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Swedish Radiation Safety Authority

2019:09

General data in accordance with the requirements in Article 37 of the Euratom Treaty

Decommissioning of the nuclear reactor Ågesta in Sweden.

Report number: 2019:09 ISSN: 2000-0456
Available at www.stralsakerhetsmyndigheten.se

Abstract

The purpose of this report is to provide the European Commission with general data relating to plans for the decommissioning of the pressurised heavy water reactor Ågesta, situated outside Stockholm, Sweden., which will enable the Commission to determine whether the implementation of the plans is liable to result in the radioactive contamination of the water, soil or airspace of another European Union Member state. The structure of the document follows the recommendations given in 2010/635/Euratom on the application of Article 37 of the Euratom Treaty.

The Ågesta reactor was Sweden´s first commercial reactor. The reactor is a pressurized heavy water-moderated reactor and is located in a rock cavern. The reactor was in operation between 1964 and 1974, and in addition to generating electricity, heat was produced and delivered. The reactor output, after some modification of the core in 1970, was 80 MWth and 12 MWe.

Since 1974, the Ågesta reactor has been in care and maintenance phase. Fuel and heavy water were removed from the site in the 1970s.

This report presents an assessment of the maximum expected emissions of radioactivity to air and water during decommissioning.

The assessment also includes a dose evaluation to a reference population living close to the power plant.

The dose to the reference group from radioactivity released during normal conditions at the plant is less than 0,001 μSv/year. As the dose to the reference group is less than 10 μSv/year, and there are no exceptional exposure pathways, no dose assessment is required for other EU member states.

The dose to the reference group from radioactivity released during a hypothetical radiological accident at the plant is less than 1 mSv.

As the dose to the reference group is less than 1 mSv, and there are no exceptional exposure pathways, no dose assessment is required for other EU member states.

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This report has been completed by the Swedish Radiation Safety Authority, SSM, mainly based on information provided by the license holder, Vattenfall AB. SSM has controlled that the general data provides the necessary information and that it follows the guideline of the most recent recommendations of the application of Article 37 of the Euratom Treaty.

Content

0. Introduction

This document describes the plans for decommissioning of the pressurised heavy water reactor Ågesta, situated in Huddinge outside Stockholm, Sweden. The purpose of this document is to serve as information for the European Commission, and to fulfil the requirements of Article 37 of the Euratom Treaty, according to which:

Each Member State shall provide the Commission with such general data relating to any plan for disposal of radioactive waste in whatever form as will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of water, soil or airspace of another Member State.

The Commission has recommended that “disposal of radioactive waste” should cover any planned disposal or accidental release of radioactive substances associated with, among other activities, the dismantling of nuclear reactors [1].

The structure of this report follows the guideline in annex 3 of the recommendation of the application of Article 37 of the Euratom Treaty (210/635/Euratom) [1].

The report has been completed by the Swedish Radiation Safety Authority (SSM) mainly based on information provided by the licence holder, Vattenfall AB. SSM has controlled that the general data provides the necessary information and that it follows the guideline of the mentioned recommendation.

0.1. Ågesta Nuclear Power Plant

The Ågesta reactor, Ågesta NPP, was Sweden´s first commercial reactor and was part of the Swedish reactor development program in the 1960s. The reactor is a pressurized heavy water-moderated reactor and is located in a rock cavern situated in the municipality of Huddinge, close to Stockholm, the capital of Sweden. The reactor was in operation between 1964 and 1974, and in addition to generating electricity, heat was produced and delivered to the district heating system for the nearby city of Farsta. The reactor output, after some modification of the core in 1970, was 80 MWth and 12 MWe.

Since 1974, the Ågesta reactor has been in care and maintenance phase, continuing to operate the functions required by the regulations applicable to a nuclear facility in this operation mode.

The rock cavern is owned by the City of Stockholm and will be returned to the owner after decommissioning of the plant. The areas outside the rock cavern are also owned by the City of Stockholm and are used by the Greater Stockholm Fire Brigade (hereinafter called the Fire Brigade) for training and education.

The reactor itself is owned by Vattenfall AB and SVAFO[1] with 50% shares each. Vattenfall AB is the holder of the nuclear licence.

[1]AB SVAFO is a non-profit company whose task is to decommission nuclear facilities from previous research and development activities in Studsvik and to implement intermediate storage of waste from the decommissioning and waste from the research period until final disposal can be carried out.

Fuel and heavy water were removed from the site in the 1970s.Two steam generators were dismantled and processed as waste at Studsvik in the early 1990s, before Sweden had obligations under the Euratom Treaty.

0.2. Decommissioning licensing

This section gives a brief overview of the licences that will be needed in order to transition between the different phases of the decommissioning project. The operator must apply for a licence from the Land and Environment Court in accordance with the Swedish Environmental Code and an updated Safety Analysis Report for decommissioning (SAR) needs to be approved by the Swedish Radiation Safety Authority (SSM) prior the beginning of the decommissioning activities.

0.2.1. Nuclear Licence

SSM reports to the Ministry of the Environment and Energy. SSM regulates the areas of nuclear safety, radiation protection and nuclear non-proliferation within Sweden, and on behalf of the Swedish Government.

The authority works to protect people and the environment from the undesirable effects of radiation. The Act on Nuclear Activities 1984:3 and the Radiation Protection Ordinance 2008:452 with instructions for the Swedish Radiation Safety Authority have been translated into English and can be found on the SSM website (www.ssm.se). The Radiation Protection Act 2018:396 is not yet published in English. These acts and ordinances, together with the Ordinance on Nuclear Activities 1984:14 and the Radiation Protection Ordinance 2018:506, stipulate the boundaries for all nuclear activities in Sweden. SSM has developed regulations (SSMFS) to give a more detailed framework for Nuclear Power. Some of the regulations are available in English.

In order to start decommissioning and dismantling, a safety analysis report (SAR) must be approved by SSM. The requirement to have an approved SAR is found in SSMFS 2008:1, The Swedish Radiation Safety Authority’s Regulations and General Advice concerning Safety in Nuclear Facilities, which is part of the Swedish Radiation Safety Authority regulations. The regulations in SSMFS 2008:1 apply to measures required to maintain safety in connection with the construction, possession and operation of nuclear facilities with the aim of, as far as reasonably achievable, taking into account the best available technology, preventing radiological accidents and preventing the unlawful handling of nuclear material and nuclear waste. The regulations comprise provisions on technical, organisational and administrative measures. Chapter 9 in SSMFS 2008:1 stipulates the requirements for decommissioning and dismantling. SSM has also issued specific decommissioning licence conditions in SSM 2016-5866.

The decommissioning process is described in a decommissioning plan.

After approval of the Safety Analysis Report (SAR), each dismantling and/demolition package/project or parts (components, systems or building) of the plant that contains contaminated or activated systems must be notified to SSM. The size of each package/project is up to the site licensee to decide. SSM conducts regular oversight activities, using a graded approach principle, during the decommissioning and dismantling process. The site will only be released from the regulatory control from the Act on Nuclear Activities by

Governmental decision, upon the recommendation of SSM once the final state report is approved.

At the time of writing this report all these licence application documents are under development.

SSM will not allow dismantling and demolition activities to occur until the European Commission provides an opinion on the Article 37 report for the decommissioning project.

The purpose of this is for other member states to be able to voice an opinion on the possible effects the decommissioning may have on their soil or airspace.
This document and any required references are part of the submission.

0.2.2. Environmental licence

Decommissioning of a nuclear reactor facility requires a licence according to the Environmental Code (1998:808). The Swedish Environmental Protection Agency, Swedish EPA, the County Administrative Board (CAB), the local Environmental and Public Health Committee and the Swedish Radiation Safety Authority (SSM) are consulted in the licensing procedure and are given the opportunity to propose specific licensing conditions.

A licence for the current operation phase was granted in 2008 and is valid until 2020. An application for decommissioning was submitted to the Land and Environment Court in October 2018.

0.3. Decommissioning funding

According to Swedish law it is the owners of the NPPs that have to pay for all the costs of dealing with spent nuclear fuel and its final disposal. They also have to pay the costs of decommissioning of NPPs or other nuclear installations. Since the mid- 1970s the nuclear power operators have been setting aside funds to cover these costs. These funds are administered by the Nuclear Waste Fund. The Swedish Nuclear Fuel and Waste Management Company, SKB, conducts regular calculations of the future costs for dealing with nuclear waste and submits the updated budget to every three years. After the calculations have been reviewed, the Swedish National Debt Office then proposes the surcharge for the next few years to the Government, which decides on the amount to be charged. The funds are then distributed to the decommissioning projects as they progress.

0.4. Decommissioning plan

This section gives an overview of the decommissioning plan. It should be noted that this plan is under development and subject to change as it is improved.
Reasons for changes are e.g. results from further radiological surveying that is performed (and will be performed after shutdown) and ongoing and future discussions with dismantling contractors.

0.4.1. Decommissioning of Ågesta

Decommissioning of the reactor is planned as soon as all necessary approvals and permits are granted. The plan is to dismantle the radioactive portions of the plant over approximately 3-6 years. Figure 0-1 shows an overview of the decommissioning planning. Radioactive waste will be moved offsite to the Studsvik-site for treatment, conditioning and/or intermediate storage to await completion of construction of the final repositories.

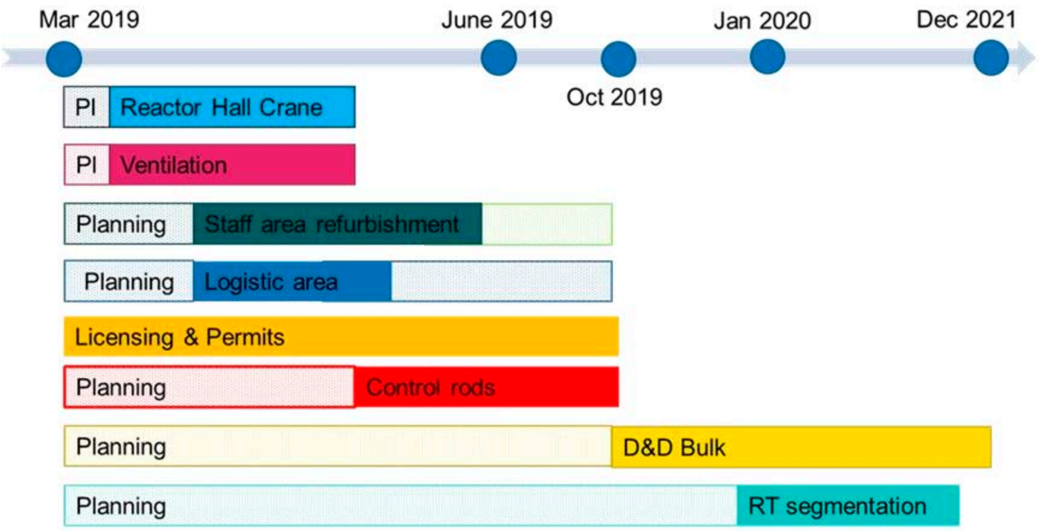

Figure 0-1. Overview of decommissioning planning

The decommissioning strategy is to start with segmentation of the reactor pressure vessel and internal components and dismantling in other part of the facility at the same time. The expansion tanks will be removed at an early stage in order to create space for waste handling as the area inside the rock cavern is limited.

Before commencing the dismantling in the plant it is necessary to carry out several activities to prepare the plant for the decommissioning, e.g. installation of a new ventilation system, modernization of the overhead crane, preparation of an area for buffer storage for transport containers outside the rock cavern, preparation of an area outside the rock cavern for clearance measurements of material on site and disposal of waste remaining from the power operation phase of the reactor, like control rods.

The decommissioning is going to be divided into two dismantling and segmentation projects. One project includes segmentation of the reactor pressure vessel and internal components. Other project includes dismantling and segmentation of other large components, parts of the biological shield, removal of residual piping systems, mechanical and electrical installations (including original ventilation systems, cables, cable trays, etc.). The resulting overall dismantling sequence will be developed in further detail during decommissioning planning. All dismantling activity will be carried out inside the cavern. No chemical decontamination is planned, mainly due to that there is no water treatment facility for contaminated water at Ågesta.

Radiological clearance of the remaining structures may take about 1-2 years after the dismantling and demolition are finished. After clearance, the cavern will be sealed with concrete plugs in both ports to prevent access, see figure 2-2. Ventilation shafts will also be sealed as well as all sewers. The rock cavern is owned by the City of Stockholm and shall be returned when the cavern is sealed. The facility will not be used for other purposes.

