Strål
säkerhets
myndigheten

Swedish Radiation Safety Authority

Author: Jonas Boson
Jan Johansson
Peder Kock
Simon Karlsson
Patrick Isaksson
Jonas Lindgren
Elisabeth Tengborn
Anna Maria Blixt Buhr
Ulf Bäverstam

2017:27e

Review of Swedish emergency planning zones and distances, Appendix 4

The fuel fabrication plant in Västerås

Report number: 2017:27e **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

Strål
säkerhets
myndigheten

Swedish Radiation Safety Authority

Authors: Jonas Boson
Jan Johansson
Peder Kock
Simon Karlsson
Patrick Isaksson
Jonas Lindgren
Elisabeth Tengborn
Anna Maria Blixt Buhr
Ulf Bäverstam

2017:27e

Review of Swedish emergency planning zones and distances, Appendix 4

The fuel fabrication plant in Västerås

Date: May 2019
Report number: 2017:27e **ISSN:** 2000-0456
Available at www.stralsakerhetsmyndigheten.se

Contents

1. Summary

The industrial park of Finnslätten, in the outskirts of Västerås, is the location of a facility for the manufacture of nuclear fuel (hereinafter referred to as 'the fuel fabrication plant'). The plant has had these premises since 1966. This plant converts enriched uranium: from uranium hexafluoride (UF_6) into uranium dioxide (UO_2). The uranium dioxide is then processed into fuel elements designed for different types of nuclear power reactors. The facility is run by Westinghouse Electric Sweden AB (WSE). The geographical location of the fuel fabrication plant is shown in Figure 1.

The facility has been classified by the Swedish Radiation Safety Authority, SSM, as belonging to emergency preparedness category II. This implies that an accident at the facility is assessed as being capable of giving rise to radiological consequences warranting urgent off-site protective actions for the population. As a part of the emergency preparedness planning that is presupposed to enable taking of such protective actions in an effective way, relevant emergency planning zones and planning distances should be established around the facility.

SSM suggests that the fuel fabrication plant should have an urgent protective action planning zone (UPZ). Within the UPZ (Figure 1), it is recommended to have capability to carry out urgent protective actions (sheltering).

The proposed design of the UPZ to surround the fuel fabrication plant is based on analyses of possible event sequences. Here, two postulated events were selected to serve as the basis of the emergency preparedness planning. For these events, representative source terms were defined describing the releases assumed to follow the respective type of event. Thereafter, SSM performed dispersion and dose calculations by using historical weather data. This was in order to estimate the distances at which it is deemed warranted to take different protective actions. Based on these distances, a tangible proposal for this emergency planning zone was produced by the Västmanland County Administrative Board, in consultation with SSM, MSB and the City of Västerås.

It is also suggested by SSM to have an ingestion and commodities planning distance (ICPD) established to provide protection against ingestion of radioactive substances.

This appendix is part of the report *"Review of Swedish emergency planning zones and distances"*. For explanations of terms and concepts, and further information not specifically relating to a facility, please see the main report.

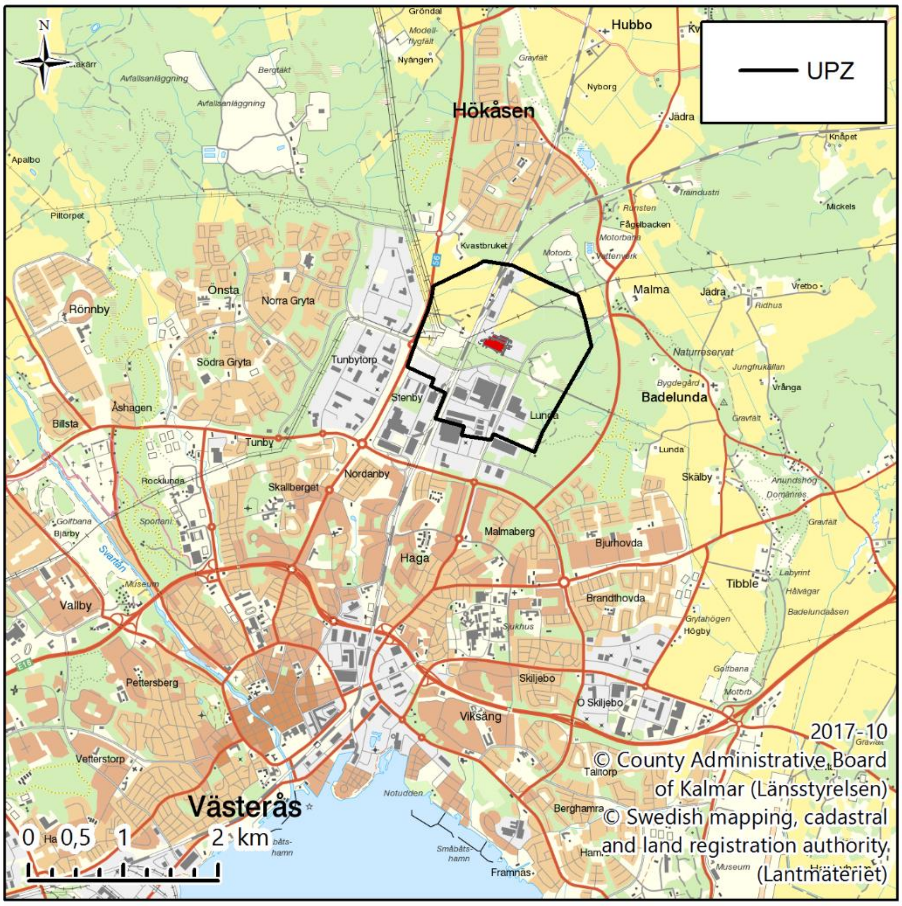

Figure 1. Location of the fuel fabrication plant in Västerås and the proposed new urgent protective action planning zone (UPZ) to surround this facility.

2. Events

As part of this project, SSM used analyses of conceivable events having environmental consequences as reported by WSE [1, 2, 3]. From a radiological perspective, these events can be roughly broken down into three categories on the basis of the kinds of environmental consequences that they give rise to: a release of uranium powder (uranium dioxide), a release of uranium hexafluoride, and criticality accidents.

Criticality accidents and releases of uranium powder have different characteristics when it comes to the kinds of environmental consequences they can give rise to. Criticality events give rise to prompt radiation (gamma and neutron radiation) in addition to releases of fission products in the form of iodine and noble gases. A release mainly results in inhalation dose and cloud dose while the plume passes, with dose to the thyroid in particular from inhalation of iodine isotopes. Releases of uranium powder mainly result in inhalation doses (because the occurring uranium isotopes above all emit alpha radiation), in addition to ground deposition of uranium. For this reason, both kinds of event should be taken into account when developing recommendations for emergency planning zones and distances.

In contrast, events involving uranium hexafluoride are not taken into account, as the radiological impact of conceivable releases of uranium hexafluoride is smaller than the impact from a release of uranium powder (see section 2.2.3), and also because the chemical hazards linked to this material outweigh the radiological hazards (see section 2.3).

2.1. Postulated events

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

- **Criticality event**. This event is due to overfilling of a container of liquid with dissolved uranium, resulting in the system becoming over-critical. The container is assumed to have a total volume of 1 m^3 with a uranium concentration of 400 g/L. The situation is ongoing for eight hours before a sufficient quantity of liquid has vaporised so that the criticality process ends.[4].

- **Event involving a fire with a release of uranium powder (UO_2)**. The event is due to a fire starting in, or spreading to, filters belonging to the process ventilation system. This scenario assumes that flame detectors and fire dampers fail to work, resulting in all the uranium powder of five bag filters, a total of 1,000 kg of uranium dioxide, being released and spread to the surroundings [1]. The fire is assumed to burn for five hours.

2.2. Selection of events

2.2.1. Criticality

The postulated event is stated by the U.S. Nuclear Regulatory Commission (NRC) as being suitable for assessing conceivable consequences of criticality accidents at fuel fabrication plants [4]. The relevant guide was published back in 1979. Nonetheless, in the assessment of SSM, the guide is still acceptable for providing a basis for estimation of possible environmental consequences [5]. This guide was also used by WSE [1]. Furthermore, events in which criticality arises due to overfilling of a container with near-critical liquid with dissolved uranium, have a rapid course which results in a greater number of nuclear fission reactions during the first pulse. The course is slower for criticality events that occur as a result of water added to dry uranium powder [3].

The probability of larger-scale events involving criticality in connection with, for instance, earthquakes or fires, is assessed as low by SSM, even in a case of substantial quantities of uranium in parts of the fuel fabrication plant. Achieving criticality presupposes both that uranium accumulates in an unfavourable geometry, and that a sufficient quantity of water is added.

2.2.2. Uranium powder

SSM is of the view that the selected event involving a release of uranium powder is appropriate for using as a postulated event for similar cases that might occur at the fuel fabrication plant. WSE provided a report stating that a large release of uranium powder into the environment is a risk that cannot be ruled out in connection with certain kinds of events [2]. SSM is nevertheless of the opinion that events involving large quantities of combustible or explosive material from an external source, e.g. large crashing aircraft, should not serve as the basis of the proposed emergency planning zone and distance to surround the fuel fabrication plant.

SSM is also of the view that other emergencies (for example, large-scale fires) are not likely to result in a more severe impact than the consequences presented in relation to the selected postulated event. In the case of fires occurring in other parts of the fuel fabrication plant, such as where conversion, or manufacture of pellets, takes place, it is reasonable to apply a release fraction in order to estimate a potential quantity of uranium released into the surroundings. Values for these fire release fractions have been published by the IAEA [6]. The IAEA suggests a release fraction of 0.001 for uranium and for nonvolatile powders; in other words, meaning that one-thousandth of the material in question is released in connection with a fire. Consequently, in the assessment of SSM, fires in other parts of the fuel fabrication plant will not result in larger releases of uranium powder than assumed in the postulated event.

2.2.3. Uranium hexafluoride

The largest release of uranium hexafluoride reported by WSE in the context of conceivable events at the plant is a total of 945 kg [1, 3]. This corresponds to a released quantity of uranium amounting to approximately 640 kg, which is of a smaller magnitude than from the postulated event involving a fire with a release of uranium powder.

When it comes into contact with moisture in the air, uranium hexafluoride forms uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF). Both uranium hexafluoride and uranyl fluoride are classified by the International Commission on Radiological Protection (ICRP) as belonging to absorption type F[1], as opposed to uranium dioxide, which is classified as absorption type S [7, p. 70]. Dose coefficients for inhalation of uranium of absorption type F are only about 5-7 per cent of the corresponding dose coefficients for uranium of absorption type S [7, pp. 115-6]. This signifies that a release of uranium hexafluoride that is of the same magnitude as the postulated event involving a release of uranium powder will result in substantially lower radiation doses. Consequently, SSM does not take this event into account.

When it comes into contact with moisture, the gas hydrogen fluoride forms hydrofluoric acid. Hydrofluoric acid is very corrosive. For this reason, the chemical hazards associated with a possible release of uranium hexafluoride outweigh the radiological hazards [3].

