1 shows the protection factors used in the report for normal residency over time in a house and in a large building.

[1] Basements are typically built of concrete. In addition, there is a considerable amount of material in the ground that also shields the radiation.

Table 1. Protection factors used in the dose calculations.

Type of protection	Type of premises	Exposure pathways	Protection factor
Unprotected	Outdoors	-	1
Sheltering indoors	House [14]	Protection against external exposure from radioactive material deposited on the ground	0.4
		Protection against internal exposure from inhalation of radioactive material in the air	0.5
		Weighted protection against all exposure pathways considered	0.5
Sheltering indoors	Large building *This includes apartments in multifamily buildings, schools, etc*.[1]	Protection against all exposure pathways considered	0.1
Sheltering indoors	Protective shelter (SR 15) [15]	Protection against external exposure from radioactive material deposited on the ground[2]	0.025
Sheltering indoors	Basement *Basement in a large concrete building* [16]	Protection against external exposure from radioactive material deposited on the ground	0.01
Sheltering indoors	Protective shelter (basement) *Protective shelter in the basement of a large concrete building or the equivalent*[3]	Protection against external exposure from radioactive material deposited on the ground[4]	0.001
Fully protected	-	-	0
Normal residency over time	House	Protection against external exposure from radioactive material deposited on the ground	0.52
Normal residency over time	Multifamily residential buildings, schools, etc.	Protection against external exposure from radioactive material deposited on the ground	0.28

[1] This report uses the identical protection factor for all exposure pathways. For many types of premises in this category, this assumption should be conservative.

[2] Protective shelters under this standard are designed to be sufficiently sealed to provide protection against chemical and biological warfare agents and fire gases [15]. This means that protection against internal exposure from inhalation of radioactive material in the air outside the protective shelter should be very effective.

[3] In this report, the Swedish Radiation Safety Authority presumes that this type of premises provides an order of magnitude better protection than a normal basement in a large concrete building.

[4] Protection against internal exposure from inhalation of radioactive material in the air outside the protective shelter should be at least as effective as for protective shelters designed according to SR 15.

4. Criteria and radiation protection evaluation

4.1. Generic criteria and dose criteria

A *generic criterion* is a value of radiation dose to an unprotected person which, when exceeded or likely to be exceeded over a specified period of time, in most instances will justify the application of protective actions. A *dose criterion* is a value of radiation dose to an unprotected person which, when exceeded or likely to be exceeded during a specified period of time, in most circumstances will justify a particular protective action or other response action. Thus, generic criteria express that protective actions should be taken while dose criteria express that a specific protective or other response action should be taken. Generic criteria and dose criteria are chosen so that the protective actions taken enable the radiation dose to the public to be kept below the chosen reference level.

For protective actions that are intended to reduce the likelihood of stochastic effects ras far as reasonably achievable, generic criteria, and for some protective actions also dose criteria, expressed in terms of effective dose or (in the case of individual bodily organs) equivalent dose may be specified. As discussed in Section 2.5, these criteria should also lead to avoidance of severe deterministic effects. For radiation doses received over a limited period of time, a dose criterion covering this period may be specified. In this report, this applies to doses to the thyroid caused by inhalation of radioactive iodine while the fallout is still occurring. Ingestion of radioactive iodine via food at a later stage is a possible exposure pathway, however this has not been addressed in this report. The lowest dose criterion for the administration of iodine tablets is consistent with the dose criterion for the intake of iodine tablets recommended by the IAEA for nuclear power plant accidents [10]. The two higher dose criteria have been chosen within the range of received thyroid doses, where medical monitoring and follow-up may be warranted or is almost always warranted [17].