The waste handling is described in section 5 in this report. In order to optimize the process several options are available. In Sweden there are two possible disposition routes for radioactive waste: clearance (also referred to as “free release”), either general or conditional, or disposal as solid radioactive waste. Disposal of solid waste can be in a surface repository approved for very low level active waste (not an option in the decommissioning of Ågesta). Sweden has a central final, geological, repository that is licensed for short-lived low and intermediate level radioactive waste (SFR). In the future there will also be a central final, geological repository licensed for long-lived low and intermediate level radioactive waste (SFL) and a final geological repository for spent fuel. See appendix 1 for more details.

1. The site and its surroundings

1.1. Geographical, topographical and geological features of the site and region

The Ågesta reactor is situated in the municipality of Huddinge near the small city Farsta, close to Stockholm – the capital of Sweden, see figures 1-1 and 1-2. The site coordinates are 59°12'N 18°4'E according to WGS84 (the World Geodetic System 1984).

Figure 1-1. The location of the Ågesta reactor (Source GeoBasis-DE/BKG, Google maps)

Distances to the closest national borders are shown in table 1-1. The nearest population centre in another Member State is Mariehamn, situated on the island of Åland, Finland, about 130 km northeast of Ågesta.

Table 1-1. Distance to neighbouring states (Source GeoBasis-DE/BKG, Google maps)

Country	Distance to border (km)	Metropolitan area	Population (millions)	Distance to metropolitan area (km)
Denmark	470	Copenhagen	2.0	510
Latvia	310	Riga	0.7	440
Estonia	240	Tallinn	0.6	380
Germany	580	Berlin	4.4	800
Finland (Åland)	220 (130)	Helsinki	1.1	400
Lithuania	420	Vilnius	0.6	680
Poland	500	Warsaw	3.2	830

The Ågesta reactor is located in a rock cavern (see figure 1-3). The soil layer in the area is thin and therefore exposed rock is widespread on the surface. Clay/silt is the most common type of soil. The area is seismically stable and there is no risk of damage to the facility due to earthquakes. The adjacent surroundings include nature reserves as well as Natura 2000 areas. The area is popular in terms of outdoor recreation.

The surroundings are sparsely populated. A small residential area lies immediately southwest of the site, Vidja (see figure 1-2), as well as a golf club and a riding club. The Fire Brigade operates a practice facility on site. There are no other facilities with corresponding emissions in the region and the nearest nuclear facility is the Studsvik site, 70 km south of Ågesta.

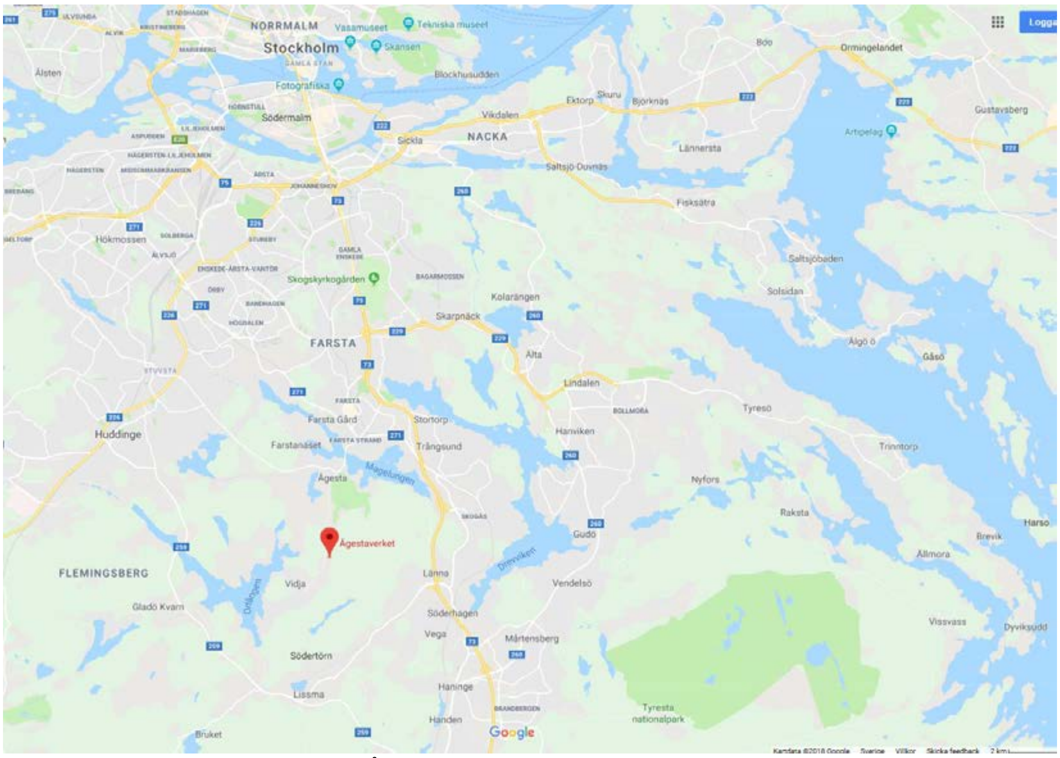

Figure 1-2. The location of the Ågesta reactor (Source Google maps)

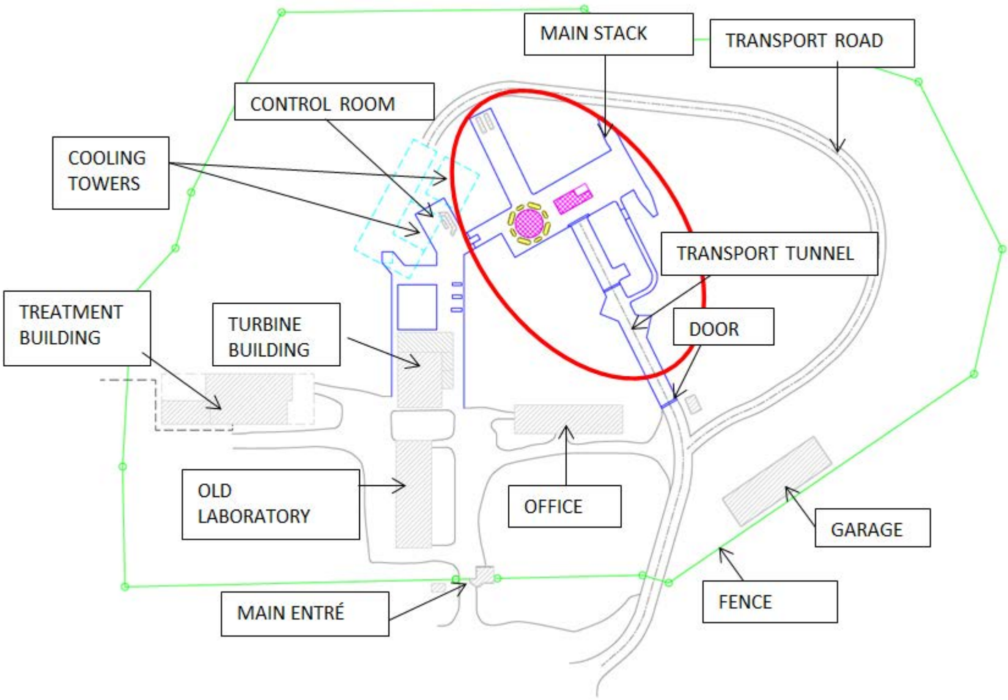

Figure 1-3. An overview of the site. Red circle illustrates the area that is target for the decommissioning

1.2. Hydrology

The Ågesta NPP is located approximately 11 km from the Baltic Sea which is the nearest coast. The plant was cooled via delivery to the district heating network during normal operation or cooling tower when the district heating was bypassed, there was therefore no need for a cooling water intake. There are two smaller lakes in Ågesta NPP's immediate surroundings, Lake Orlången and Lake Magelungen. During reactor operation water from the waste treatment facility was released to Magelungen. The waste treatment facility no longer exists and the pipe to Magelungen has been cut. Magelungen has no connection to the Baltic Sea. Water drainage from the inside of the cavern but the outside of the pressure-retaining steel lining is collected in a drainage pit before it flows via a ditch to Lake Orlången. Measurements of the drainage water verify the absence of radionuclides in the drainage water. Orlången has no connection to the Baltic Sea. Therefore, it is reasonable to assume that there is no body of water providing a potential contamination pathway to another Member State. It should also be noted that the ground water in the area is not a pathway of exposure to other countries either. The hydrology is therefore not described any further in this report.

1.3. Meteorology

Meteorological data for the site is based on data from two nearby meteorological stations, Riksten and Tullinge. These stations are situated approximated 10 km from Ågesta. Like Ågesta, they are not situated by the coast, see figure 1-4. The Tullinge station monitored the weather from 1951-1985 and the Riksten station started recording measurements in 1996.

Figure 1-4. Location of meteorological stations, Riksten and Tullinge

1.3.1. Wind

Wind directions and speed from 160000 measurements have been analysed. The most common wind direction is from the southwest, see figures 1-5, 1-6 and 1-7.

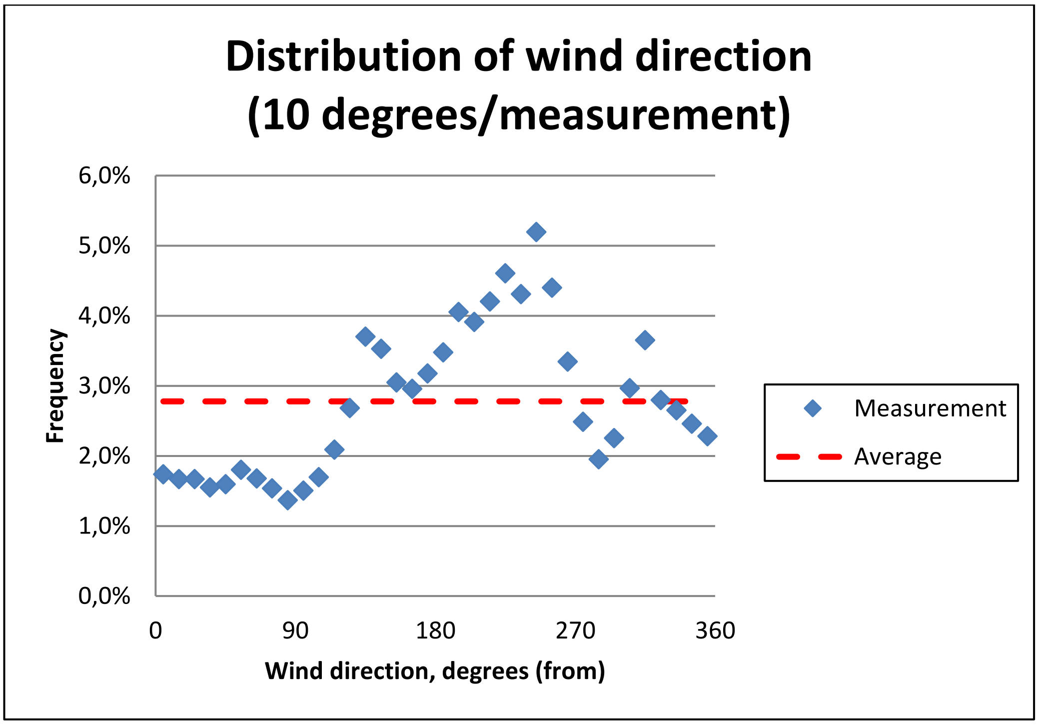

Figure 1-5. Frequency of different wind directions.