2.3. Chemical hazards

It is pointed out in the report *Analys av tänkbara större olyckor vid ASEA-ATOM:s bränslefabrik* ("Analysis of conceivable emergencies at the ASEA-ATOM fuel fabrication plant") [3] that the chemical hazards of the fuel fabrication plant outweigh the radiological hazards. Apart from uranium hexafluoride, the fuel fabrication plant is also the location of large quantities of ammonia. The government assignment regarding emergency planning zones and emergency planning distances does not take chemical hazards into account. Nonetheless, it is important to have the comprehensive planning for emergency preparedness at the fuel fabrication plant take both radiological hazards and chemical hazards into account.

For instance, in the event of a large fire with a potential release from the fuel fabrication plant, it is uncertain whether it is possible to determine if radiological or chemical releases are occurring during the ongoing event. Uncertainty associated with an ongoing release sequence should not lead to an unnecessary delay in emergency response actions, or to confusion regarding the allocation of responsibility between relevant stakeholders. In this context, it is important to note that under the *Civil Protection Ordinance (2003:789),* chemical releases are dealt with by municipal rescue services, whereas an external release of radioactive materials from a nuclear facility implies central government rescue services, with the county administrative board in charge.

Uranium is not only radioactive, but toxic as well. The present project did not take this aspect into account.

[1]Materials of absorption type F are quickly absorbed into the bloodstream via the respiratory system (fast rate of absorption). Materials belonging to absorption type S (slow rate of absorption) are relatively insoluble in the respiratory system [8]. Solubility affects the duration of the material's retention in the lungs, and consequently the material's dose coefficients.

3. Representative source terms

3.1. Criticality

SSM has developed a representative source term for the postulated criticality event. The source term is based on the one presented in NRC Regulatory Guide 3.34 [4]. As mentioned previously, this event is due to overfilling of a container of liquid with dissolved uranium. The container has a volume of 1 m^3, with the liquid having a uranium concentration of 400 g/L. The criticality sequence is ongoing for eight hours until enough liquid has vaporised to make the system subcritical [4].

3.1.1. Nuclide content

NRC states that 100 per cent of noble gases (krypton and argon), 25 per cent of iodine, and 0.005 per cent of nonvolatile fission products[2] are produced by the liquid with dissolved uranium in which criticality has arisen [4]. This project has only taken into account noble gases and iodine, including relevant decay products. Cs-137 and other nonvolatile fission products have been excluded from the source term. During the criticality event, substances such as 4.4E+08 Bq Cs-137 are generated [3], of which only 2.2E+04 Bq is released. Here, this activity quantity is negligible, implying that ground deposition of caesium is a risk that can be ruled out at the fuel fabrication plant.

In the dispersion and dose calculations, all the nuclides listed by the NRC [4] have been included. As some of these nuclides have brief half-lives (a few minutes), assumptions concerning durations and possible delays before a release to the surroundings takes place are of key significance for estimating the percentage of generated activity that is released. The representative source term for the criticality event takes into account decay and ingrowth of the originally generated nuclides and relevant decay products. Rb-88, Rb-89, Sr-89 and Cs-138 are included in the source term, as are daughter nuclides of Kr-88, Kr-89 and Xe-138. However, Rb-87, Cs-135 and Cs-137 are excluded from the source term, as ingrowth of these nuclides is negligible due to their relatively long half-lives.

3.1.2. Durations and correcting for decay and ingrowth

The postulated criticality event gives rise to 1E+19 nuclear fissions, of which 10 per cent (1E+18) occur during the first burst. This is followed by additional bursts of 1.9E+17 nuclear fissions every ten minutes over a period of eight hours [4].

In the case of criticality events, SSM set the period of forewarning at five minutes. This is the period of time as of criticality, when the fission products are generated, up until a release commencing from the building. WSE has reported that the period of forewarning may be as brief as a few minutes. In the dispersion and dose calculations, SSM has postulated that the release from each burst has a duration of 10 minutes. The activity content in each release has been corrected for decay and ingrowth up until the middle of the respective release interval.

In conclusion, this means that the activity generated in connection with the criticality event is corrected for decay and ingrowth over a period of 10 minutes (5 minute period of

[2] WSE states that nonvolatile fission products will subsequently reduce by a factor of 3000 by filters before they reach the surroundings [3]. However, it is assumed in this investigation that releases will not pass via filters.

forewarning plus half of the release interval). One-tenth of the activity is released during the first 10 minutes of the release sequence, with the remaining nine-tenths being distributed evenly over the duration of the remaining eight hours that this sequence is ongoing.

Prompt gamma and neutron radiation arises instantaneously in connection with criticality, meaning that there is no period of forewarning. People who are nearby will be irradiated at the same time as the sensors of the criticality alarm. Thus, the prompt radiation generated by the first pulse, corresponding to 10 per cent of the total dose from the promt radiation in this scenario, is unavoidable by taking of protective actions. However, there is potential for avoiding prompt radiation from subsequent pulses, which occur every 10 minutes.

3.1.3. Sensitivity analyses

In WSE's analyses of environmental consequences, the release height was set at 20 m (height of the stack). As the possibility cannot be ruled out that the postulated events analysed can take place simultaneously as, or owing to, other serious events (e.g. powerful earthquakes or large-scale industrial fires), there is a risk that a possible release will not pass through the stack. As the height of the release is a significant factor behind air concentration of radioactive materials in the vicinity of the plant, and thus affecting both inhalation doses and ground deposition, SSM also performed dispersion and dose calculations in which the height of the outlet point was set at 10 m. This height is an approximate level corresponding to the height of the building and a point where the ventilation system connects to the stack. There is nevertheless a possibility that a de facto release might take place through an open door or the like, which would warrant calculations that take an even lower outlet point into account (1-2 m). However, the models used for the dispersion and dose calculations are not valid for releases at heights this low (for example, effects due to the proximity of buildings would be significant). Furthermore, SSM has assumed that this kind of release would instead result in more dire consequences in the absolute vicinity (on-site), because the release is partially retained in the building wake. In contrast, the consequences off-site are likely to be of a smaller magnitude. For this reason, calculations for lower release heights have not been performed.

3.1.4. Representative source term

Table 1 below summarises the representative source term (nuclides and levels of activity for the postulated event with criticality at the fuel fabrication plant. The release of iodine isotopes is assumed to occur in particulate form. Dispersion and dose calculations have been performed for the release heights 10 m and 20 m.

The release it is assumed to originate from the stack of the fuel fabrication plant, which has the coordinates 6613007, 589401 (SWEREF99 TM). No heat content is assumed (i.e. no plume rise[3]).

[3] Plume rise refers to the height to which the release is lifted from the outlet point, depending on the relative heat content of the release in relation to the surroundings.

Table 1. Nuclides and levels of activity of the representative source term for criticality at the fuel fabrication plant in Västerås. The table presents the total release of activity, the activity generated by the first pulse (0-10 min.) and activity from subsequent pulses (10-480 min.). The levels of activity are corrected for decay and ingrowth over a period of 10 minutes.

Release group	**Nuclide**	**Half-life**	**Activity (Bq)**		
			Total	0-10 min.	10-480 min.
Noble gases[1]	Kr-83m	110 min.	5.6E+12	5.6E+11	5.0E+12
	Kr-85	10.8 y	6.1E+07	6.1E+06	5.5E+07
	Kr-85m	4.48 h	5.4E+12	5.4E+11	4.9E+12
	Kr-87	76.3 min.	3.3E+13	3.3E+12	3.0E+13
	Kr-88	2.84 h	2.3E+13	2.3E+12	2.1E+13
	Rb-88[1]	17.8 min.	7.6E+12	7.6E+11	6.8E+12
	Kr-89	3.15 min.	1.7E+14	1.7E+13	1.5E+14
	Rb-89[1]	15.4 min.	2.1E+14	2.1E+13	1.9E+14
	Sr-89[1]	50.5 d	1.6E+10	1.6E+09	1.4E+10
	Xe-131m	11.9 d	3.0E+09	3.0E+08	2.7E+09
	Xe-133	5.24 d	6.7E+10	6.7E+09	6.0E+10
	Xe-133m	2.19 d	1.0E+12	1.0E+11	9.0E+11
	Xe-135	9.14 h	5.3E+13	5.3E+12	4.7E+13
	Xe-135m	15.3 min.	1.4E+13	1.4E+12	1.3E+13
	Xe-137	3.82 min.	3.0E+14	3.0E+13	2.7E+14
	Xe-138	14.1 min.	2.9E+14	2.9E+13	2.6E+14
	Cs-138[1]	33.4 min.	7.1E+13	7.1E+12	6.4E+13
Halogens	I-131	8.02 d	3.2E+11	3.2E+10	2.9E+11
	I-132	2.30 h	3.9E+13	3.9E+12	3.5E+13
	I-133	20.8 h	5.9E+12	5.9E+11	5.3E+12
	I-134	52.5 min.	1.5E+14	1.5E+13	1.3E+14
	I-135	6.57 h	1.7E+13	1.7E+12	1.5E+13

[1] Including decay products from noble gases.

3.2. Fire with a release of uranium powder

SSM has defined a representative source term for the postulated event involving a fire with a release of uranium powder. The source term encompasses 1,000 kg of uranium dioxide (equivalent to approximately 880 kg of uranium) with a degree of enrichment of U-235 of 3.9 per cent. Chemical separation of the fuel is assumed to have taken place more than 100 days ago.

3.2.1. Enrichment

Natural uranium is made up of U-238 (99.3 per cent), U-235 (0.7 per cent) and U-234 (0.005-0.006 per cent). Enriched uranium hexafluoride is handled in the fuel fabrication plant. WSE has stated that the average enrichment, that is, the percentage of U-235 in the uranium to be converted over the next twelve months, is 3.9 per cent. During the enrichment process, the concentration of U-234 is also increased to the same extent as U-235 (due to a small difference in atomic mass). Given a conservative assumption regarding the concentration of U-234 in natural uranium (0.006 per cent), this results in U-234 having a concentration of 0.033 per cent in the enriched uranium.

3.2.2. Selection of nuclides

In nature, uranium isotopes occur together with decay products in their respective decay chains. During the enrichment process, the uranium is chemically separated from other elements, resulting in removal of the decay products. However, after the separation, ingrowth of decay products reoccurs. The activity of the respective decay product will therefore be determined by the duration since chemical separation, and the nuclides' half-lives. The first parts of these decay chains for U-238 and U-235 are illustrated by Figure 2. In its calculated levels of activity for decay products of uranium, SSM assumes that a minimum of 100 days have passed since separation.

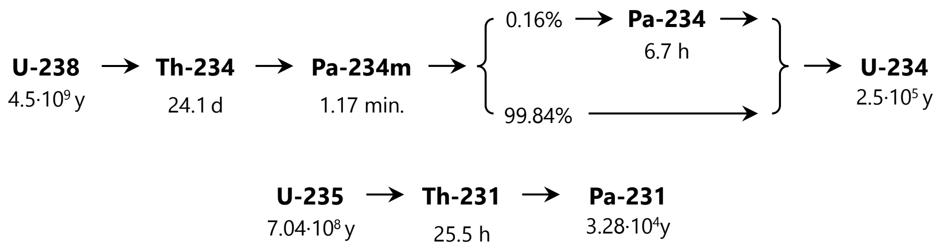

Figure 2. Parts of decay chains (with half-lives) for U-238 and U-235 of relevance for source terms from the fuel fabrication plant.