When different combinations of protective actions over a longer period of time are possible, it is not clear which dose criteria should be used for individual protective actions. Among the protective actions evaluated in this report are sheltering indoors and relocation. It is conceivable that sheltering indoors is directly followed by relocation. In this case, virtually all the dose is received during the initial sheltering indoors. Similarly, it is conceivable that sheltering indoors in good protection will lead to very low radiation doses initially. In this case, virtually all of the dose is received due to exposure from the radioactive material deposited on the ground after the sheltering indoors is discontinued. On this basis, in this report SSM has established dose criteria for both sheltering indoors and relocation due to ground contamination at the same value as the reference levels. In this way, the dose criteria for sheltering indoors and relocation, respectively, represent levels of effective dose at which the protective actions must be applied in all circumstances if the selected reference level is not to be exceeded.

For combinations of different protections initially and different protections during the remainder of the first year, generic criteria are used. As the evaluation concerns exposure over an entire year, the generic criteria can be set at the same value as the reference levels. The generic criteria and dose criteria given are for one-year-old children and adults. Refer to Table 2 for a summary of the generic and dose criteria used in the report for combinations of protective actions and individual protective actions.

Table 2. Generic and dose criteria for combinations of protective actions and individual protective actions.

Protective action(s)	Criterion	Value	Magnitude and time duration
Combinations of different initial protection[1] and different protection during the remainder of the first year.	Generic criterion	100, 500 and 1,000 mSv	Effective dose over a period of one year
Sheltering indoors	Dose criterion	100, 500 and 1,000 mSv	Effective dose over various periods of time[2]
Relocation due to ground contamination	Dose criterion	100, 500 and 1,000 mSv	Effective dose over varying periods of time[3]
Administration of iodine tablets	Dose criterion	50, 100 and 500 mSv	Committed equivalent dose to the thyroid gland during the deposition period.[4]

[1] "Initially" refers to periods of up to one week.

[2] During the first week.

[3] From the time that sheltering indoors is terminated until one year after the nuclear explosion.

[4] As long as radioactive iodine is present in the air (SSM's modelling of the dispersion has encompassed two days).

For other response actions aimed at mitigating the consequences of already received radiation doses, individual dose criteria can be defined. The occurrence of severe deterministic effects normally requires that a high radiation dose is received in a short period of time. In the first instance, RBE-weighted absorbed dose is primarily used to evaluate severe deterministic effects. This report uses RBE-weighted absorbed dose to red bone marrow, skin and the thyroid gland [10]. SSM also provides a dose criterion for whole body dose expressed in effective dose which, if exceeded, indicates an increased likelihood of severe deterministic effects [12]. The dose criteria given are for one-year-old children and adults respectively. Embryos and foetuses are particularly sensitive to exposure from ionising radiation, especially during certain phases of development. The cut-off point is the embryo 2-7 weeks after fertilisation and the brain of the foetus 8-15 weeks after fertilisation. However, this report does not deal with embryos or foetuses, so dose criteria for embryos or foetal brain are not given. See Table 3 for a summary of the dose criteria used in the report for the need to manage severe deterministic health effects.

Table 3. Dose criteria for the need to manage severe deterministic health effects.

Measures	Organ	Value	Size
Management of severe deterministic health effects	Red bone marrow	1 Gy	RBE weighted absorbed dose to red bone marrow when exposed for 10 hours.
	Skin	10 Gy	RBE-weighted absorbed dose to the skin at a depth of 0.4 mm for up to 10 hours.
	Thyroid gland	2 Gy	RBE-weighted absorbed dose to the thyroid gland[1] during the dispersion phase.
	Whole-body dose	1 Sv	Effective dose[2] during the initial phase

[1] RBE-weighted absorbed dose to the thyroid gland can be calculated using the equivalent dose to the thyroid [18].

[2] Effective dose provides an indication of the distance at which severe deterministic health effects may occur from the fallout following a nuclear explosion.

4.2. Radiation protection evaluation

Using dispersion and dose calculations, SSM has evaluated the greatest distances at which a certain radiation dose can be exceeded. Evaluations have been made for various time periods and for varying degrees of protection.