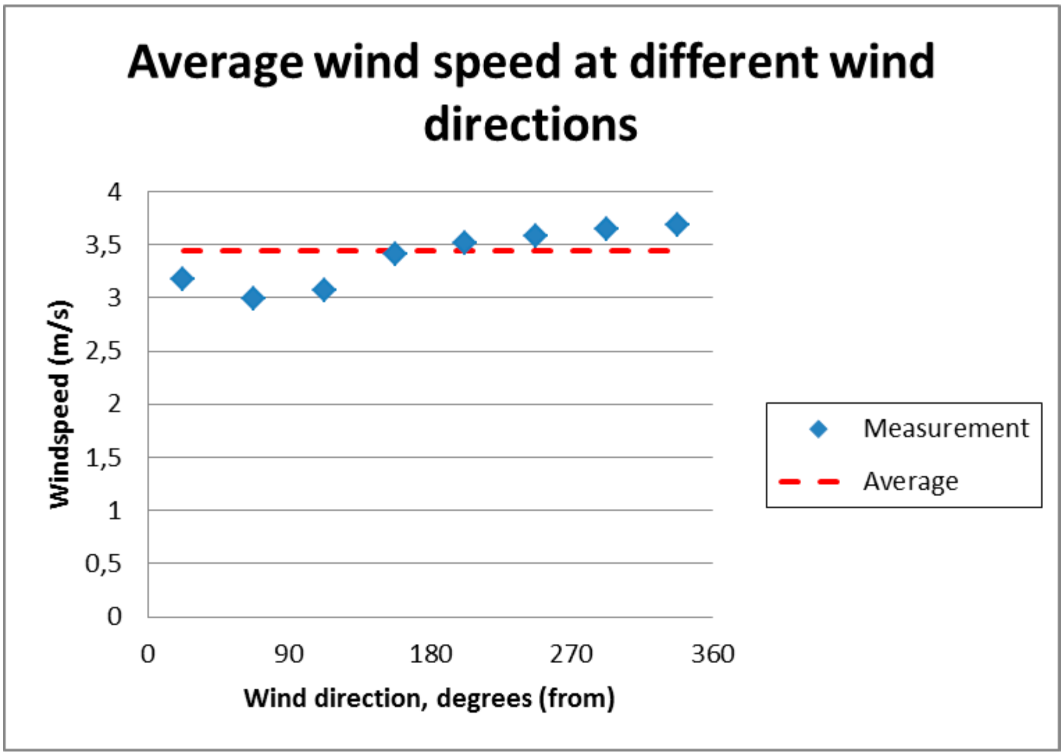

Figure 1-6. Wind speed distribution at different wind directions.

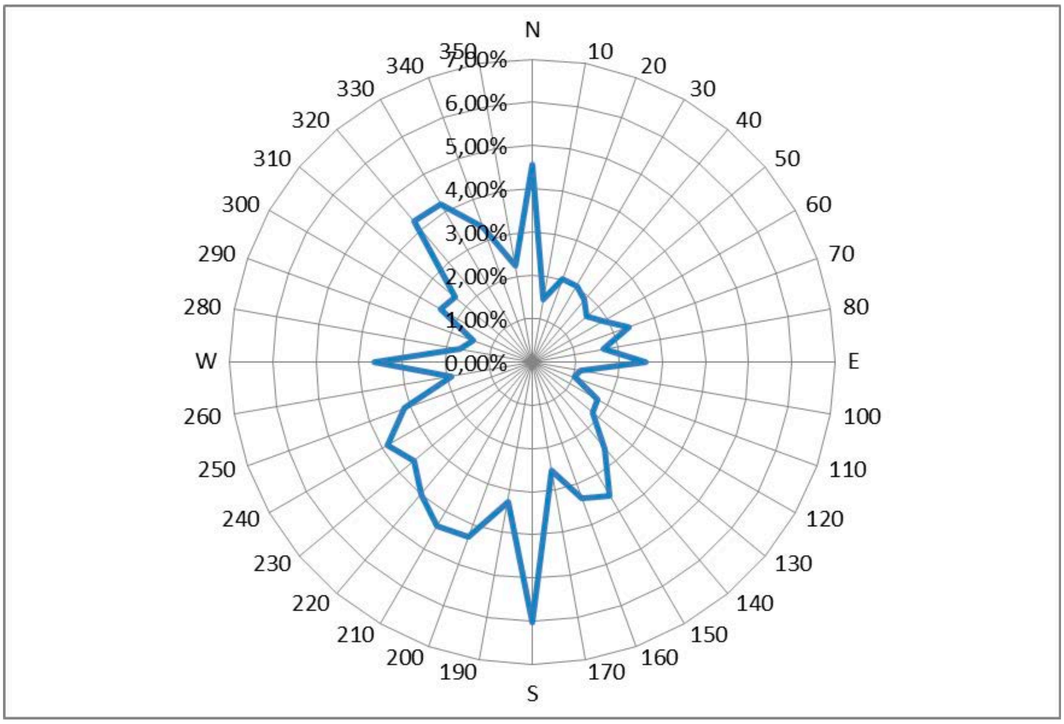

Figure 1-7 Wind direction and duration.

Pasquill atmospheric stability class is a measurement of turbulence in air and is a parameter used in calculations of radioactivity in air. Values range from A (very unstable) to F (stable) and how turbulent the air is affects the spread of activity. Most frequent for the Ågesta location is class D.

There are no specific calculations available for the probability of local temperature inversion. Calm conditions, 1-2% of the time and small height differences do not typically yield inversions.

1.3.2. Precipitation

The heaviest rainfall occurs during the summer and usually over a short period of time when thunder clouds appears. Annual precipitation in the area is about 600 mm. Transports or planned operation during the decommissioning are not particularly sensitive to the weather conditions as planned operation occurs in the cavern. There are two drainage pits and pumps that ensure that drainage water inside the rock cavern, but outside the pressure-retaining steel, is pumped away from the plant.

1.3.3. Extreme weather

Extreme weather (storm, tornados, ice storm, heavy rainfall) is rare in Sweden, especially on the Swedish east coast, in relation to other parts of the world. Transports or planned operation during the decommissioning are not particularly sensitive to the weather conditions as planned operation occurs in the cavern.

1.4. Natural resources and foodstuff

The County of Stockholm have two water treatment plants, Norsborg and Lovö which distribute drinking water to 1.4 million people in Stockholm. The water is retrieved from Lake Mälaren, Rödstensfjärden. Rödstensfjärden is located 17 kilometres northwest of Ågesta and is the nearest protected area for drinking water.

Groundwater or surface water has no impact on water used in any neighbouring states, see section 1.3.

There are not many agricultural activities around Ågesta. Primary uses of the land are recreation, protected areas and populated areas.
The types of crops produced in 2015 and the numbers of different livestock in 2016 are shown in tables 1-2 and 1-3. The data is taken from the database DAWAS, compiled by the Swedish Board of Agriculture. No specific information exists of export of crops or livestock from this region to other member states. Since the region around Ågesta does not produce any large quantity of foodstuffs, it is fair to assume that the significance of large exports is negligible.

Table 1-2. Crops produced in Sweden as a total and in the County of Stockholm. The data is taken from the database DAWAS, compiled by the Swedish Board of Agriculture, for the year 2015.

Crop	Sweden (ton/year)	Stockholm(ton/year)
Cerial	5 621 300	80 200
Peas	83 100	5 900
Rape	356 500	6 000
Total	**6 060 900**	**92 100**
Percentage	100	1,5

Table 1-3. The quantities of different types of livestock in Sweden, produced in Sweden as a total, in the county of Stockholm and in the municipal of Huddinge. The data is taken from the database DAWAS, compiled by the Swedish Board of Agriculture, for the year 2016.

Livestock	Sweden no.	Stockholm no.	Huddinge no.
Cattle	57 874	19 166	112
Sheep	1 489 624	17 057	286
Total	**1 547 498**	**36 223**	**398**
Percentage	100	2,34	0,03

2. The installation

This chapter provides a brief description of the facilities to be dismantled and their waste management systems. As waste treatment activities will be minimal at Ågesta most waste treatment will take place at off-site facilities. Only general descriptions of off-site waste management are provided as they are beyond the scope of this report. The descriptions are kept at the level of an overview with the purpose of providing an understanding of the factors relevant to evaluation of the risk to other EU-member states. Details that do not serve this purpose have been omitted from this report.

2.1. Brief description and history of the installation to be dismantled

Figure 2-1 illustrates the geographical area, marked in red, in which dismantling and demolition of the Ågesta plant will occur. After clearance measurements and approval from SSM, the rock cavern will be sealed off with concrete casting, as the owner has no further use of it. The facility will be sealed off at the personnel airlock, at the intermediate door and at the end of the emergency exit tunnel, see figure 2-2. Ventilation shafts will also be sealed as well as all sewer lines.

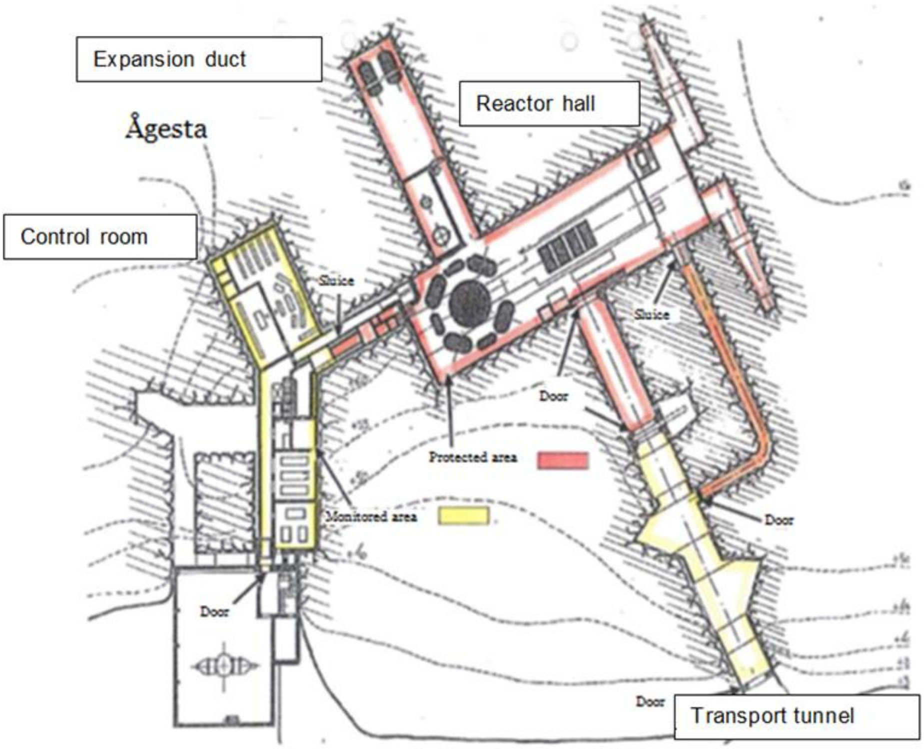

Figure 2 - 1 Overview of Ågesta plant seen from above.

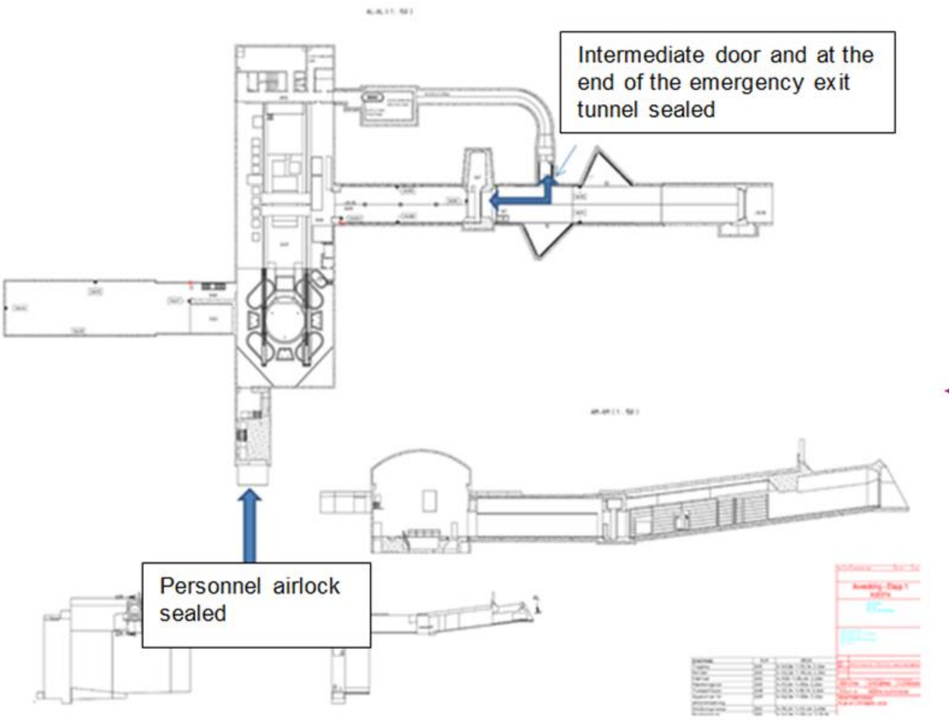

Figure 2-2 The facility will be sealed off at the personnel airlock, at the intermediate door and at the end of the emergency exit tunnel (marked in the figure). Ventilation shafts will also be sealed as well as all sewers.