The activity of decay products with half-lives shorter than the parent nuclide is built up until equilibrium is achieved. Full equilibrium is achieved after a duration equivalent to approximately 10 half-lives on the part of the decay product. The activity of Th-234 is 94 per cent of the activity of U-238 after 100 days [7] (see Figure 3). In its turn, Pa-234m will achieve equilibrium with Th-234 within approximately 15 minutes. The half-life of U-234 is so long that the ingrowth of this nuclide is negligible in these contexts. In the decay chain of U-235, Th-231 achieves equilibrium with U-235 within around 10 days. Ingrowth of Pa-231 is negligible (see Figure 4).

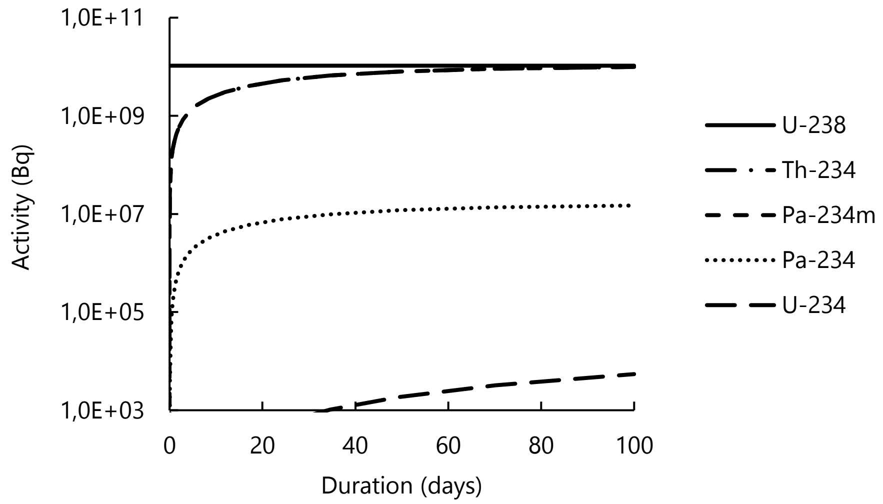

Figure 3. Ingrowth of decay products of U-238 over a period of 100 days. Decay products of U-234 are excluded. The initial level of activity of U-238 is 1.05E+10 Bq. Note that Pa-234m is in equilibrium with Th-234, for which reason the curves overlap in the diagram.

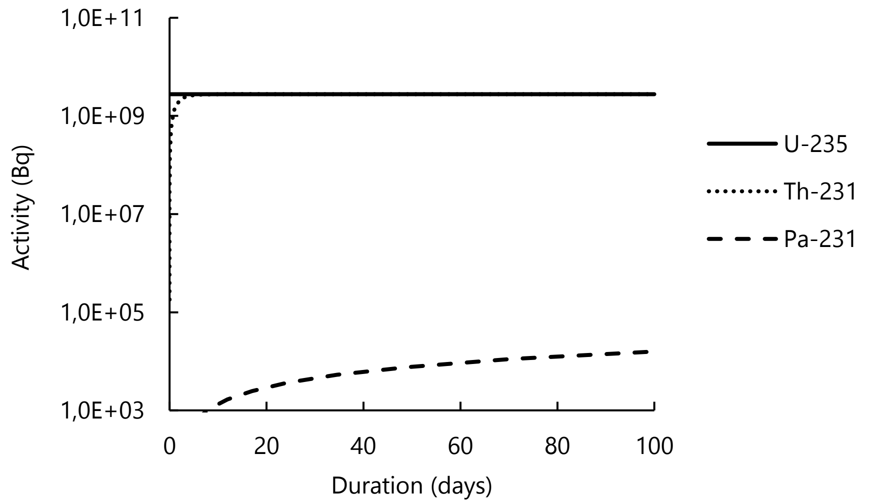

Figure 4. Ingrowth of decay products of U-235 over a period of 100 days. Decay products of Pa-231 are excluded. The initial level of activity of U-235 is 2.75E+09 Bq.

Apart from the uranium isotopes of U-234, U-235 and U-238, SSM has also included Th-231, Th-234 and Pa-234m in the source term for the event involving a fire with a release of uranium powder. The decay products are nonetheless expected to contribute slightly to total dose. Pa-234 is excluded because the branching ratio for decay to this nuclide is only 0.16 per cent. Also, the dose coefficient for Pa-234 in connection with inhalation is only circa 1/1000th of the dose coefficient for U-238 [8]. Consequently, the dose contribution from Pa-234 is negligible.

Th-234 and Pa-234m are assumed to be in equilibrium with U-238, and Th-231 in equilibrium with U-235. The levels of activity of the defined source term are illustrated in Table 2 of section 3.2.4.

3.2.3. Sensitivity analyses

As the height of the release is a significant factor behind air concentration of radioactive materials in the vicinity of the plant, and thus affects both inhalation doses and ground deposition, dispersion and dose calculations were performed in which the heights of outlet points were set at both 10 m and 20 m (see section 3.1.3).

In the case of the fire with a release of uranium powder, SSM also investigated the impact of assumed particle size and density. When estimating levels of ground deposition, these parameters are decisive for the outcome, because they influence deposition velocity. Particle size is also of significance for inhalation doses, since larger particles have lower dose coefficients due to the particles being absorbed at a lower rate by the respiratory system.

The particle size in the dispersion and dose calculations varies between 1 µm, 5 µm, and 10 µm. It is difficult to predict the de facto particle size in a release. WSE has stated that assuming a particle size of 5 µm is feasible, based on a study of occurring particle sizes in the air inside the fuel fabrication plant [9]. However, the same conditions might not apply after the uranium has accumulated on filters, followed by a subsequent fire that spreads the uranium into the surroundings. For this reason, SSM does not make assumptions on the most probable particle size. Particle sizes larger than 10 µm have not been taken into account. Larger particles have a substantially higher deposition velocity, which results in greater concentrations in the vicinity of the plant, and thus shorter distances where dose criteria may be exceeded. Due to lower dose coefficients, larger particle sizes will also result in lower inhalation doses.

Apart from particle size, SSM also elected to look into the impact of density on outcomes of the dispersion and dose calculations. WSE stated that the density of the uranium in the fuel fabrication plant can vary in the range of 1.3-10.5 g/cm^3. SSM performed dispersion and dose calculations using densities of 1 g/cm, 5 g/cm, and 10 g/cm^3.

Lastly, SSM postulated two different release durations: 60 minutes and 300 minutes. WSE stated that the fire is assumed to burn for 5 hours. It is possible that a shorter release sequence may result in higher radiation doses, as the released activity could be spread over a smaller area due to smaller shifts in wind direction.

3.2.4. Representative source term

An overview of nuclides and released activity is provided in Table 2 Values for other source term parameters are presented in Table 3. Uranium and thorium are assumed to be of absorption type S.

The release is assumed to originate from the stack of the fuel fabrication plant, which has the coordinates 6613007, 589401 (SWEREF99 TM). No heat content is assumed (i.e. no plume rise).

In an event involving a fire in the process ventilation system, the risk cannot be ruled out that a general emergency is declared first when elevated activity concentrations are detected in the stack. For this reason, SSM assumed that there is no time for forewarning that gives scope for taking of protective actions before the release commences.

Table 2. Nuclides and levels of activity of the representative source term for a fire with a release of uranium powder.

Nuclide	**Half-life**	**Percentage** (of uranium)	**Mass** (kg)	**Specific act.** (Bq/g)	**Activity** (Bq)
U-234	2.46E+05 y	0.00033	0.29	2.3E+08	6.8E+10
U-235	7.04E+08 y	0.039	34	8.0E+04	2.7E+09
U-238	4.47E+09 y	0.96	850	1.2E+04	1.0E+10
Th-234[1]	24.1 d	-	1.2E-08	8.6E+14	1.0E+10
Th-231[2]	25.5 h	-	1.4E-10	2.0E+16	2.7E+09
Pa-234m[1]	1.17 min.	-	4.1E-13	2.5E+19	1.0E+10

[1] in equilibrium with U-238

[2] in equilibrium with U-235

Table 3. Parameter values used in sensitivity analyses.

Parameter	**Values**
Height (m)	10, 20
Release duration (min.)	60, 300
Particle size (µm)	1, 5, 10
Density (g/cm^3)	1, 5, 10

4. Dispersion and dose calculations

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

This chapter presents outcomes showing the distances at which dose criteria are exceeded for evacuation and sheltering, in addition to intake of ITB. The greatest distance at which a dose criterion is exceeded, given a certain percentage of weather scenarios being taken into account, was used by SSM as a basis for the dimensioning of the respective protective action. The intervention level for ground deposition of uranium was used to indicate the areas within which advice and recommendations to the public are warranted for the purpose of reducing ingestion of radioactive substances. For more information about dispersion and dose calculations, as well as dose criteria and intervention levels, please refer to the main report.

4.1. Criticality

Outcomes are presented below from dispersion and dose calculations for the postulated event involving criticality. Besides a release of fission products, the criticality process also gives rise to prompt radiation, both gamma radiation and neutrons. Thus, in order to correctly estimate environmental consequences, this means adding radiation doses from releases of fission products and radiation doses from prompt radiation. The dose from prompt radiation can be estimated using Equations 1 and 2 below [4].

$$D_\gamma = \frac{2.1 \cdot 10^{-19} \cdot N}{d^2 \cdot e^{3.4d}} \tag{1}$$

$$D_n = \frac{7 \cdot 10^{-19} \cdot N}{d^2 \cdot e^{5.2d}} \tag{2}$$

In the equations above, D_γ and D_n represent the dose in mSv from gamma radiation and neutron radiation, respectively. N is the number of nuclear fission reactions, and d represents the distance in km.

In order to estimate radiation doses to the population, protection from prompt radiation (calculated using the equations above) is assumed in the form of shielding equivalent to 20 cm of concrete. The resulting shielding factors are 2.3 for neutron radiation and 2.5 for gamma radiation [4]. The resulting total radiation doses are shown in Figure 5 below. However, it should be noted that only one-tenth of the total dose from direct radiation is generated by the initial puls; 90 per cent of the dose is evenly distributed over the remaining eight hours during which the process is ongoing, (in one burst every 10 minutes). This gives good potential to reduce exposure by taking the relevant protective actions.