In cases where the radiation doses were calculated for an unprotected person during a limited period of time, the evaluation was performed in relation to dose criteria for individual protective actions according to Table 2 and Table 3. The protective actions evaluated in this way are sheltering indoors for varying periods of time during the first week, administration of iodine tablets during the dispersion phase, and the management of severe deterministic health effects for red bone marrow and skin where exposure starts at different times shortly after the nuclear explosion and then continues for a maximum of 10 hours. Management of severe deterministic health effects on the thyroid gland has also been evaluated in a similar way, but the dose criterion is not exceeded within the distances covered by the calculations, *i.e.* at distances longer than 8 km.

In cases where radiation doses have been calculated for persons taking an individual protective action during a limited period of time, the evaluation has been performed in relation to values chosen by SSM[2]. The protective actions evaluated in this way are sheltering indoors with different degrees of protection for different periods of time during the first week and the administration of iodine tablets given both sheltering indoors with different degrees of protection for different periods of time during the first week and the administration of iodine tablets in connection with the dispersion phase.

In cases where radiation doses are calculated for combinations of initial protection and protection during the remainder of the first year (through normal residence, see above), the evaluation has been performed against generic criteria according to Table 2 if no specific

[2] For practical reasons, SSM has chosen values that correspond to the dose criteria for each protective action.

protective actions are taken and against reference levels if one or more protective actions are taken. The combinations of initial protection and protection during the remainder of the first year evaluated in this way are presented in Table 4. The combination of complete initial protection followed by normal residency in a house or a large building for the remainder of the first year can also be evaluated against the dose criterion for relocation due to ground contamination as shown in Table 2.

Table 4. Combinations of initial protection and protection during the remainder of the first year for the evaluation of greatest distances at which reference levels may be exceeded.

Initial protection	Protection during the remainder of the first year
Unprotected	Unprotected
Unprotected 1, 2, 3, and 7 days	Normal residency in a house or large building
Unprotected 1, 2, 3, and 7 days	Evacuated immediately, after one week[1] or after one month[1]
Sheltering indoors for 1, 2, 3 and 7 days in premises with a protection factor between 0.001 and 1	Normal residency in a house or large building
Sheltering indoors for 1, 2, 3 and 7 days in premises with a protection factor between 0.001 and 1	Evacuated immediately, after one week[1] or after one month[1]
Fully protected 1, 2, 3 and 7 days	Normal residency in a house or large building
Fully protected 1, 2, 3 and 7 days	Evacuated after one week[1] or after one month[1]

[1] Normal residency in a house or large building until evacuation/relocation.

Using dispersion and dose calculations, SSM has furthermore evaluated the highest effective doses at specified distances for different combinations of initial protection and protection during the remainder of the first year. The evaluated combinations are presented in Table 5.

Table 5. Combinations of initial protection and protection during the remainder of the first year for the evaluation of the highest radiation doses at specified distances.

Initial shielding	Protection during the remainder of the first year
Sheltering indoors in a house or a large building	Normal residency in a house or large building
Sheltering indoors in a protective shelter (SR 15)	Normal residency in a house or large building
Sheltering indoors in a protective shelter (basement)	Normal residency in a house or large building

The Swedish Radiation Safety Authority has also used dispersion and dose calculations to evaluate the highest effective doses from different exposure pathways at specified distances. The exposure pathways evaluated in this way are external exposure from radioactive material deposited on the ground and in the air and internal exposure via inhalation of radioactive material. SSM has also roughly estimated the highest RBE-weighted absorbed doses to the skin at specified distances where exposure starts at different times shortly after the nuclear explosion and then continues for a maximum of 10 hours.

SSM has used dispersion and dose calculations to evaluate the maximum distances at which a certain level of radioactive material deposited on the ground (H+1) can be exceeded. See Section 4.6 of the main report for an explanation of the term "H+1". SSM has also used dispersion and dose calculations to evaluate the highest ground contamination (H+1) at specified distances. The results are presented in Appendix 6 (Detailed Results (General)) and can be used to retrospectively evaluate *e.g.* consequences for food and drinking water for human consumption.

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

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