2.1.1. Brief description of Ågesta

Ågesta was the first reactor of its kind in the world and led the way for reactor development in Sweden with the use of natural uranium as fuel and heavy water as moderator. Ågesta was mainly used for supplying district heating, with an approximate thermal output of 55 MW, to the nearby community Farsta, located south of Stockholm. A small part of the production, 10 MW, was used to produce electrical power. After 1970 the core was redesigned, and Farsta received 68 MW heat and the grid 12 MW electricity.

On the 2nd of June 1974 Ågesta was shut down because of financial reasons. The heavy water inventory was sold to Canada and transported there later that year. Used fuel was removed and is stored in Clab[2]. The Ågesta facility is currently in care and maintenance operation, which means that there is no fuel present and the reactor is shut down. Besides fuel and heavy water, two steam generators have been removed, and the facility's operation today includes maintenance, regulatory controls and radiological area control.

Buildings and components

Note that the following sections describe only the buildings and components relevant for the decommissioning. The facilities which house the turbines, laboratory, waste water

[2] Central interim storage for spent fuel.

processing station and office buildings are located outside the rock cavern and are not included in the decommissioning. An application for the decision of free release of those buildings is currently being reviewed by SSM.

Rock cavern

The rock cavern is where the reactor, auxiliary systems, control room, ventilation system and switchgear are located. On top of the mountain there is the cooling tower (only one remaining) as well as inlets and outlets for the former ventilation system. The Expansion Duct, a part of Ågesta's pressure control system, extends from the reactor at a 90 degree angle, and the transport tunnel extends at a 90 degree angle in the opposite direction.

The control system, the switchgear and the ventilation systems are located outside the pressure-retaining steel liner but are connected to it.

Personnel areas are also located in the rock cavern. These areas will be rebuilt during 2019 to ensure sufficient capacity for the decommissioning personnel teams. These include the office, laboratory and changing rooms. Water processing outside the controlled area will be performed using communal resources, and water processing in controlled area will be managed by using portable containers. Electricity, ventilation and other functions will be replaced in the rebuilt areas.

Containment (in rock cavern)

The rock cavern is clad in a pressure-retaining steel liner and these barriers function together as the facility's containment.
The reactor pressure vessel and two steam generators remain inside the containment.

Security boundaries

The entire rock cavern is within the monitored or ”protected” area of Ågesta. The containment belongs to the “protected” area, the first security boundary level. Contamination is only expected in the protected areas.

Technical data

Relevant technical data on the Ågesta facility is summarized in Table 2-1.

Table 2 -1 Technical data for the Ågesta reactor

	Unit	Value
Main supplier		ASEA
Reactor Pressure Vessel		Degerfors
Moderator		
Heavy water (total amount)	Ton	74
Time		
Construction start	Year	1 956
Start of operation	Year	1 964

Volumes		
Total construction in mountain	m^3	30 000
Concrete inside containment	m^3	3 182
Pressure-retaining steel liner		
Length	m	60
Width	m	45
Height	m	26
Steel liner thickness	mm	4
Reactor plant		
Thermal power to Farsta	MW	55 (68)
Electric power to grid	MW	10 (12)
Reactor pressure vessel		
Height (maximum)	mm	6 000
Inner diameter	mm	4 555
Wall thickness	mm	70
RPV weight	kg	293 900
Control rods		
Weight	kg	1 811
Number (total used)		30
Transport tunnel		
Length	m	56,5
Width	m	5,8
Height	m	6,1
Expansion duct		
Length	m	37
Width	m	9

Height	m	5
Fuel		
Number of fuel assemblies (removed from the plant)		140

2.2. Ventilation systems and the treatment of gaseous and airborne wastes

A new ventilation system is planned for the dismantling and demolition work. The system will be designed so that it can be used during the entire decommissioning project. The detailed design of the system will be carried out in continuous dialogue with SSM to ensure that relevant monitoring and/or other requirements are met. A general description is presented below and illustrated in figure 2-3. A preliminary flow diagram is presented in appendix 3.

The main stack used previously was dismantled and sold after the reactor was shut down, leaving only a short stack structure present. In the new ventilation system, this stack will be extended to achieve a sufficient exhaust release height, about 5-10 meters above the mountain top. The previous air inlet is today covered and will not be used for the new ventilation system. This is due to the fact that the Fire Brigade conducts fire-fighting exercises in close proximity to the old air inlet, and hazardous chemicals are present in the area. Instead, a new ventilation inlet will be made through the rock into the transport tunnel.

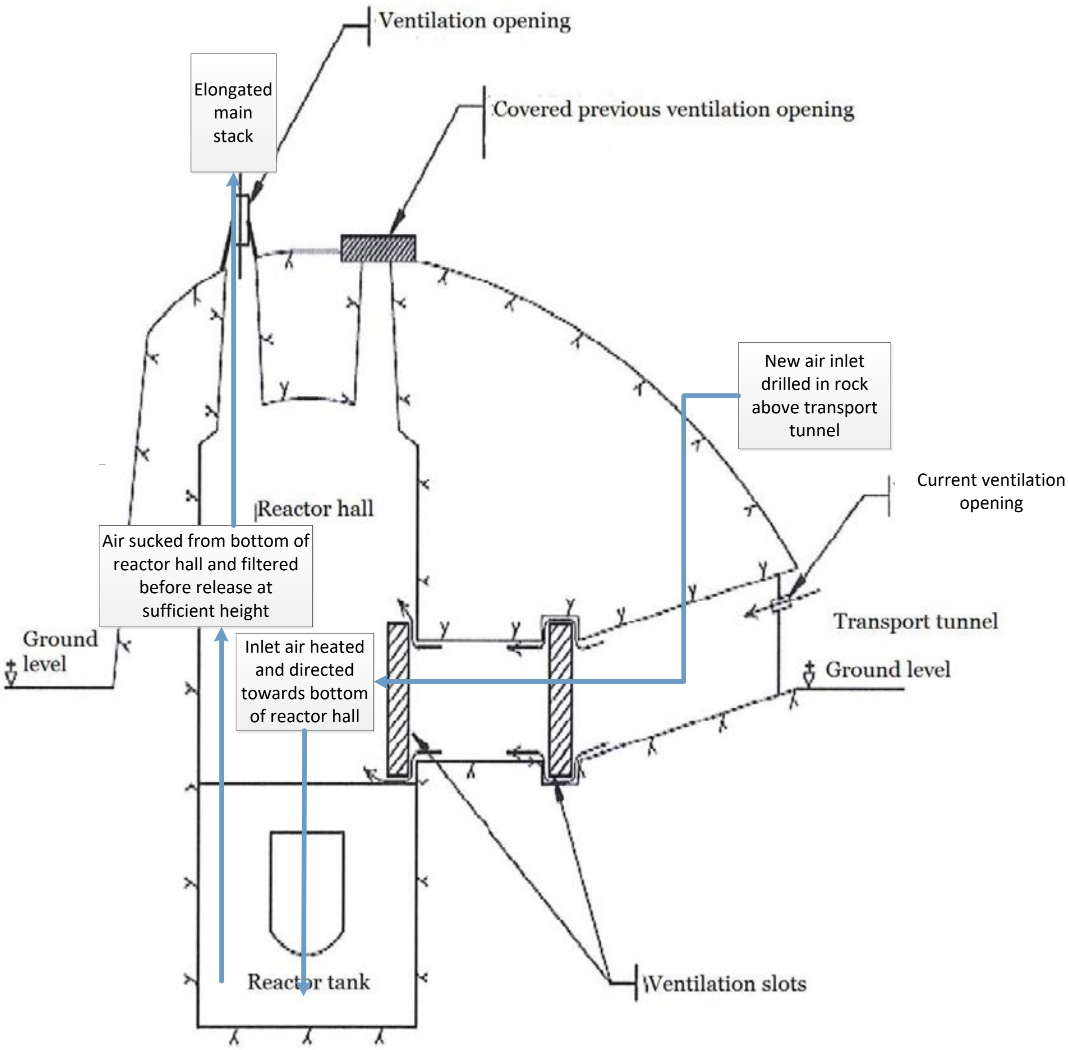

Figure 2- 3 Overview of planned (in blue) modernized Ågesta ventilation as well as existing (in black) ventilation.

The new ventilation systems serves three functions:

- to ensure that occupational safety limits are not exceeded in order to maintain a healthy working environment for personnel,
- to minimize the risk of spreading contamination inside and outside the facility and, in case of fire,
- to evacuate smoke and fumes,

The ventilation system will be designed, so that the air flows towards spaces where risk of airborne contamination is increased and airflow is directed towards the point of re-lease.

The ventilation system's exhaust air will flow through the existing piping on the top of the mountain. As the chimney has already been dismantled and removed, the existing pip-ing will be extended by to achieve a suitable release height, about 5-10 meters above the mountaintop. Any airborne radioactive effluents will pass through the particle filters placed in the ventilation system before the release point (see figure 2-4).

The ventilation system will include isokinetic collection equipment to collect samples in order to monitor release of tritium and other isotopes. If the sampling system is out of service, mobile or manual measurement equipment will be used.

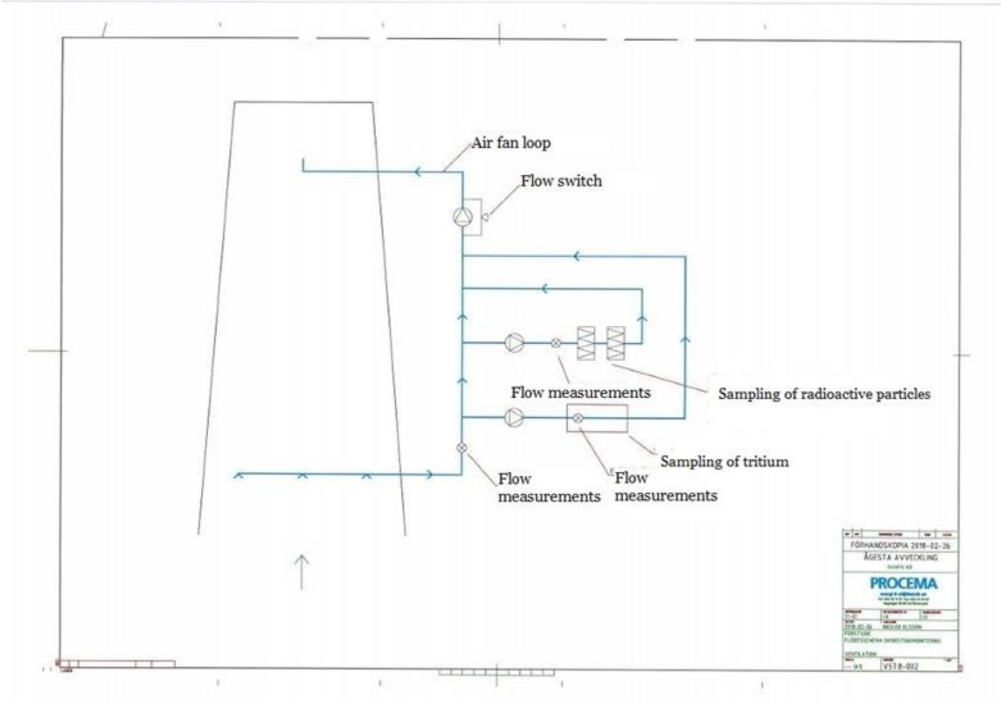

Figure 2-4 A principle scheme over a new monitoring system in the main stack.

Spent filters from the ventilation system will be treated as solid waste.

It should be noted that the last time any fission took place in the Ågesta reactor was 1974. Short-lived radioactive gaseous isotopes such as noble gases, iodine, etc., are no longer present as they have decayed during this time. Any potential airborne contamination would therefore be caused by mobilising previously non-airborne contamination.

Ventilated containment tents can be used when performing local demolition or dismantling work. These tents will be ventilated with their own fans and air will be filtered before being returned to the surrounding facility or directly to the ventilation system. Such local ventilation may also be required for the removal of hazardous materials such as asbestos. Another option available is to use portable filters as an alternative or as a complement to containment tents, which can be especially beneficial when the demolition/dismantling work is performed during shorter time intervals in smaller areas.

Chapters 3 and 6 describe the consequences of a release of the entire inventory of radioactive material from Ågesta. This applies as the potential worst case for an unfiltered release through the ventilation system during the decommissioning project. As releases have been shown to have not exceed dose rate limits on citizens in a third country, no further analysis of discharges through the ventilation system have been performed.

2.3. Liquid waste treatment

There is no water treatment facility for contaminated water at Ågesta, so all water discharged from controlled areas will be handled in closed systems. Contaminated water will be collected in IBC[3] or similar containers and be transported to an approved water treatment facility, for instance SVAFO's evaporation facility. All activities which require water in potentially contaminated areas will be kept at a minimum.