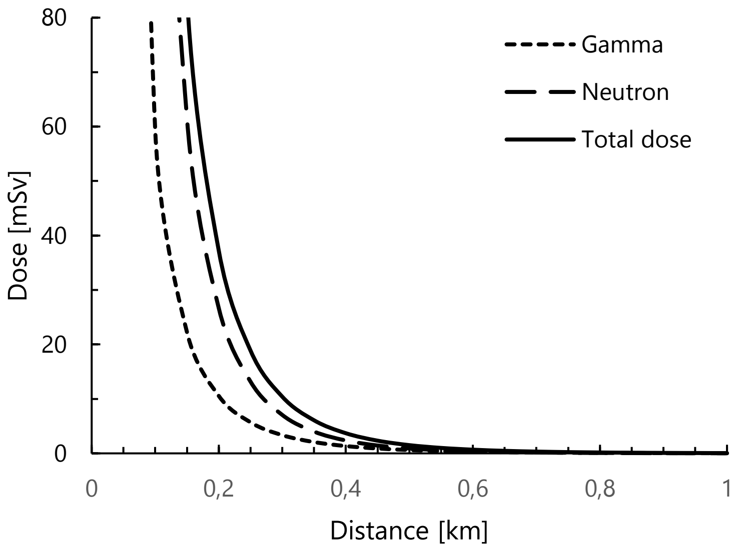

Figure 5. Effective dose from prompt radiation to an unprotected person who is outdoors throughout the criticality event. Shielding equivalent to 20 cm of concrete is assumed.

4.1.1. Evacuation and relocation

Dispersion and dose calculations pertaining to releases of fission products during the criticality event demonstrate that the dose criterion for evacuation, at 20 mSv effective dose, is not exceeded off-site during the postulated criticality event. However, due to prompt radiation, this dose criterion may be exceeded out to a distance of approximately 250 m (see Figure 5).

As the release mainly constitutes noble gases (which do not deposit on the ground) as well as iodine isotopes that all are relatively short-lived, no ground deposition can occur that warrants relocation after a release.

4.1.2. Sheltering

The greatest distance at which the dose criterion for sheltering, at 10 mSv effective dose, is exceeded for children is shorter than 100 m in 90 per cent of the weather scenarios, in the case of a release height of 10 m (see Figure 6). Distances are shorter in the case of a release height of 20 m and in relation to adults (both release heights).

Direct radiation may result in exceeding the dose criterion for sheltering out to a distance of approximately 300 m (see Figure 5).

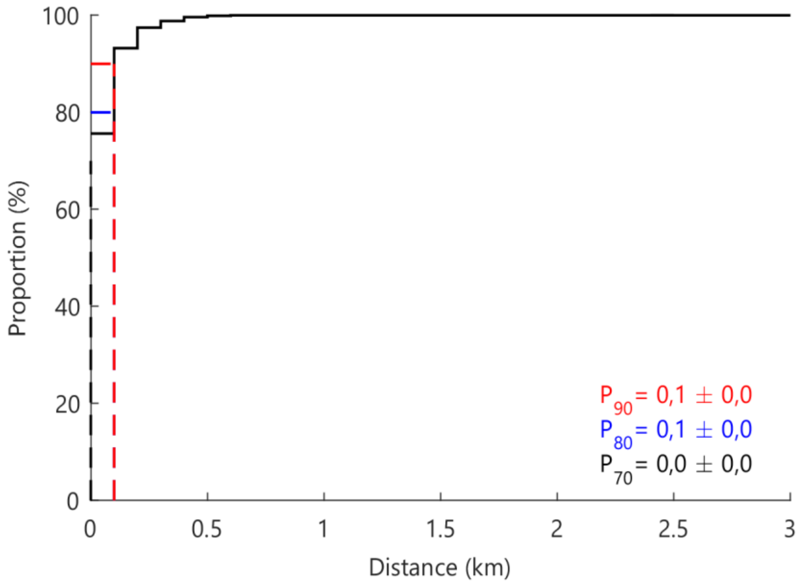

Figure 6. Distribution of the greatest distances at which the dose criterion for sheltering, at 10 mSv effective dose to children, is exceeded in the case of the criticality event at the fuel fabrication plant, and for the release height of 10 m. In the diagram, the 70th, 80th and 90th percentiles are marked.

4.1.3. Iodine thyroid blocking

The dose criterion of 50 mSv equivalent dose to the thyroid is exceeded off-site solely in the case of children at a release height of 10 m. The greatest distances at which the dose criterion is exceeded are less than 300 m in 90 per cent of the weather scenarios analysed (see Figure 7).

SSM has also studied the distances at which equivalent dose to the thyroid on the part of children might exceed 10 mSv. In this context, the results indicate the distances at which it would be warranted to recommend sheltering for the purpose of reducing doses to the thyroid, even in a case where the level of thyroid dose does not warrant predistribution of ITB. In the case of a release occurring via the stack (a height of 20 m), the greatest distance at which the level is exceeded is shorter than 500 m in 80 per cent of the occurring weather scenarios. At a release height of 10 m, the distance increases to 900 m.

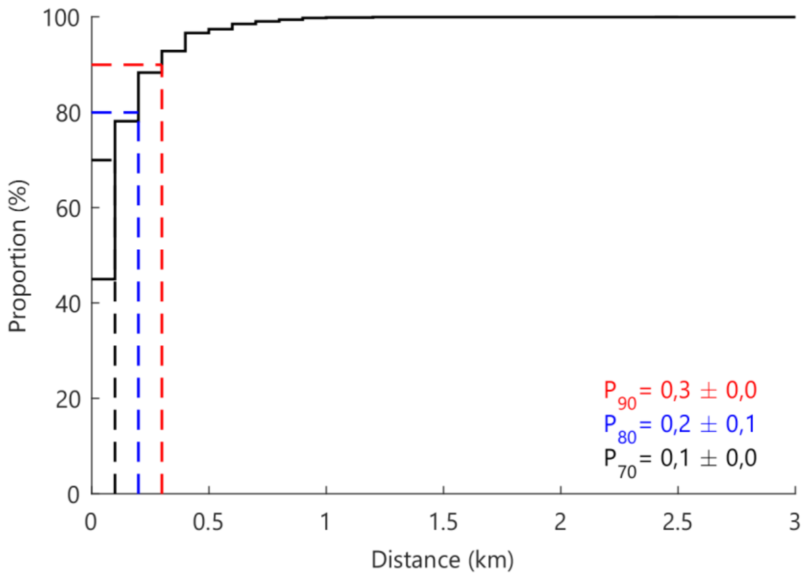

Figure 7. Distribution of the greatest distances at which the dose criterion 50 mSv equivalent dose to the thyroid on the part of children is exceeded in the case of the criticality event at the fuel fabrication plant, and for the release height of 10 m. In the diagram, the 70th, 80th and 90th percentiles are marked.

4.1.4. Ground deposition

The respective outcomes for ground deposition of iodine (I-131) and strontium (Sr-89 and Sr-90) are shown in Figure 8 and Figure 9. The intervention level for ground deposition of I-131, at 5 kBq/m^2, may be exceeded out to a distance of approximately 3.5 km. The intervention level corresponds to a level of ground deposition on pasture land that might lead to exceeding the EU’s maximum permitted levels for foodstuffs/radioactive contamination limits for foodstuffs in the case of milk. However, I-131 has a half-life of approximately eight days. Consequently, ground deposition is not a long-term concern. Ground deposition of strontium exceeding the intervention level (10 kBq/m^2 for the total of Sr-89 and Sr-90), and thus with a potential impact on food production, can only occur in the immediate vicinity around the facility.

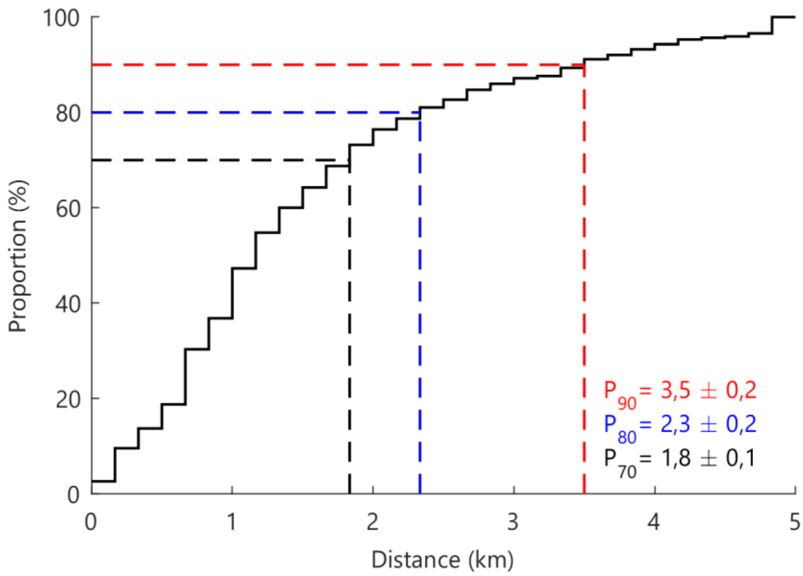

Figure 8. Distribution of the greatest distances at which the intervention level of 5 kBq/m^2 of I-131 is exceeded in the case of the criticality event at the fuel fabrication plant, and for the release height of 10 m. In the diagram, the 70th, 80th and 90th percentiles are marked.

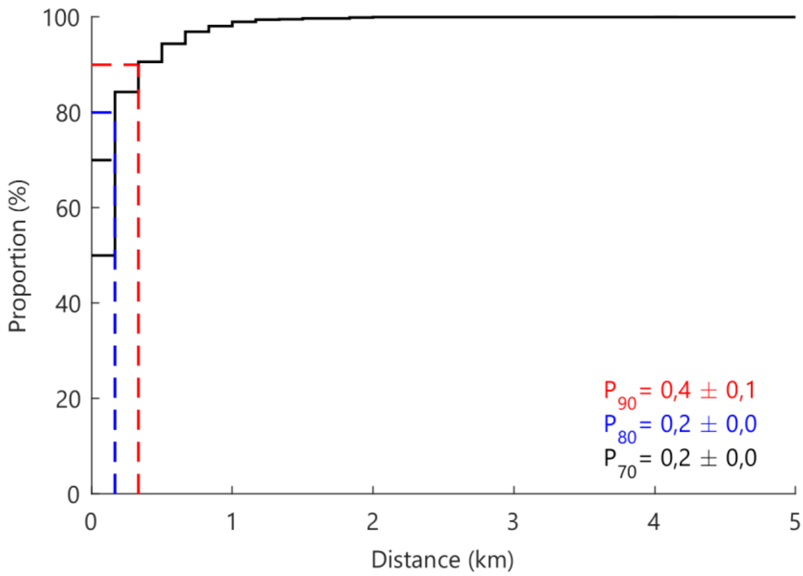

Figure 9. Distribution of the greatest distances at which the intervention level of 10 kBq/m^2 total ground deposition of Sr-89 and Sr-90 is exceeded in the case of the criticality event at the fuel fabrication plant, and for the release height of 10 m. In the diagram, the 70th, 80th and 90th percentiles are marked.

4.2. Fire with a release of uranium powder

Outcomes of dispersion and dose calculations for the event involving a fire with a release of uranium powder are presented below. The main outcomes presented relate to adults, as the dose criteria in connection with events involving releases of uranium powder are generally exceeded at distances that are somewhat greater for adults than compared to children. Children usually receive higher radiation doses than adults because children are more sensitive to radiation (higher dose coefficients). However, events involving fire with a release of uranium powder are predominated by the dose contribution from inhalation. Adults receive a higher intake of uranium owing to their higher rate of inhalation (volume per unit of time) compared to children [10]. The relative difference in inhalation rate is, in this case, greater than the relative difference in dose coefficients between children and adults. The older the child, the smaller the difference in received dose compared with adults; when comparing between 15-year-olds and adults, there is no significant difference in dose.

4.2.1. Evacuation and relocation

For an illustration of the distribution of distances at which the dose criterion is exceeded for evacuation in the event of a fire with a release of uranium powder, at 20 mSv effective dose in the case of adults, see Figure 10. The greatest distance at which the dose criterion is exceeded is shorter than 300 m in 80 per cent of the occurring weather scenarios. In the case of smaller particle sizes, the distances may be somewhat longer.

It is unwarranted to carry out relocation due to ground deposition following a fire with a release of uranium powder.

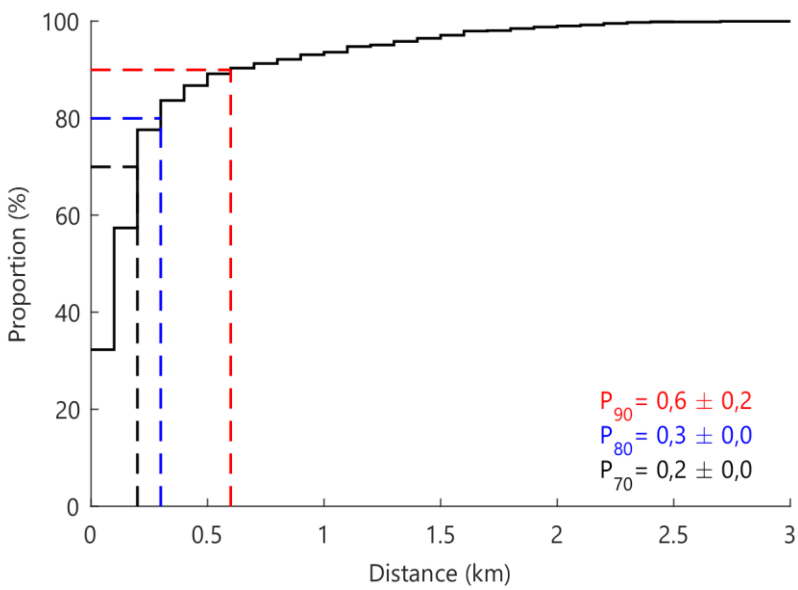

Figure 10. Distribution of the greatest distances at which the dose criterion of 20 mSv total effective dose is exceeded in the case of adults in the event of a fire with a release of uranium powder from the fuel fabrication plant (particle size 5 µm; density 5 g/cm^3; release height 10 m; release duration 60 min.). In the diagram, the 70th, 80th and 90th percentiles are marked.

4.2.2. Sheltering

For an illustration of the distribution of distances at which the dose criterion for sheltering, at 10 mSv effective dose in the case of adults, is exceeded in the event of a fire with a release of uranium powder, see Figure 11. The greatest distance at which the dose criterion is exceeded is shorter than 600 m in 80 per cent of the occurring weather scenarios.

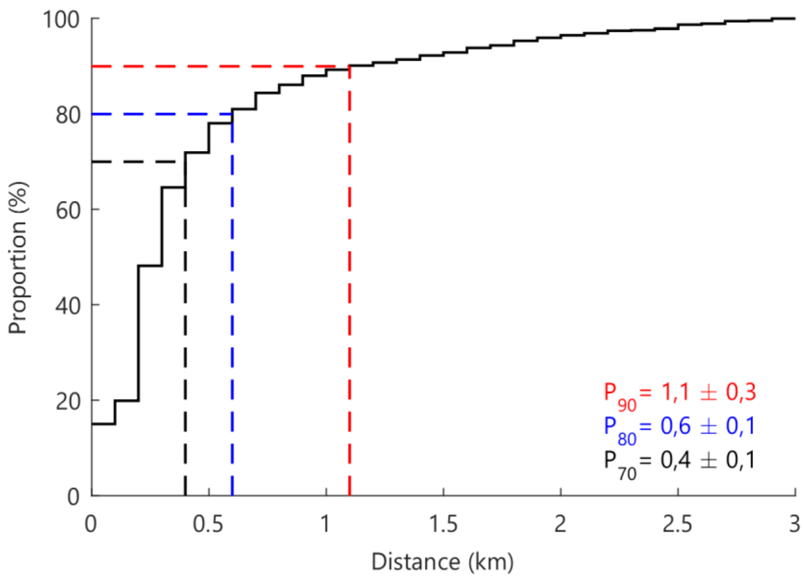

Figure 11. Distribution of the greatest distances at which the dose criterion of 10 mSv total effective dose is exceeded in the case of adults in the event of a fire with a release of uranium powder from the fuel fabrication plant (particle size 5 µm; density 5 g/cm^3; release height 10 m; release duration 60 min.). In the diagram, the 70th, 80th and 90th percentiles are marked.

Figures 12 to 15 illustrate the impacts of particle size, density, release height and release duration. Particle size has a substantial impact on the outcome, where larger particle sizes result in lower radiation doses. This is because larger particles are absorbed at a lower rate by the respiratory system, and for this reason have lower dose coefficients. On the other hand, particle density has little impact on the outcome. A certain tendency is apparent in the form of fewer outcomes at great distances. This may be explained by higher rate of deposition in the vicinity of the plant, and thus lower air concentrations at greater distances. The dose coefficients for inhalation are the same for different densities, but the deposition velocity is closely correlated to this parameter. In the same way as for releases owing to criticality, lower release height gives higher radiation doses in the vicinity of the plant, and thus larger distances at which the dose criteria are exceeded. This also applies to a shorter release sequence, although the impact on the outcome is smaller for this parameter.

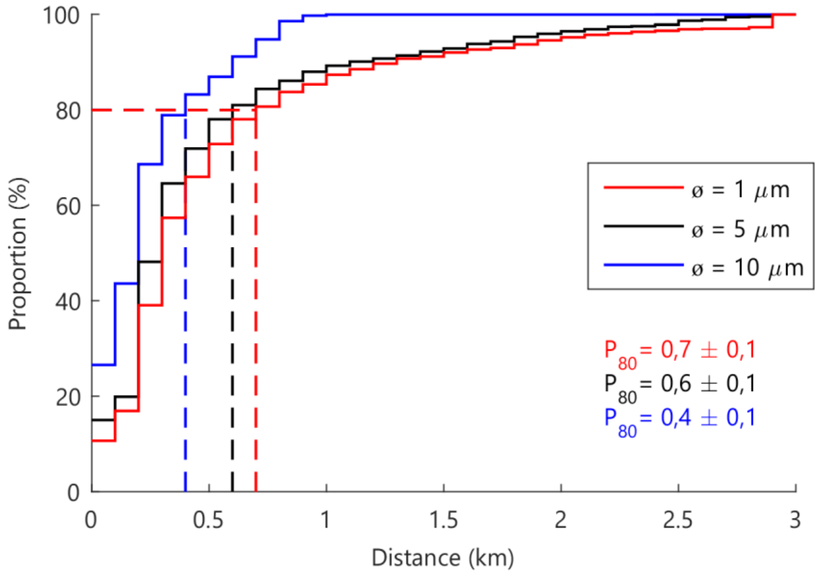

Figure 12. Outcome of sensitivity analysis for the impact of particle size (ø) on the distribution of the greatest distances at which the dose criterion of 10 mSv effective dose is exceeded in connection with a postulated event involving a fire with a release of uranium powder from the fuel fabrication plant. Density of 5 g/cm^3, release height 10 m, release duration 60 min. The 80th percentile for the distance is marked in the diagram in relation to respective particle sizes.

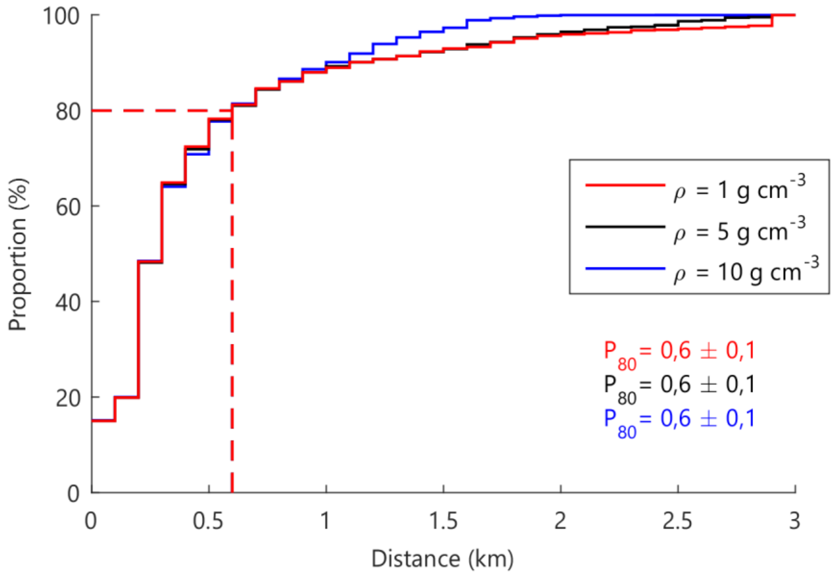

Figure 13. Outcome of sensitivity analysis for the impact of density (ρ) on the distribution of the greatest distances at which the dose criterion of 10 mSv effective dose is exceeded in connection with a postulated event involving a fire with a release of uranium powder from the fuel fabrication plant. Particle size 5 µm, release height 10 m, release duration 60 min. The 80th percentile for the distance is marked in the diagram in relation to respective densities.

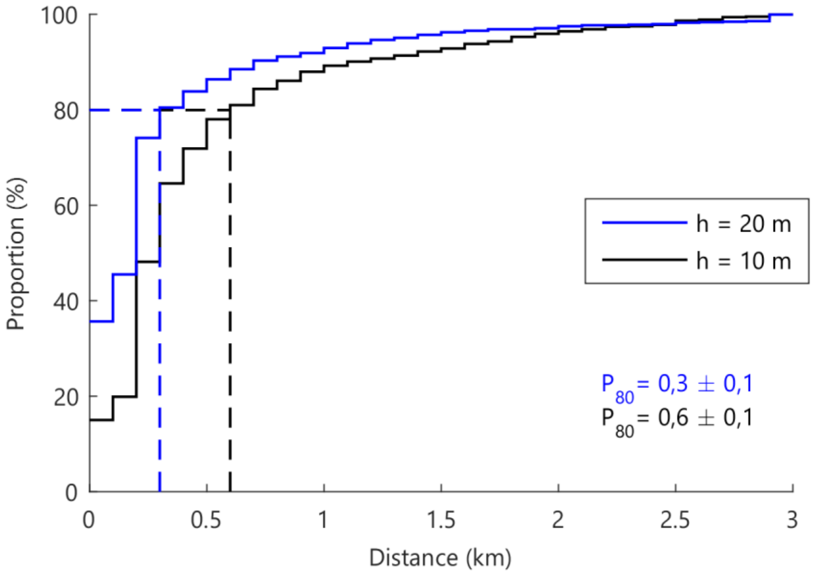

Figure 14. Outcome of sensitivity analysis for the impact of release height (h) on the distribution of the greatest distances at which the dose criterion of 10 mSv effective dose is exceeded in connection with a postulated event involving a fire with a release of uranium powder from the fuel fabrication plant. Particle size 5 µm, density 5 g/cm^3, release duration 60 min. The 80th percentile for the distance is marked in the diagram in relation to respective heights.