2.4. Solid waste treatment

The decommissioning of Ågesta will provide two main challenges – the logistics of waste management in confined area, and the transition from care and maintenance operation, to an active decommissioning phase.

The challenge in establishing the waste management system for the decommissioning project is logistical as well as operational. There are no permanent solid waste treatment facilities available, therefore on site mobile solutions and temporary modifications will be applied as needed. Some of the challenges can be mitigated by adapting the facility to the decommissioning phase e.g. the rebuilding the personnel areas to allow for a larger work force.

Some areas inside the rock cavern will be made available for storage and handling of waste, e.g. the expansion tunnel with a floor area of 9x37 meters and a ceiling height of 5 meters. An area outside the rock cavern is planned for buffer storage of packaged waste awaiting transportation.

Sweden has an established system for the disposal of radioactive waste, see appendix 1, which includes transportation. This means that there is experience available in the production of waste packages for operational waste that are suitable for disposal in approved and operating disposal facilities. This system can be suitably adapted for use in the Ågesta decommissioning program.

The general sequence in all solid waste management performed in the decommissioning project is:

1. Dismantling, e.g. cutting a section of a system or segmenting an internal component.
2. Collection & Segregation, e.g. sorting the generated waste based on the waste type, contamination level, etc.
3. Treatment, e.g. decontamination, stabilization, compaction etc. The need for this step is based on several factors and only performed if it is deemed that it adds value to the entire waste management chain.
4. Conditioning, e.g. packaging the waste in its final container. In Ågesta, some waste may be conditioned on site using mobile equipment and waste that requires further handling may be conditioned at the Studsvik site where it is prepared for interim storage.
5. Measurement of the radiological parameters, such as nuclide-specific contents, dose rates and surface contamination levels. This data is required for transportation but further measurements may be necessary after conditioning at the Studsvik site.

[3] intermediate bulk container

6. Temporary storage of waste awaiting transportation in a designated area outside the rock cavern.
7. Transport of waste container to the Studsvik site.
8. Possible conditioning of waste and measurements after conditioning.
9. Storage until the waste package is ready to be accepted at a disposal site at the existing interim storage facility at Studsvik site.
10. Transport to the disposal site, mainly using the SKB transport system.
11. Final disposal.

The sequence described above is not applicable in its entirety to waste that is treated off-site, e.g. in the case of melting or incineration of waste. Additional information about the waste streams as well as radiological levels is presented in chapter 5.

2.5. Containment

Activity present in Ågesta is largely bound to a material, but may be released during dismantling and demolition. An example could be the oxide coating that normally occurs on the inside of the system, which is protected until the process of dismantling has begun. Releases to air goes by the ventilation system and are minimised using filtration, see section 2.2.

Active components will be handled within the rock cavern to contain any risk of radioactive release outside the building. Dismantled components and building waste will be free released, after clearance, or sorted according to activity levels and then packed according to clearly defined routines. Contaminated water will be handled within the rock cavern and transported to an approved water treatment facility, see section 2.3.

For all nuclear power plants in Sweden there is an established system, the Swedish system, managed by SKB AB on behalf of the nuclear industry in order to ensure the safe disposal of all nuclear waste and fuel, see appendix 1.

For each waste type a description of the specific waste handling process from the time the waste is produced until it has been finally deposited into SFR or SFL is required, including interim storage criteria and transportation criteria. This is a requirement from SSM.

For external treatment facilities, the acceptance criteria for waste to be treated are established by the supplier performing the treatment, and the requirements must be met by the waste producer before the waste is treated. The supplier will package any residual radioactive waste in accordance with the associated waste type description[4].

In accordance with the above, one of the most important documents, ensuring well-planned and safe waste management is the waste handling plan for the decommissioning. This plan forms part of the safety analysis report (SAR). The specific waste type descriptions will also be produced, both at Ågesta (as the waste producer) at the Studsvik facility and SFR. Before a new type of waste is produced, the waste type description is submitted to SSM for review and approval.

[4] Note that the owner of the waste sent for treatment is still the owner of any secondary waste generated during the treatment process.

3. Release of airborne radioactive effluents in normal conditions

3.1. Authorisation procedure in force

3.1.1. Legislation on nuclear activities

The Act on Nuclear Activities SFS 1984:3 and the Radiation Protection Ordinance (SFS 2018:506) with instructions for the Swedish Radiation Safety Authority (SFS 2008:452) have been translated into English and can be found on the SSM website (www.ssm.se). The Radiation Protection Act (SFS 2018:396 is not yet published in English. These acts and the ordinance, together with the Ordinance on nuclear activities SFS 1984:14 and the Radiation Protection Ordinance (SFS 2018:506), stipulate the boundaries for all nuclear activities in Sweden. SSM has developed regulations (SSMFS) to provide a more detailed framework for e.g. nuclear power plants. Some of the regulations are available in English.

SSM is responsible for regulating radiological safety and security at all nuclear licensed sites in Sweden. SSM issues regulations and permits and verifies that the licensee is in compliance with these. The objective is to optimise radiation protection for personnel and the public while limiting releases of radioactive substances to the lowest possible reasonably practicable levels.

The most important regulations and licence conditions with respect to this are:

- SSMFS 2008:1: The Swedish Radiation Safety Authority’s Regulations and General Advice concerning Safety in Nuclear Facilities
- SSMFS 2018:1 The Swedish Radiation Safety Authority´s regulations concerning basic provisions for practises involving ionising radiation subject to mandatory licensing.
- SSMFS 2018:3: The Swedish Radiation Safety Authority’s regulations and general advice concerning clearance of materials, rooms, buildings and land in practices involving ionising radiation

Radioactive releases from nuclear facilities that are being dismantled and decommissioned are not specifically regulated in any SSMFS at present, but have been issued as (future) licensing conditions in [8]. These state, among other conditions (not verbatim);

- Discharges of radioactive substances from nuclear facilities and exposure of the environment to ionising radiation shall be limited as far as reasonably practicable considering available technology as well as social and economic factors.
- The effective dose to any individual in the reference group resulting from an annual discharge of radioactive substances to water and air from all facilities situated within the same geographical area shall not exceed 0.1 mSv. If the estimated dose is 0.01 mSv or higher per calendar year, realistic calculations shall be performed regarding the most affected area. The calculation method shall be in accordance with SSMFS 2018:1.
- Discharges of radioactive substances from nuclear facilities to air and water shall be checked by means of measurements, as far as reasonably practicable.

- Environmental surveys shall be conducted in the vicinity of a nuclear facility according to a survey scheme approved by SSM.
- The licensee shall have a documented plan for limiting, reducing and monitoring releases of radioactive substances to the environment.
- Requirements on reporting information about releases to the environment to SSM are specified in licence condition 26.

3.1.2. Discharge limits and associated requirements for decommissioning

In Sweden there are no discharge limits in Bq for the time before the envisaged dismantling operations or the dismantling operations themselves. Instead, the annual dose to the public is estimated in accordance with 2-3 § SSMFS 2018:1 from all nuclear facilities situated in the same area to verify that it does not exceed 0,1 mSv.

3.2. Technical aspects

Small or no measurable amounts of airborne radioactive effluents are expected to be discharged during dismantling (Tritium is likely to be measurable in small amounts). The statement is based on measurements during the recent dismantling of the research reactor R2 at the Studsvik site. Measurements of particle filters, placed at the different release points at R2, have been performed. No gamma-emitting nuclides have been detected in the nuclide specific measurements. In the non-nuclide-specific measurements, a small quantity of alpha-emitting nuclides was detected. Up to 10 kBq have been measured for one year. A conversion of the alpha-release to dose can be performed by applying the dose factor for Am 241, which is $8{,}8 \times 10^{-15}$ Sv/Bq. An annual release of 10 kBq Am-241 thus corresponds to an effective committed dose to an infant in the most exposed representative family of $8{,}8 \times 10^{-11}$ Sv or $8{,}8 \times 10^{-8}$ mSv. Discharge of airborne radioactive effluents during the dismantling of the R2 reactor was consequently negligible. The dismantling of the reactor at Ågesta will take place inside the leak-tight steel layer within the rock cavern and there is no reason to assume that measurable amounts of airborne radioactive effluents will be discharged during dismantling.

Best available technology will be used to reduce the release of radioactive effluents from the systems, components or structures that are taken apart and subsequently packed. When components are cut into pieces, local filters and filters in the ventilation system will be used. Areas where cutting is performed will be separated from other areas.
The release point of the ventilation system is situated on top of the rock cavern. Any release of airborne radioactive effluents would pass the particle filters installed in the ventilation system before the release point.

3.2.1. Origins of the radioactive effluents, their composition and physico-chemical forms

All radioactive waste materials at Ågesta are situated within the rock cavern and inside pressure-retaining steel liner.
Radioactivity originates from the period of power operation and was mainly produced in the following processes:

- Neutron activation of materials close to the core. For example activation of silver in the control rods, activation of cobalt in internal components and activation of deuterium in the cooling water.
- Neutron activation of corrosion products from surrounding systems that followed the cooling media through the core and e.g. deposited on system surfaces.
- Contamination of systems and construction parts. For example tritium contamination of the refuelling machine and tritium contamination of concrete structures.

Radioactivity from contamination or activation is bound in systems, components or constructions. All waste is solid and there is no radioactive waste in gaseous or liquid form present at Ågesta. Parts of the plant with relatively high amounts of radioactivity include the reactor pressure vessel, the biological shield, control rods, refuelling machine and portions of the primary system. The six nuclides with the highest radioactivity are listed in table 3-1. The reference date for the inventory is 1st of January 2020 and includes 29 nuclides in total. Only nuclides that are expected to exceed the limit values for conventional waste treatment have been included in the total inventory.

Table 3-1. The six nuclides with the highest radioactivity at Ågesta as of 1st of January 2020.

Nuclide	T1/2	Activity (Bq)
Ni-63	98.7 y	4.6×10^{13}
H-3	12.3 y	4.2×10^{13}
Ag-108m	438 y	1.9×10^{12}
Ni-59	76.0 ky	5.3×10^{11}
Co-60	5.27 y	2.7×10^{11}
C-14	5.70 ky	9.0×10^{10}

As previously mentioned, no releases of radioactive effluents are expected during the dismantling of the Ågesta reactor. However, assumed release fractions of the six nuclides with the highest radioactivity were applied to calculate a rough conservative estimate of the dose to a representative person. A release fraction of 10^{-7} per year was assumed for five of the nuclides presented in the table (all nuclides except tritium). Measurements performed during segmentation of internal parts (e.g. steam separators and core spray) at unit 3 at the Oskarshamn NPP in 2012 resulted in a release fraction of 10^{-7} for cobalt during segmentation. No discharges to the atmosphere were observed during the actual cutting, but the activity remained in the pools and was released later when water was removed and areas dried.

Tritium can be assumed to be more volatile than the other nuclides and according to IAEA TECDOC 1162, the release fraction of tritium is 500 times that of Co-60. Even though the release fractions are estimated for a fire taking place, the relationship is assumed to be the same during segmentation. The release fraction of tritium is therefore assumed to be 5×10^{-5} of the total inventory per year. Assumptions of the release of airborne radionuclides are presented in table 3-2.

Table 3-2. Assumption of annual release of airborne radionuclides.

Nuclide	$T_{1/2}$	Activity (Bq)
Ni-63	98.7 y	4.6×10^6
H-3	12.3 y	2.1×10^9
Ag-108m	438 y	1.9×10^5
Ni-59	76.0 ky	5.3×10^4
Co-60	5.27 y	2.7×10^4
C-14	5.70 ky	9.0×10^3

3.3. Monitoring of discharges

Isokinetic measurements of aerosols and tritium will be performed of the air that exits the rock cavern via the main stack, see figure 2-4. Aerosol and tritium filters will be installed in by-pass lines adjacent to the main stack. The filters will be replaced once a month and analysed for the presence of radionuclides.

All analyses will be performed at an external laboratory. The collection is continuous. Together with the total volume that has passed through the filters and the average air flow in the main stack it is possible to calculate the discharges to the air.

Automatic alarms will be installed to detect low flow in the main stack and low flow in the sampling loops.

3.4. Evaluation of transfer to man

3.4.1. Models, including where appropriate generic models, and parameter values used to calculate the consequences of the releases in the vicinity of the plant

If the assessed maximum exposure levels from discharges during normal conditions to adults, children and infants in the vicinity of the plant are below 0.01 mSv per year and there are no exceptional pathways of exposure, e.g. involving the export of foodstuffs, then no data on effective dose in other affected member states are required if doses to the reference group in the vicinity of the plant are provided.