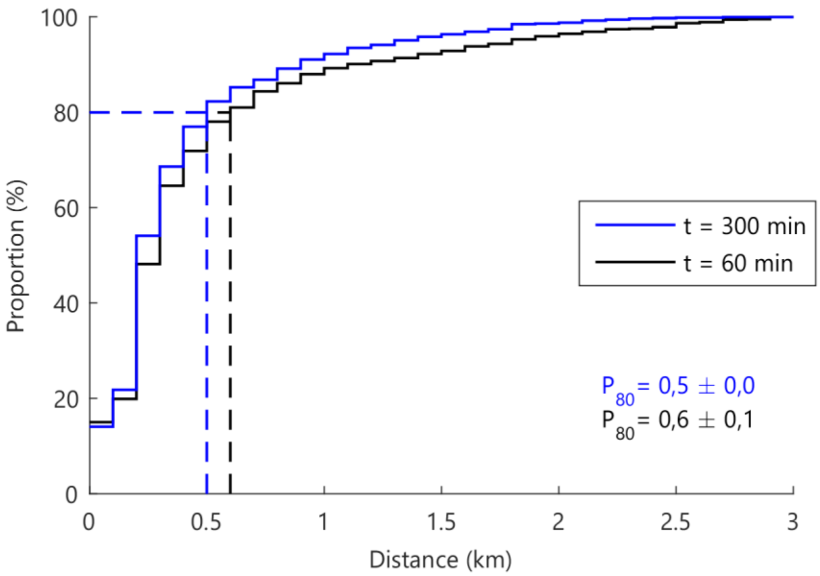

Figure 15. Outcome of sensitivity analysis for the impact of release duration (t) on the distribution of the greatest distances at which the dose criterion of 10 mSv effective dose is exceeded in connection with a postulated event involving a fire with a release of uranium powder from the fuel fabrication plant. Particle size 5 µm, density 5 g/cm^3, release height 10 m. The 80th percentile for the distance is marked in the diagram in relation to respective durations.

4.2.3. Ground deposition

For an illustration of the distribution of the greatest distances at which the intervention level of 10 kBq/m^2 of uranium (the total of U-234, U-235 and U-238) is exceeded in the case of a fire with a release of uranium powder, see Figure 16. The greatest distance at which the intervention level is exceeded is shorter than 2 km in 80 per cent of the weather scenarios analysed.

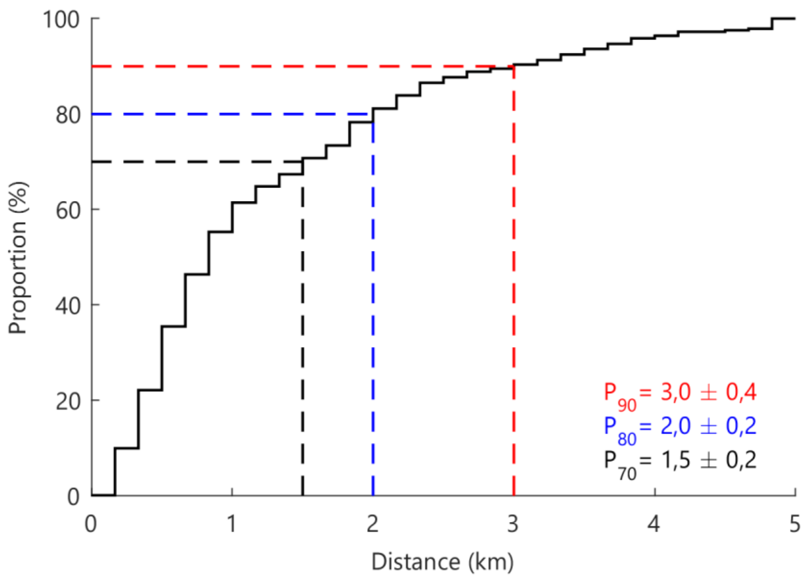

Figure 16. Distribution of the greatest distances at which the intervention level of 10 kBq/m^2 total ground deposition of U-234, U-235 and U-238 is exceeded in the case of a fire with a release of uranium powder from the fuel fabrication plant (particle size 5 µm; density 5 g/cm^3; release height 10 m; release duration 60 min.). In the diagram, the 70th, 80th and 90th percentiles are marked.

Figures 17 to 20 illustrate the impacts of particle size, density, release height and release duration at distances where the intervention level for ground deposition is exceeded. Particle size and density both have a significant effect on the outcomes. However, the ground deposition appears to be less significantly impacted by the height of the outlet point. Statistically, the difference in outcomes is insignificant. Shorter release sequences give slightly larger distances.

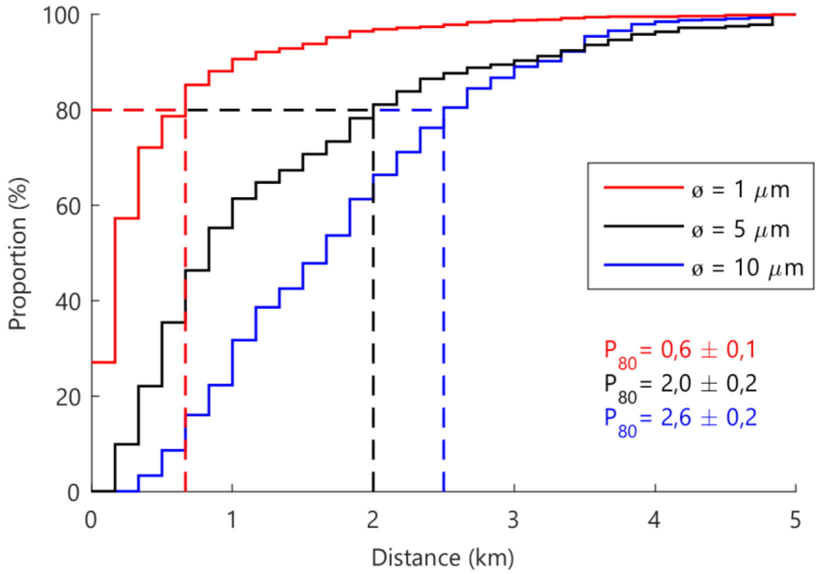

Figure 17. Outcome of sensitivity analysis for the impact of particle size (ø) on the distribution of the greatest distances at which the intervention level of 10 kBq/m^2 of total ground deposition of U-234, U-235 and U-238 is exceeded in the event of a fire with a release of uranium powder from the fuel fabrication plant. Density 5 g/cm^3, release height 10 m, release duration 60 min. The 80th percentile for the distance is marked in the diagram in relation to respective particle sizes.

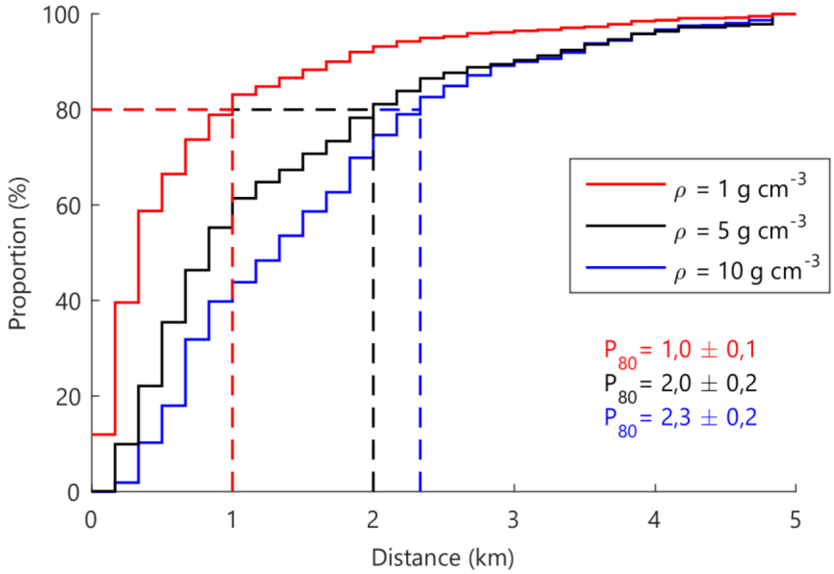

Figure 18. Outcome of sensitivity analysis for the impact of density (ρ) on the distribution of the greatest distances at which the intervention level of 10 kBq/m^2 of total ground deposition of U-234, U-235 and U-238 is exceeded in the event of a fire with a release of uranium powder from the fuel fabrication plant. Particle size 5 µm, release height 10 m, release duration of 60 min. The 80th percentile for the distance is marked in the diagram in relation to respective densities.

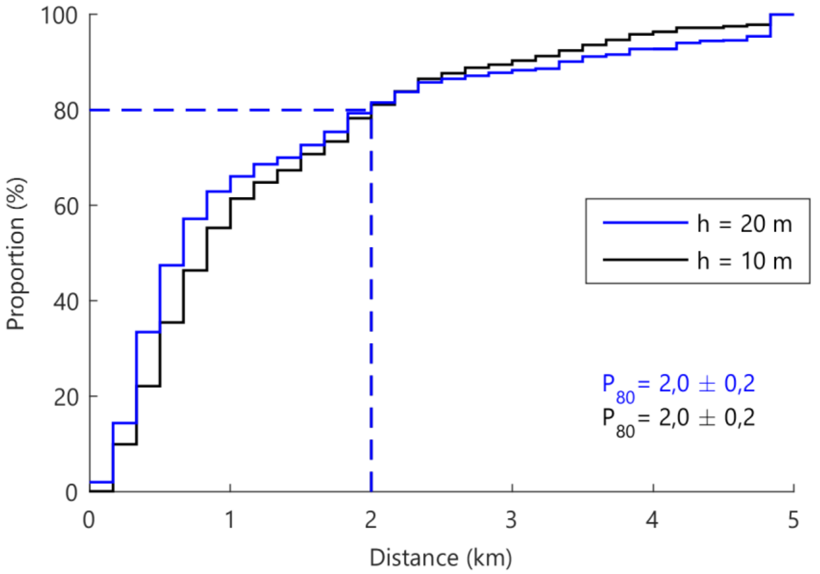

Figure 19. Outcome of sensitivity analysis for the impact of release height (h) on the distribution of the greatest distances at which the intervention level of 10 kBq/m^2 of total ground deposition of U-234, U-235 and U-238 is exceeded in the event of a fire with a release of uranium powder from the fuel fabrication plant. Particle size 5 µm, density 5 g/cm^3, and release duration of 60 min. The 80th percentile for the distance is marked in the diagram in relation to respective heights.

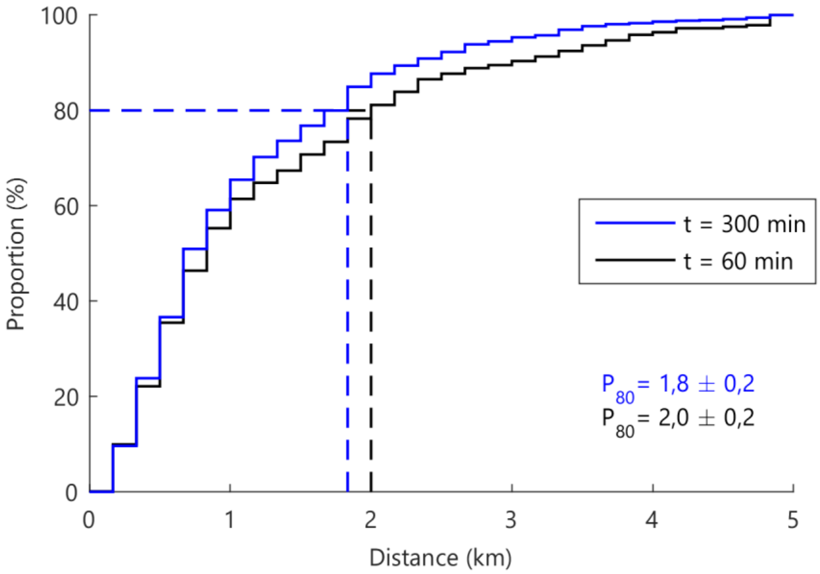

Figure 20. Outcome of sensitivity analysis for the impact of release duration (t) on the distribution across the greatest distances at which the intervention level of 10 kBq/m^2 of total ground deposition of U-234, U-235 and U-238 is exceeded in the event of a fire with a release of uranium powder from the fuel fabrication plant. Particle size 5 µm, density 5 g/cm^3, and release height 10 m. The 80th percentile for the distance is marked in the diagram in relation to respective durations.

5. Emergency planning zones and distances

The results from the dispersion and dose calculations show that in the cases of the postulated events, it is warranted to recommend sheltering in the area surrounding the fuel fabrication plant. For this reason, SSM suggests the establishment of an urgent protective action planning zone (UPZ) to surround this facility.

However, the postulated events at the fuel fabrication plant do not give rise to such ground depositions as to warrant relocation. Consequently, there is no need to establish the kind of extended planning distance (EPD) proposed by SSM to surround the NPPs, or around the central interim storage facility for spent nuclear fuel (Clab).

SSM's proposals:

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

5.1. The basis for the urgent protective action planning zone

5.1.1. Evacuation

The greatest distance at which the dose criterion for evacuation, at 20 mSv effective dose, is exceeded is shorter than 300 m in 80 per cent of the weather scenarios. In the case of unfavourable conditions (minute particle size and low release height), and if 90 per cent of the weather scenarios are taken into account, this distance increases to 700 m. Nonetheless, SSM is of the opinion that planning for evacuation of the public in this area is unwarranted, since sheltering provides sufficient protection. Most of the buildings in this area are industrial premises that would provide satisfactory protection against not only inhalation of radioactive materials, but also exposure to the passing cloud. An additional perspective is that most of the postulated events at the fuel fabrication plant are of relatively brief duration, suggesting a lack of time for carrying out evacuation before a release occurs. Thus, evacuation risks resulting in outdoor exposure of individuals while the plume passes, giving higher radiation doses.

5.1.2. Sheltering

The results from the dispersion and dose calculations show that if an event should occur involving a fire with a release of uranium powder, it is warranted to recommend sheltering in the area surrounding the fuel fabrication plant. The greatest distance at which the dose criterion for sheltering, at 10 mSv effective dose, is exceeded is shorter than approximately 600 m in 80 per cent of the weather scenarios (Figure 11). However, this distance hinges upon the parameters selected, where both particle size and release height in particular have a major impact on the outcomes. It is impossible to predict the characteristics of a release in real life (in terms of these parameters).

The present UPZ surrounding the fuel fabrication plant is a minimum range of approximately 700 m. This distance signifies that the estimated radiation doses outside this zone are below the dose criterion for sheltering in just over 80 per cent of the weather scenarios (Figure 11). As far as concerns most combinations of values belonging to the parameters defined in the sensitivity analyses, the radiation doses will be lower; in other words, doses remain below the dose criteria at the zone boundary in the majority of weather scenarios. In no case does the percentage of weather scenarios where the dose criterion is exceeded at the zone boundary fall below 80 per cent. As a result, SSM is of the view that the range of the present UPZ is adequate for the most part. It may be warranted to slightly increase its size, provided that this larger zone does not unreasonably complicate the practical management of an event. For example, the UPZ should be reasonably easy to cordon off by means of limited resources.

Sheltering also provides protection against direct radiation from a criticality event. The buildings closest to the fuel fabrication plant are at a distance of approximately 300 m. An unprotected individual present at this distance throughout the criticality sequence would receive a dose from prompt gamma and neutron radiation of approximately 10 mSv (Figure 5). The dose drops quickly in pace with increasing distance. In the assessment of SSM, sheltering within an area of approximately 700-800 m from the fuel fabrication plant also gives adequate protection during a criticality event.

5.1.3. Iodine thyroid blocking

According to outcomes of the dispersion and dose calculations, the dose criterion of 50 mSv equivalent dose to the thyroid on the part of children is not exceeded at distances beyond approximately 300 m from the fuel fabrication plant. However, the calculations do show that out to a distance of approximately 1 km, it may be warranted to recommend sheltering in order to reduce thyroid dose on the part of children. This is due to a risk of exceeding the level of 10 mSv equivalent dose to the thyroid.

At the present time, there are no residents or preschools within this distance from the fuel fabrication plant. Here, the buildings mainly comprise industrial premises. The only school in the area is ABB Industrigymnasium, an upper secondary school located approximately 800 m from the fuel fabrication plant. SSM is of the opinion that predistribution of ITB to students at the school is unwarranted, since staying indoors in the school building gives adequate protection against inhalation of radioactive materials. Furthermore, for optimal protection, iodine tablets should be taken before possible inhalation of radioactive iodine. Consequently, iodine thyroid blocking gives only limited protection during events without any forewarning plus a brief sequence.

5.2. The proposed urgent protective action planning zone

The Västmanland County Administrative Board has proposed a new design for the extent of the proposed UPZ to surround the fuel fabrication plant, as illustrated by Figure 21. The proposal is based on the existing emergency planning zone. The detailed design of the UPZ was prepared in consultation with SSM, MSB and the City of Västerås. In the proposed zone, sheltering should be recommended in connection with criticality events as well as during suspected or observed releases of uranium due to a fire.

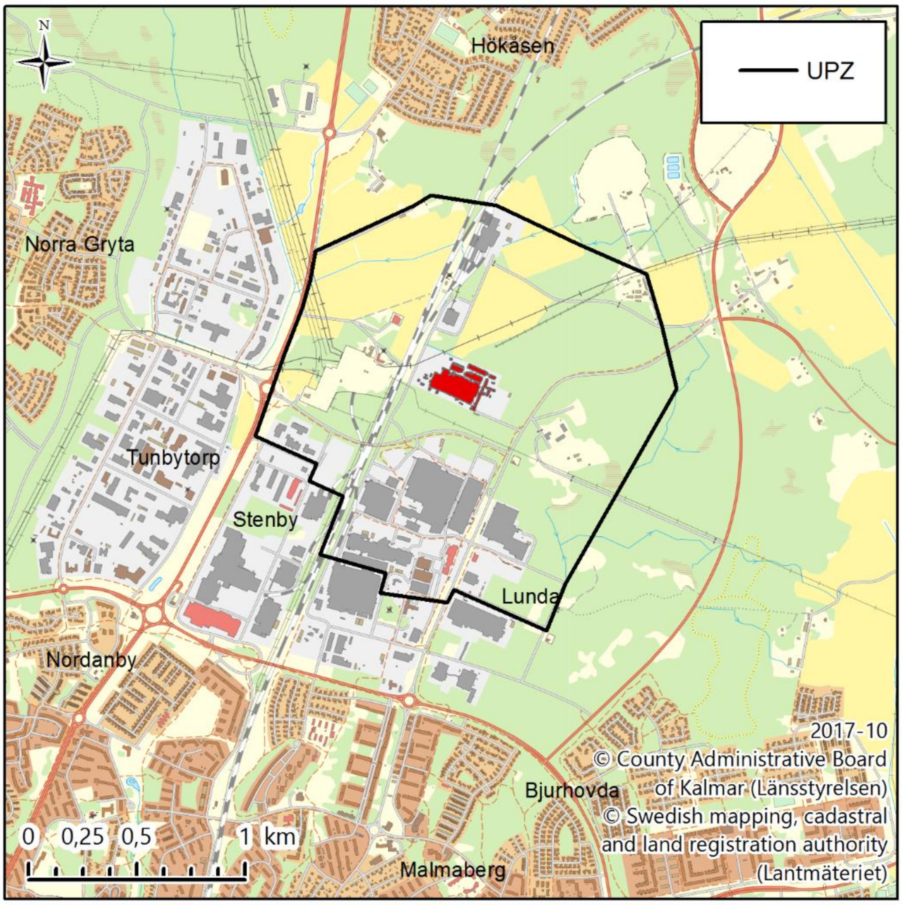

Figure 21. Proposed urgent protective action planning zone (UPZ) to surround the fuel fabrication plant in Västerås.

The UPZ has been extended somewhat towards the south in order to include the ABB Industrigymnasium trade school and an adjacent restaurant.

The design of this zone towards the southwest has been adapted to enable effective emergency response. Traffic to and from this area is facilitated by excluding certain roads and buildings from the UPZ.

The road Bergslagsvägen (road 56), west of the fuel fabrication plant, serves as a key through road. This road passes around 800 m from the plant, and is to constitute a section of the geographical outer boundary of the UPZ. Possible cordoning off of the UPZ are facilitated by excluding the road itself from this zone. Instead, the zone boundary should be defined as constituting the eastern edge of the road. In the assessment of SSM, an individual travelling along this road at the time of an ongoing release will receive a negligible dose.

Train services between Västerås and Stockholm pass close by the plant. Train services should be suspended in the event of a declared general emergency at the fuel fabrication plant. During a limited period of time, this is not expected to give rise to major difficulties. It should be possible to have these services resume as soon as it has been established that the event is under control and that any releases have ceased. In the assessment of SSM, an individual travelling here by train once a release has ceased will receive a negligible dose.

A power grid station is located west of the fuel fabrication plant. This station is a key node for the supply of power. Usually, the power grid station is unstaffed. Its location should not affect the design of the proposed UPZ. Nonetheless, it is important to have the power grid station taken into account as part of emergency preparedness planning. This is to facilitate necessary and urgent maintenance or repair measures so that they, if needed, can be performed in the event of a declared general emergency at the fuel fabrication plant.

5.2.1. Checks for personal contamination

SSM considers it unwarranted to carry out large-scale checks for personal contamination of members of the public who were present outside the facility at the time of a release from the fuel fabrication plant. As a precaution, affected individuals may be advised to shower and to wash their hair once they are home, as well as change and launder their clothing.