As previously mentioned, no releases of radioactive effluents are expected during the dismantling. However, the releases as presented in table 3-2 have been used in a rough conservative estimate of the dose to a representative person. The concept of representative person is defined in ICRP publication 101.

A national effort has recently been made to determine dose factors for the different release points at seven nuclear sites in Sweden [15]. Dose factors have been proposed (awaiting final approval by SSM) for the release of 1 Bq of a specific radionuclide and the factors are expressed in Sv/year per Bq/year. The dose models and the dose factors are established according to chapter 5 in SSMFS 2018:1, which implements ICRP 101 and dose coefficients recommended by ICRP. Once applied, the result is the annual effective committed dose for the highest exposed individuals at the maximum 100th year of annual radionuclide releases. No specific dose factors have been determined for the Ågesta site. The closest facility for which dose factors have been determined is Studsvik which is approximately 70 km away, and the factors for a fictive release point at Studsvik [16] [17] have been used for estimation of doses to the public from aerial discharges from Ågesta during normal operation. Appendix 4 presents an analysis of the usage of dose factors from the PREDO model for the Studsvik site and it is shown that lifestyle and environmental aspects in the area surrounding Ågesta do not differ significantly compared to the area surrounding Studsvik.

Below follows a short description of models used in PREDO:

The methodology for atmospheric dispersion has been developed by the Swedish Meteorological and Hydrological Institute (SMHI) and it is based on a local-scale analytical Gaussian model. Five-year weather data statistics was utilized to derive time-averaged surface air concentrations and deposition fields (both wet and dry deposition). The model uses hourly pre-processed meteorological data based on similarity theory. Re-suspension is not considered in the model.

Food chains, inhalation, external exposure (from ground and from cloud) and living habits (such as time spent outdoors) are determined for three age groups i. infants, ii. children and iii. adults, belonging to the following families:

- Average family
- Farmer (general) family
- Farmer (dairy producer) family
- Fisherman family
- Hunter family
- Vegetarian family

In the food chain model various foods are divided into different groups and each group is treated in a specific manner in the calculations. The following groups are included for food:

- Aquatic food types
- Wild berries
- Crop types
- Herbivores/Game
- Meat types
- Milk types
- Mushrooms
- Eggs

To obtain the fraction of a food type that is locally produced, different studies on consumption and/or on import and export have been used.

Dose factors were determined for all release points at Studsvik, and the so called fictive release point showed the highest dose factors. Dose factors were determined for all age groups and for all different families and conservatively, the highest determined dose factors for each of the six radionuclides in table 3-1 are applied here for the estimation of effective dose during Ågesta decommissioning. For all radionuclides except H-3, the highest dose factors are found for the infant in the vegetarian family. For H-3 the infant in the farmer or dairy farmer family show the highest values.

Table 3-3 shows the dose factors, obtained from the PREDO result report for Studsvik [17], used for calculations of effective committed dose during decommissioning of Ågesta.

Table 3-3 Dose factors used for estimation of effective committed dose during decommissioning of Ågesta. The highest estimated dose factors for each radionuclide are used.

Nuclide	Dose factor (Sv/Bq)	Description of dose factor
Ni-63	1.86×10^{-17}	Infant, vegetarian family
H-3	7.36×10^{-20}	Infant, farmer or dairy farmer family
Ag-108m	1.38×10^{-15}	Infant, vegetarian family
Ni-59	8.68×10^{-18}	Infant, vegetarian family
Co-60	6.05×10^{-16}	Infant, vegetarian family
C-14	1.30×10^{-17}	Infant, vegetarian family

A comparison of dose factors for the six nuclides analysed was performed for the three age groups and all the release points at the seven Swedish nuclear sites. In all cases except one the dose factors used here were the highest. The exception was found for the dose factor of C-14 at the release point Ustore at the nuclear fuel manufacturing facility in Västerås. That dose factor is twice as large as the factor used here. However, the dose factor for the Studsvik site are still used for the estimation of committed effective dose, see Appendix 4.

3.4.2. Evaluation of the concentration and exposure levels associated with the envisaged discharge limits for the dismantling operations cited in 3.1 above:

The committed effective dose is calculated by multiplying the dose factor in table 3-3 with the conservative assumption of annual release of airborne radionuclides in table 3-2. The results are shown in Table 3-4.

In summary, the committed effective dose to an infant in an “imaginary conservative family” (combination of dose factors for the vegetarian and the farmer/dairy farmer families) is conservatively estimated to be 5.2×10^{-10} Sv (or 0.00000052 mSv). The above calculation shows that it is not feasible that the representative person in the vicinity of the plant can receive an annual committed effective dose greater than 0.01 mSv during dismantling. No exposure levels in other Member States are therefore estimated or presented in this report. Nor are there any other installations from which discharges need to be considered in conjunction with those from the installation in question.

Table 3-4 Dose factors used for estimation of effective committed dose during decommissioning of Ågesta. The highest estimated dose factors for each radionuclide are used. The committed effective dose is calculated by multiplying the dose factor by the assumed annual release in table 3-2. The highest estimated dose factor for each radionuclide was used.

Nuclide	Committed effective dose (Sv)
Ni-63	8.6×10^{-11}
H-3	1.6×10^{-10}
Ag-108m	2.6×10^{-10}
Ni-59	4.6×10^{-13}
Co-60	6.5×10^{-11}
C-14	1.2×10^{-13}
Total	$\mathbf{5.2 \times 10^{-10}}$

4. Release of liquid radioactive effluents in normal conditions

4.1. Authorisation procedure in force

See Section 3.1 for a general description of legislation and authorisation procedures.

4.2. Technical aspects

Under normal circumstances, the use of water will be minimised during dismantling of Ågesta. There are no water pipes within the area where radioactive waste is present and no drains from that area.

In special circumstances, such as decontamination of personnel, water may be used. In such an event, waste water is collected in tanks that can be transported to Studsvik for waste water treatment.

4.3. Monitoring of discharges

Measurements are currently performed to verify that water inside the rock cavern but outside the pressure-retaining steel liner does not penetrate the steel. There are 35 penetrations in the steel liner to handle drainage water. The water is led through the steel liner, inside closed pipes, and then it is collected in a drainage pit before it continues in a ditch to lake Orlången. Water that passes through the containment is not exposed to its atmosphere. Measurements of the water in the drainage pit and of the water, as well as the sediment, in the ditch verify the absence of radionuclides in the drainage water. This monitoring will continue while the reactor is being dismantled.

4.4. Evaluation of transfer to man

As stated in chapter 4.2, no discharge of water is expected during dismantling. No evaluation of the transfer to man has therefore been performed.

5. Disposal of solid radioactive waste from the installation

5.1. Solid radioactive waste

This chapter describes the Swedish requirements governing the management of radioactive solid waste and how the waste arising from the decommissioning of Ågesta will be managed. The chapter supplements the information provided in chapter 2.4.

The licensees are responsible for the nuclear waste arising during operation and decommissioning of a nuclear facility. This responsibility ceases once the waste has been placed in a final repository that has been finally sealed.

Swedish regulations require the waste generator to produce a waste handling plan as well as a specific description of each waste type. Both the waste handling plan and the waste type descriptions (WTD) undergo safety reviews and form part of the safety analysis report for each facility where the waste is handled. This includes the facility of origin, in this case Ågesta, as well as any offsite treatment facilities and the final repository. The WTD describes the handling sequence, from the time the waste is produced until it has been finally deposited in SFR (Final repository for short-lived radioactive waste) or SFL (Planned final repository for long-lived radioactive waste). The WTD lists the relevant waste acceptance criteria (WAC) together with a description of how compliance with the WAC is verified. Before a particular waste type can be produced and disposed of at the SFR-facility, the WTD must be approved by the Swedish Radiation Safety Authority.

The system for managing radioactive waste in Sweden is described in chapters 2.4-2.5 and appendix 1.

5.1.1. Categories of solid radioactive waste and estimated amounts

The initial sorting of materials, buildings and site areas from a radiological and hazard perspective as well as the estimated quantities is derived from previous studies. Taking into account the information compiled in previous studies, operational records and other relevant information, the waste expected to arise during the dismantling and demolition has been defined and quantified for the purposes of this report.

The waste is further divided into different waste streams: Metal, Combustible and Other radioactive solid waste (concrete, sand, etc.).

Levels of radioactive waste are defined based on the content and half-life of the respective radionuclides in the waste.

In Sweden there are five levels of low and intermediate level radioactive waste defined in SKB's waste manual [4]. These levels dictate how radioactive waste is disposed of.

Short-lived very low level waste (VLLW): Contains short-lived radionuclides with half-life less than 31 years. The dose rate on the waste container (and unshielded material) < 0.5 mSv/h. This waste is often secondary waste (such as gloves, protective clothing and equipment). This waste meets the acceptance criteria for final disposal in BLA (Rock vault for low level waste in SFR) or may be disposed in a surface repository. VLLW which fulfils acceptance criteria can be sent to facility for incineration. Disposal in a surface repository is not an option for waste originating from Ågesta.

Short-lived low level waste (LLW): Contains short-lived radionuclides with half-life less than 31 years. The dose rate on the waste container (and unshielded material) < 2 mSv/h. Long-lived radionuclides with half-life greater than 31 years are present in limited quantities. The waste meets the acceptance criteria for final disposal in BLA (Rock vault for low level waste in SFR).

Short-lived intermediate level waste (ILW): Contains significant quantities of short-lived radionuclides with half-life less than 31 years. The dose rate on the waste container < 500 mSv/h for disposal in Silo and < 100 mSv/h for disposal in BMA (Rock vault for intermediate level waste). Long-lived radionuclides with half-life greater than 31 years are present in limited quantities. The waste meets the acceptance criteria for final disposal in Silo or BMA.

Long-lived low level waste: Contains long-lived radionuclides with half-life greater than 31 years and in significant quantities greater than the limits that apply to short-lived waste. No dose rate limit for disposal has been specified. The waste will be disposed of in SFL (Final repository for long-lived waste).

Long-lived intermediate level waste: Contains long-lived radionuclides with half-life greater than 31 years and in significant quantities greater than the limits that apply to short-lived waste. No dose rate limit for disposal of this waste has been specified. The waste will be disposed of in SFL (Final repository for long-lived waste).

Table 5-1 lists the total quantity in tons for each waste level and stream for Ågesta and is presented in figures 5-1 which depicts the quantities of the waste levels projected to arise during decommissioning of Ågesta.

Table 5-1 lists the total quantity in tons for each waste level and stream for Ågesta and is presented in figure 5-1 which depicts the quantities of the waste levels projected to arise during decommissioning of Ågesta.

Level/Stream	Metal	Combustible	Other	Total (tons)
LLW (short-lived)	100	100	250	450
ILW (short-lived)	200	0	0	200
LLW (long-lived)	0	0	50	50
ILW (long-lived)	300	0	0	300
Total				**1000**

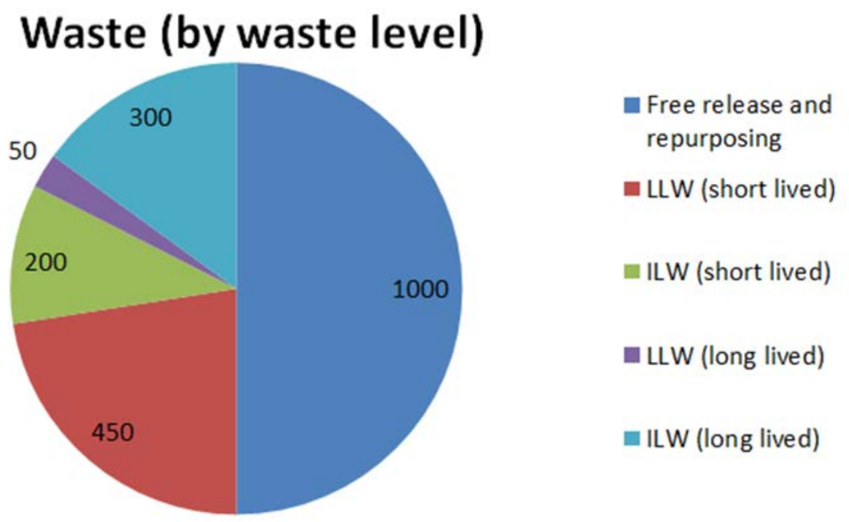

Figure 5-1. Decommissioning waste sorted by waste level from the SKB waste manual (tons).

The primary waste streams are described below:

Metallic waste

The metallic waste is comprised of both long-lived and short-lived radioactive waste, where the long-lived waste consists solely of reactor internals that have been neutron-activated. The metallic waste originates from:

- Process systems
- Steel structures
- Electrical equipment
- Large components

Process systems and other sources of metallic waste will be dismantled and when necessary cut into smaller segments.

Metallic waste is primarily treated through melting. If not melted it is sent to SFR or SFL.

Combustible Waste

Combustible waste is generated mostly as secondary waste from the dismantling and decommissioning activities. Secondary waste includes for instance contaminated protective clothing, gloves, plastic for example.

Other Solid Waste

Other radioactive solid waste is comprised primarily of concrete and sand. Concrete is present in conventional building material and as radiation shielding in the biological shield. ILW concrete is expected to arise solely from the demolition of the biological shield.

5.1.2. Processing, packaging and disposal

Most requirements for processing and packaging of radioactive solid waste are determined by the intended disposal. If the waste will be disposed of in a repository then the waste acceptance criteria must be met, which may entail specific treatment and packaging. If the waste is intended for clearance then it may be subject to treatment before this can take place. See chapter 2.4 for more information.

More than one disposal option may be applicable for several of the waste streams. The appropriate option is selected based on several factors, for instance, radiation protection, logistics, environmental impact and risks.

In Ågesta, some waste may be conditioned onsite and other which require further handling may be conditioned on the Studsvik site to be prepared for interim storage.

Processing

Radioactive solid waste is processed or treated with the objective of ensuring that it can either be cleared or rendered compliant with waste acceptance criteria for disposal. This treatment can also include volume reduction to maximize packing efficiency in the geological repository. Processing includes segregation of waste in different streams and levels, segmentation of piping and components, decontamination, fixing of loose surface contamination and compaction. Melting or incineration at an offsite facility is also possible.

Incineration is performed of organic radioactive waste at the Cyclife facility (see 5.3 for more information). It provides an efficient volume reduction and destroys chemically reactive substances. The portion of waste from Ågesta that is combustible and has a contact dose rate less than 0.5 mSv/h may be sent for incineration. Nuclide-specific activity concentration limits must also be met in order for the waste to be acceptable for incineration. Secondary waste (ash) produced as a result of incineration will be disposed of as low-level waste.

Melting of waste reduces its volume and surface as well enables verification of the activity contents for an object. Activity not separated in smoke or slag will be homogenously distributed, and activity is bind in the metal structure. Material suitable for melting is steel, aluminium, copper, brass and lead. Melting is performed at the Cyclife facility at Studsvik. Material for melting is mainly metal from components, process systems and other metallic parts.

Packaging

Packaging criteria for radioactive solid waste are dictated by both transportation and disposal requirements. Low level waste is transported and disposed of in ISO containers or other approved containers that meet specified standards. Short-lived intermediate level waste is packaged in steel or concrete moulds and long-lived intermediate level waste is packaged in steel tanks.

Disposal

The options available in Sweden to dispose of radioactive solid waste are in the geological repository (SFR) or in a surface repository. The later one does not apply to decommissioning waste from Ågesta; even VLLW will be sent to the geological repository for disposal. For the waste that is suitable for clearance, the option is conventional disposal or recycling. Clearance is addressed in chapter 5.4.

At the moment the repository for short lived radioactive waste, SFR, only accept operational waste for deposition. SFR is in the process of being extended in order to provide sufficient capacity in the repository for future decommissioning waste. An application for this extension was submitted to the Swedish Radiation Safety Authority in 2014 and is presently being reviewed. In the meantime, until the extension is completed, low level and intermediate level waste are temporarily being stored in an interim storage facility off site (see figure 5-2). SFR is planned to accept short-lived low and intermediate level decommissioning waste for disposal in 2030.

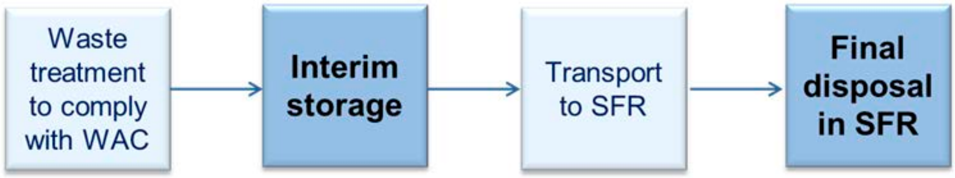

Figure 5-2. Handling sequence for waste sent for geological disposal.

For long-lived low level and intermediate level radioactive waste, a geological repository (SFL) is planned to be in operation 2045. Long-lived radioactive waste needs to be stored in the interim storage until SFL is available.

An overview of the Swedish system for disposal of radioactive waste is provided in Appendix 1.

5.2. Radiological risks to the environment

The waste to be handled during the dismantling process consists of various radioactive components and materials.

Radiological risks to the environment during decommissioning consist of releases during the handling of radioactive components and materials and accidents in the plant, such as fire or leakage of radioactive water. Transport of radioactive waste is also a potential radiological risk. However, no high activity waste will be transported from Ågesta. A risk analysis is presented in chapter 6 in this report.

Precautions will be taken to prevent impact to the environment during dismantling and demolition. Examples of equipment that will be used during dismantling to mitigate risk include systems to detect releases to air, modernized parts of the controlled ventilation system and fire detection equipment. Some of these systems are already in place at the plant or new temporary solutions will be installed.

In order to prevent accidents associated with the transport of radioactive waste, including loading and unloading, all transports will be conducted according to ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road) regulations [18] and in approved transport containers. The transports will follow the recommended road network for dangerous goods and all personnel loading, transporting and unloading the waste will have the required ADR training.

5.3. Off-site arrangements for the transfer of waste

In order to transfer waste from the decommissioning site to another location in Sweden, the first step is to verify that the waste meets the acceptance criteria established by the recipient. The recipient may be a final repository, a central storage or treatment facility or an offsite treatment facility, such as that located on the Studsvik site. This verification is documented by a waste type description for each waste type, as mandated in the SSM regulations. These waste type descriptions form part of the safety analysis report for the receiving facility, thereby ensuring that safety is maintained when handling the waste.

The Swedish nuclear industry has an established transportation system that has been in use since the 1980s. This system is primarily based on transport by sea using SKB's specially designed ship M/S Sigrid, see Appendix 1. Intermediate level waste is normally transported by sea in Sweden, but since Ågesta is located further away from the coast other transportation solutions may be applicable. Transport by road is necessary to reach the coast and will thus be used for waste which is to be transported by M/S Sigrid. Low level waste in ISO-containers can be transported by road. Shipments of radioactive waste in Sweden comply with the requirements stipulated in the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) [5] and the International Maritime Dangerous Goods Code (IMDG) [6].

SKB owns and maintains casks for the transport of intermediate level waste, each of which can hold multiple waste containers.

The Studsvik site (see Figure 5-3) is located outside Nyköping on the east coast of Sweden. This is where the interim storage as well as the Cyclife facility are located. Cyclife is a recipient for some of the waste both for treatment and storage. Cyclife Sweden provides waste treatment including volume reduction e.g. metal treatment by melting and thermal treatment of organic waste by incineration or pyrolysis.

For transportation to and from the Studsvik site, both the sea route system and the roadway system are applicable. It is also here that the interim storage for waste is located.

Figure 5-3 Studsvik site location - indicated in orange

Necessary interim storage of all low level and intermediate level radioactive waste produced during decommissioning will take place offsite at the Studsvik site in SVAFO's interim storage facility. The unavailability of the SFR and SFL repositories requires the interim storage of short-lived waste until after 2030 when the extended SFR is planned to open and of long-lived waste until 2045 when SFL is planned to commence operations.

The strategy for dismantling of the reactor pressure vessel has not been finally decided in Ågesta. There are two options – segmentation at site or transportation in two parts to Studsvik site for segmentation.

If the reactor pressure vessel is removed to be transported in parts, other large components will likely be transported whole from Ågesta. The destination is the Studsvik site for waste management, segmentation, decontamination, melting and possible clearance.

Several of these components can be transported in containers. Prior to transportation all openings are sealed so as to avoid the spreading of contamination in the facility or container. If a component does not fit in a container, the transportation will be done in accordance with stipulations from SSM.

If the option of segmenting the reactor pressure vessel onsite, it is likely that other large components will be segmented there as well. Waste level definition and sorting will probably be done in following to this.

5.4. Release of materials from the requirements of the basic safety standards

5.4.1. National strategy, criteria and procedures for the release of contaminated and activated materials

SSM regulations concerning the clearance of material, rooms, buildings and land used in activities involving ionising radiation, SSMFS 2018:3 were published on May 31, 2018. The objective of the regulation is to enable rational processing and use of materials, rooms, buildings and land that could have been contaminated with radioactive substances. This regulation brings Swedish regulations into line with directives from Euratom pertaining to clearance criteria.

The management of decommissioning waste from Ågesta will be based on the recommendations and guidelines for clearance described in [14]. The methodology presented in the report was developed jointly by nuclear power suppliers and other nuclear facility owners in Sweden. This report was issued two years before the new SSM regulations governing clearance but the methods and guidelines are still applicable.

5.4.2. Clearance levels established by competent authorities for disposal, recycling and reuse

In Sweden there are two types of clearance – general and conditional. General clearance entails that material and waste can be reused, recycled or deposited without imposing any further radiological control requirements. General clearance as per SSMFS 2018:3 [8] applies to clearance levels for free use. As examples, the clearance limit for Co-60 and for Cs-137 is 0.1 Bq/g. Appendix 2 in the regulation lists the clearance level for radionuclides, and is provided in Appendix 2 of this report.

Conditional clearance as per SSMFS 2018:3 applies to some types of hazardous waste. The clearance limit for Co-60 is 1 Bq/g and for Cs-137 10 Bq/g. Appendix 2 also includes tables with the corresponding clearance levels for buildings and contaminated oil and other hazardous waste.

The regulations allow for the granting of exemptions to allow for the clearance of materials provided there is no unacceptable risk of radiation exposure to people or the environment. This type of clearance requires special permission from the Swedish Radiation Safety Authority.

5.4.3. Envisaged types and amounts of released materials

It is estimated that the dismantling and demolition of Ågesta will require the clearance of 1 000 tons of material. Most of this material will consist of metal and concrete.

Clearance of materials can take place either directly after removal or after treatment. The nuclide-specific activity of the materials is determined to ensure that the levels comply with the requirements for clearance (see figure 5-4).

Figure 5-4. Management of local clearance.

6. Unplanned releases of radioactive effluents

6.1. Review of accidents of internal and external origin which could result in unplanned releases of radioactive substances

The licensee of a nuclear facility must verify that the probability of serious disturbances or mishaps is low and that, should such an event nevertheless occur, the consequences to the environment and personnel are acceptable. SSM regulation SSMFS 2008:1 [2] stipulates “The safety analyses shall be based on a systematic inventory of events, event sequences and conditions which can lead to a radiological accident”. For decommissioning it further stipulates that ”The safety analysis for the decommissioning of a facility should particularly take into account factors such as rapid changes in facility status, the removal of both active and passive safety functions, the handling of large quantities of nuclear waste, as well as unusual and changing working conditions”.

Since the nuclear fuel has been removed from the site, there are no inherent driving mechanisms present for release of radioactivity to the environment. Potential events that may cause a release of radioactivity therefore always include an external impact. For example, a fire may cause a release of radioactivity to the environment. However, the radioactivity is bound in systems, components and construction parts and even if a large fire did occur, the radioactivity is not easily released. Events leading to a possible release of radioactivity to the environment are listed in the safety analysis report for dismantling as:

- Fire
- Internal events (e.g. internal flooding)
- External events (e.g. external flooding, extreme weather or earthquake)
- Human errors (e.g. illicit removal of radioactive waste or loss of a heavy load)

6.2. Reference accident(s) taken into consideration by the competent national authorities for evaluating possible radiological consequences in the case of unplanned releases

The Swedish authorities have not specifically considered any accidents during decommissioning, since this is the responsibility of the licensee. A list of the events that the licensee has identified as potentially generating external releases in an accident scenario is presented in chapter 6.1.

6.3. Evaluation of the radiological consequences of the reference accident(s)

6.3.1. Accidents entailing releases to atmosphere

Realistic releases to the atmosphere are not estimated for the different accidents described above. Instead, a conservative postulated release is assumed. The results from the analyses are summarized below and details can be found in [9]. The entire radioactive inventory is multiplied by fire release fractions from IAEA-TECDOC-1162 [10]. Duration of the release to the atmosphere is assumed to be one hour. The activity of released radionuclides is presented in table 6-1.