During unfavourable conditions (particle size 10 µm, density 10 g/cm^3, height 10 m, duration 60 min.), ground deposition of 100 kBq/m^2 (total of U-234, U-235 and U-238) may in most weather scenarios (90 per cent) occur at a maximum distance of 800 m from the outlet point. Assuming that an individual is outdoors while the entire plume passes, the committed effective dose will be (including the relevant composition of uranium isotopes) approximately 0.1 mSv, given these factors: contamination of clothing and skin equivalent to this activity concentration, and that the individual ingests all activity from 200 cm^2 (corresponding to an area of approximately two hand palms). Consequently, in the assessment of SSM, the dose contribution from accidental ingestion of uranium from external contamination is small compared with the dose from inhalation.

Apart from this, measuring external contamination by alpha-emitting materials on skin and clothing is a difficult and time-consuming task. Performing contamination checks of all people who were present in the UPZ would require extensive and advanced resources. This work might take several days to carry out. However, it may be warranted to perform contamination checks of individuals who were inside the facility.

6. Residual dose

SSM used the reference level 20 mSv effective dose as a basis for dimensioning the proposed UPZ to surround the fuel fabrication plant. The reference level refers to the residual dose, which is the dose received after protective actions have been taken. The actual protective actions that can be taken in a nuclear or radiological emergency depend on the circumstances of the event. However, planning for emergency preparedness has the aim of keeping doses below the selected reference levels.

Reference levels are not directly applicable to dispersion and dose calculations. With this rationale in mind, SSM selected dose criteria for different protective actions applying to an unprotected person over a period of seven days, and instead used these criteria in the dispersion and dose calculations. For example, in the case of the protective action of sheltering, the dose criterion is 10 mSv effective dose to an unprotected person over a period of seven days. The distribution of the greatest distances calculated using this dose criterion serves as the basis of SSM's rationale concerning the recommended distances at which sheltering should be pre-planned.

In order to verify that the emergency preparedness 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 sheltering is feasible in the UPZ to surround the fuel fabrication plant.

The closest buildings located outside the site of the fuel fabrication plant, where the public may be assumed to be present following a declared general emergency, are at a distance of approximately 300 m. For this reason, SSM performed calculations of possible radiation doses that might be received at this distance during sheltering. These calculations assumed that sheltering in different indoor locations provides differing degrees of protection (shielding factors). Most of the buildings in the area are industrial premises which may be assumed to provide satisfactory protection against radiation, including filtered ventilation (for example). Consequently, SSM's assumption was that sheltering reduces radiation doses to one-tenth (shielding factor 0.1). Representing a more conservative assumption, SSM also performed calculations in which radiation doses were reduced by half, corresponding to the protection offered by an ordinary detached house (shielding factor 0.5). In the case of prompt radiation, only the shielding factor of 0.5 was applied. SSM has also performed calculations of the radiation dose that might be received by an unprotected individual who was present just outside the UPZ during the release.

6.1. Criticality

In the case of sheltering in the UPZ, the maximum radiation doses from prompt radiation (at shielding factor 0.5) might amount to approximately 5 mSv effective dose at a distance of 300 m (Figure 5). Outcomes of dispersion and dose calculations demonstrate that the additional dose from fission products (at shielding factor 0.1) at this distance will be below 0.5 mSv effective dose if 90 per cent of the weather scenarios are taken into account. If the more conservative shielding factor of 0.5 is postulated instead, the dose contribution is 2.5 mSv. Consequently, at this distance, the total effective dose in connection with sheltering is a maximum of 7.5 mSv in 90 per cent of the weather scenarios.

An individual who is present outside the UPZ, and thus might be outdoors during the accident sequence, could receive radiation doses from the release of fission products. These doses may amount to a maximum of 3 mSv effective dose if 90 per cent of the weather scenarios are taken into account. At these distances, the dose contribution from prompt radiation is negligible in relation to the dose from a release of fission products.

Consequently, in the assessment of SSM, the proposed UPZ gives a good margin of safety for keeping doses below the reference level of 20 mSv in connection with a criticality event at the fuel fabrication plant.

6.2. A fire with a release of uranium powder

The dispersion and dose calculations show that an unprotected person might receive an effective dose of approximately 40 mSv at a distance of 300 m from the fuel fabrication plant if 90 per cent of all the weather scenarios are taken into account. This is equivalent to an indoor dose of 4 mSv, given a shielding factor of 0.1. In the case of a more conservative assumption concerning the shielding factor, the effective dose is 20 mSv.

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

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

7. Remediation and food production measures

Around the fuel fabrication plant, it is unwarranted to take further urgent protective actions outside the UPZ. For this reason, SSM has not proposed any EPD of the type that should surround the nuclear power plants.

On the other hand, there is a need to perform planning for radiation monitoring and sampling for assessment of possible ground deposition. Following an external release of radioactive materials, the stakeholders in charge will need to issue recommendations to the general public concerning the possible need to impose restrictions for the purpose of reducing ingestion of radioactive substances. This information may for example relate to own food crops, work that gives rise to significant resuspension, or recommendations for behaviours that can reduce exposure. Recommendations to be issued in an early phase of an event must be established in advance. After a release has ceased, recommendations should be based on data on deposition magnitude and dispersion by means of sampling and radiation monitoring. It is also important to have capability to communicate which areas are unaffected by possible deposition. Assessments of ground deposition are also important input for determining the need for remedial action.

All county administrative boards are subject to the Civil Protection Ordinance, which requires planning to be in place for radiation measurements in the event of a release of radioactive materials from nuclear facilities. As a release of uranium (which is an alpha emitter) from the fuel fabrication plant would differ substantially from a release from the NPPs, both in terms of relevant protective actions and methods of measurement, this presupposes separate planning for the fuel fabrication plant, beyond pre-existing planning in place in other parts of the country.

For the purpose of accurately dimensioning these emergency preparedness measures, SSM suggests the establishment of an ICPD to surround the fuel fabrication plant to provide protection against ingestion of radioactive substances.

SSM's proposals:

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

7.1. The basis for the proposed ICPD

7.1.1. Remediation

Usually, when it comes to events involving a release of hazardous substances from non-nuclear facilities, the party conducting the activities bears the responsibility for potential remediation work. However, under the Civil Protection Ordinance, county administrative boards have a designated mandate in the case of an event involving a release of radioactive materials from nuclear facilities.

Provided that dispersion of ground deposition comprising uranium powder around the fuel fabrication plant is relatively limited, SSM's assessment is that there is potential for complete subsequent restoration of affected areas. This means that site release is possible. At the present time, there are no established clearance levels for ground contaminated by uranium [11]. As part of this project, SSM elected to use the pre-existing clearance levels laid down for buildings and rooms [11, pp. 13-14]. Consequently, the intervention level has been set at 10 kBq/m^2 for the total of U-234, U-235 and U-238. The clearance level for land will be established after an event, depending on the circumstances of the specific case.

Dispersion and dose calculations that have been carried out for the event involvning a fire with a release of uranium powder demonstrate that it is possible for ground deposition to occur corresponding to the intervention level out to a distance of 2-3 km from the fuel fabrication plant. This depends on the calculation parameters and percentage of weather scenarios taken into account.

7.1.2. Foodstuffs

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

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

The water supply from the source of water located northeast of the fuel fabrication plant should be immediately disconnected in the event of a declared general emergency. It should not be reconnected until the risk can be ruled out of water contamination exceeding the maximum permitted levels. Uptake via groundwater is not an area of concern in emergency management; however, there is potential for contamination of drinking water by means of the open pools located at the Fågelbacken waterworks. Thereafter, recurring checks may be warranted to ensure that no leakage to groundwater takes place. However, this is not an urgent measure.

7.2. The proposed ICPD

The outcomes produced through the dispersion and dose calculations show that it is warranted to have a plan in place for radiation monitoring and sampling to enable quantification of possible ground deposition after a fire with a release of uranium powder. SSM recommends an ICPD of 3 km.

In this context, is important to keep in mind that the ICPD has the purpose of defining the measurement capability relating to the fuel fabrication plant. An ICPD does not comprise the largest conceivable distance at which ground deposition might occur corresponding to the intervention levels applied. There are conceivable weather scenarios in which higher levels of ground deposition may occur at greater distances.

References

[1] Westinghouse Electric Sweden AB, *Westinghouse Bränslefabrik - Riskanalys: Omgivningskonsekvenser vid antagna störningar och haverier* (Westinghouse fuel fabrication plant: risk analysis. Environmental consequences of postulated transients and accidents), NTC 94-214 rev 3, Västerås, 2014.

[2] Westinghouse Electric Sweden AB, *Westinghouse bränslefabrik - SSMFS2008:1 - Analys av yttre händelser* (Westinghouse fuel fabrication plant: Regulation SSMFS 2008:1. Analysis of external events), BS 99-286, rev 1, Västerås, 2014.

[3] Kemakta Konsult AB, *Analys av tänkbara större olyckor vid ASEA-ATOM:s bränslefabrik i Västerås* (Analysis of conceivable emergencies at the ASEA-ATOM fuel fabrication plant in Västerås), ASEA-ATOM, Västerås, 1980.

[4] U.S. Nuclear Regulatory Commission, "Regulatory Guide 3.34," 1979.

[5] D. Mennerdahl, *Omgivningskonsekvenser av nukleär kriticitetsolycka - Bränslefabrik* (Environmental consequences of a nuclear criticality accident: Fuel fabrication plant), 2016.

[6] IAEA, "Generic procedures for assessment and response during a radiological emergency," IAEA-TECDOC-1162, Vienna, 2000.

[7] D. Delacroix, J. P. Guerre, P. Leblanc and C. Hickman, "Radionuclide and Radiation Protection Data Handbook," *Radiation Protection Dosimetry,* 2002.

[8] ICRP, "Compendium of Dose Coefficients based on ICRP Publication 60," ICRP Publication 119. Ann. ICRP 41 (Suppl.), 2012.

[9] E. Hansson, H. Pettersson and M. Eriksson, "Uranium aerosol characteristics at a nuclear fuel manufacturing site - particle size, morphology and chemical composition," SSM2015:38, Solna, 2015.

[10] ICRP, "Human Respiratory Tract Model for Radiological Protection," ICRP Publication 66. Ann. ICRP 24 (1-3), 1994.

[11] SSMFS 2011:2. The Swedish Radiation Safety Authority's regulations and general advice concerning clearance of materials, rooms, buildings and land in practices involving ionising radiation, SSM, 2011.

[12] Westinghouse Electric Sweden AB, *Stråldosberäkningar i Lena* (Calculating radiation dose using the Lena program), BSA 15-069, Västerås, 2015.

[13] Swedish University of Agricultural Sciences (SLU), Swedish Defence Research Agency (FOI), National Food Agency (SLV), Swedish Radiation Protection Authority (SSI), and Swedish Board of Agriculture (SJV), *Livsmedelsproduktionen vid nedfall av radioaktiva ämnen* (Food production in the case of fallout of radioactive substances), Västerås, 2002.

[14] IAEA, "Preparedness and Response for a Nuclear or Radiological Emergency," IAEA General Safety Requirements No. GSR Part 7, Vienna, 2015.

2017:27e

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

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

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

Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

SE-171 16 Stockholm
Solna strandväg 96

Tel: +46 8 799 40 00
Fax: +46 8 799 40 10

E-mail: registrator@ssm.se
Web: stralsakerhetsmyndigheten.se

Ale Tryckteam AB, 2019