Table 6-1 Activities of radionuclides in the postulated release

Radionuclide	$T_{1/2}$	FRF[5]	Released activity (Bq)
H-3	12,3 y	0.5	$2,1 \times 10^{13}$
C-14	5.70 ky	0.01	9.0×10^{8}
Cl-36	302 ky	0.5	4.4×10^{4}
Ca-41	100 ky	0.01	1.9×10^{6}
Fe-55	2.75 y	0.01	1.6×10^{8}
Co-60	5.27 y	0.001	2.7×10^{8}
Ni-59	76.0 ky	0.01	5.3×10^{9}
Ni-63	98.7 y	0.01	4.6×10^{11}
Sr-90	28.8 y	0.01	6.5×10^{7}
Nb-94	20.3 ky	0.01	1.2×10^{6}
Tc-99	211 ky	0.01	1.8×10^{7}
Ag-108m	438 y	0.01	1.9×10^{10}
Cd-113m	14.1 y	0.01	5.9×10^{8}
In-115	441 Ty	0.01	3.3×10^{3}
Sb-125	2.76 y	0.01	1.1×10^{3}
I-129	16.1 My	0.5	1.3×10^{3}
Cs-134	2.06 y	0.01	5.9×10^{-1}
Cs-135	2.30 My	0.01	3.1×10^{3}
Cs-137	30.1 y	0.01	1.4×10^{8}
Sm-151	94.7 y	0.01	2.7×10^{5}
Eu-152	13.5 y	0.01	1.3×10^{8}

[5] Fire Release Fraction

Eu-154	8.60 y	0.01	6.2×10^{6}
Eu-155	4.75 y	0.01	9.5×10^{2}
Pu-238	87.7 y	0.001	1.7×10^{4}
Pu-239	24.1 ky	0.001	1.9×10^{5}
Pu-240	6.56 ky	0.001	1.3×10^{5}
Pu-241	14.3 y	0.001	7.3×10^{5}
Am-241	433 y	0.001	2.6×10^{5}
Cm-244[6]	18.1 y	1.0	4.9×10^{4}

Committed effective dose is determined for a member of the public using a tool called DoseCalc [11]. The tool is a MatLab-script and it was developed as a response to an injunction from SSM on how radiological consequences of an unplanned radioactive release should be analysed. Following the injunction, a common methodology handbook was developed by the licensees. DoseCalc thereby follows the methodology as specified in Methodology Handbook for Realistic Analysis of Radiological Consequences [12] The handbook presents methods, data and parameters for analysing the individual doses following a radioactive release.

There are no assumptions applied regarding the release path, i.e. the entire inventory is released from a point near ground. The calculations are done for a release height of 10 m (representing releases from 0 to 25 m height) and the dose point is at 200 m distance from the release point (representing distances from 0 to 500 m from the release point).

All of the iodine is assumed to be in elemental form, since this form has the highest dose coefficient for inhalation. A Gaussian plume model is used to determine the atmospheric dispersion and the ground deposition. Dispersion of the cloud in air is modelled using a Gaussian distribution in the horizontal direction (perpendicular to the wind speed direction) and in the vertical direction. Methodology and parameter values in the model are chosen to fulfil the requirements as stated in the injunction from SSM [13]. For example, the dose is determined 1 m above ground. The release height is less than 25 m above ground and the weather data is therefore as specified in table 6-2.

Table 6-2 Weather data as specified in the injunction from SSM.

Wind speed (m/s)	2
Stability (Pasquill class)	F
Height of inversion layer (m)	100

Dry deposition velocity is 0.001 m/s for all elements, except for iodine which has the deposition velocity of 0.01 m/s. The dry deposition velocity is multiplied by a factor of two, to take precipitation into account. Resulting deposition velocities are therefore 0.002

[6] FRF is missing for curium and FRF for Cm-244 is therefore conservatively set to 1.

m/s for all elements, except for iodine which has the deposition velocity of 0.02 m/s. Ground roughness is set to 0.1 m. Re-suspension is not included in the model.

Exposure pathways included in the model are external radiation from the radioactive cloud, external radiation from deposited radionuclides on the ground and internal radiation from inhalation of air included in the radioactive cloud. No countermeasures are taken into account, which means that the person is standing outdoors in the plume direction. As mentioned above, the duration of the release is one hour and the integration time is 30 days, which means that the person is assumed to stay outdoors in the plume direction for 30 days. Dose coefficients used in DoseCalc are from the Dose Coefficient File Package DCFPAK 3.0.

Inhalation dose coefficients for adults and different children age groups were compared. The largest difference occurs between adults and infants; the dose coefficients (inhalation) are between one and eight times higher for infants compared to adults. To obtain a conservative estimate of the committed effective dose to an infant, the dose from inhalation for an adult was multiplied by a factor of eight. Resulting doses for an infant are also presented in table 6-3.

Resulting doses to an adult were calculated and the results are presented in table 6-3.

Table 6-3 Calculated dose to adult and infant

Exposure pathway	Dose (mSv)	
	Adult	Infant
Cloud dose	1.1×10^{-4}	1.1×10^{-4}
Ground dose	0.034	0.034
Inhalation dose	0.078	0.62
Total dose	**0.11**	**0.66**

Nuclide-specific contributions to the committed effective dose are presented in figure 6-1.

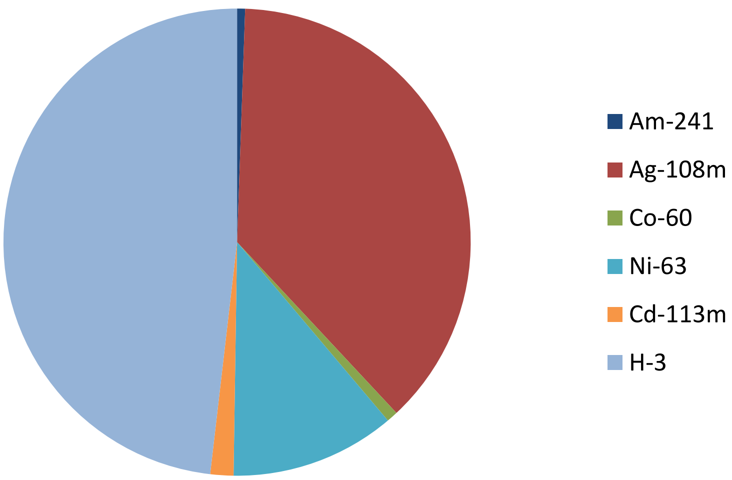

Figure 6-1 Nuclide-specific contributions to the committed effective dose. Only radionuclides that contribute to at least 1 % of the total dose are shown.

According to figure 6-1, the postulated release gives that the inhalation of tritium gives the largest consequence for the general public.
This means that even in the very conservative postulated scenario, the exposure level is below 1 mSv in the vicinity of the plant. The entire inventory is assumed to be consumed in a fire and released during one hour. No delay or retention due to the rock cavern or other structures is assumed in the model. Additionally no food exports are expected from the vicinity of Ågesta, see section 1.5.

6.3.2. Accidents entailing releases into an aquatic environment

No accident has been identified that could cause a release to the aquatic environment during the decommissioning period that could affect the surrounding member states.
In [9] results from a postulated release to aquatic environment are presented. The released inventory presented in table 6-1, is assumed to be released to water instead of air. Resulting doses are less than the corresponding doses from an atmospheric release, see table 9 in [9].

7. Emergency plans, agreements with other member state

All nuclear fuel has been transferred off-site to a licensed facility on which an opinion has already been given under the terms of Article 37. Therefore no data is required regarding emergency plans, agreements with other member states according to 2010/635/Euratom.

8. Environmental monitoring

8.1. General Description

The purpose of the radiological environmental monitoring programme is to examine the impact to the environment associated with the operation of nuclear power plants as well as activities related to dismantling and demolition. Environmental monitoring provides continuous information about the levels of radionuclides in the vicinity of the plant. Environmental monitoring complements emissions monitoring, which describes the magnitude and composition of the emissions. The purpose of area monitoring is primarily to provide a picture of long-term changes in radionuclide levels in the local environment which provides a basis for assessing potential effects on the biological life in the recipient. The objective of environmental monitoring is mainly to detect larger unregistered emissions and diffuse emissions. The information in the environmental monitoring programme can also be used for informing the public and as a basis for international reporting and other collaborations in the environmental area.

8.2. Monitoring at Ågesta

Ågesta is exempted from radiological environmental monitoring in accordance with the Swedish Radiation Safety Authority's Regulations (SSMFS 2008:23) on Protection of Human Health and the Environment from Releases of Radioactive Substances from Certain Nuclear Facilities. Since 1974 the plant has a monitoring programme according to the licence conditions.

After Ågesta was shut down and the fuel shipped off-site in 1974 the radioactive substances measured in environmental samples have decreased. Today there are only a few samples that indicate measurable levels of radioactive substances. Based on the current operating mode and previous test results, SSM made a decision about modifying the area monitoring programme for Ågesta. This modification entails designating the sampling period as April 1 to October 30, which is favourable from a sampling point of view.

The environmental monitoring programme for the Ågesta site during the care and maintenance phase is summarised in Table 8-1.

Table 8-1. Monitoring programme for Ågesta.

Monitoring programme for Ågesta, annual sampling			
Position	Type of sample	Parameter	Frequency
Ditch to lake Orlången	water	H-3 (Bq/l), Cs-137 (Bq/l), Co-60 (Bq/l)	Summer/autumn
Pressure-retaining steel lining	water	H-3 (Bq/l), Cs-137 (Bq/l), Co-60 (Bq/l)	Summer/autumn

Cavern drainage	water	H-3 (Bq/l), Cs-137 (Bq/l), Co-60 (Bq/l)	Summer/autumn
Ditch to lake Orlången	sediment	Cs-137 (Bq/kg), Co-60 (Bq/kg)	Summer/autumn

The results of the monitoring are reported to the Swedish Radiation Safety Authority. The licensees are responsible for performing the analyses. To verify the results, the Swedish Radiation Safety Authority collects random samples for analysis.

In June 2017 the Swedish Radiation Safety Authority issued specific conditions applicable to the decommissioning, several of which concern the environmental monitoring [8]. An updated monitoring programme for the decommissioning phase is therefore being developed. The updated monitoring programme needs to be approved by SSM prior to commencing decommissioning activities.

The update of the monitoring programme consists of an extension regarding sampling and measurement of biota. Different types of samples have been considered, e.g. grass or spruce shoots, beef and milk.

Since grass is less sensitive to individual variation than, e.g., spruce shoots, grass has been selected. Grass, from the vicinity of Ågesta (approximately 100 meters from the main stack, is going to be collected and analysed during the growth period. Beef and milk are not available in the immediate area and milk is primarily an indicator of iodine that is not likely to occur in the emissions.

Water and sediment in the ditch and water in the drainage and the containment will continue as before, see Table 8-1. Considering that no new liquid emissions are expected during dismantling and demolition, the aquatic environment controls will remain unchanged. Sampling of fish or other aquatic biota is not considered warranted as no liquid emissions occur other than to the ditch where only very low levels are measured.

Definitions and abbreviations

Definition or abbreviation	Description
AB SVAFO	Non-profit company whose task is to decommission nuclear facilities from previous research and development activities in Studsvik and to implement intermediate storage of waste from the decommissioning and waste from the research period until final disposal can be carried out
BLA	Rock vault for low level waste in the final repository for short-lived radioactive waste (SFR)
Care and maintenance period	Commences when all nuclear fuel has been transported from the facility. The Care and maintenance period prevails until the Dismantling and demolition commences. Planning for the Dismantling and demolition is included in the planning for Care and maintenance period
Clab	Central interim storage for spent fuel
EPA	Environmental Protection Agency
ILW	Intermediate level waste
LLW	Low Level Waste
NPP	Nuclear Power Plant
Reference group	Representative (real or hypothetical) group of people from the population that is expected to receive the highest radiation dose from Ågesta.
SAR	Safety Analysis Report
SFR	Final repository for short-lived radioactive waste
SFS	Swedish Code of Statutes
SSM	Swedish Radiation Safety Authority
SSMFS	Swedish Radiation Safety Authority regulations
SFL	Final repository for long-lived radioactive waste
SKB	Swedish Nuclear Fuel and Waste Management Company. SKB's assignment is to manage and dispose of all radioactive waste from Swedish nuclear power plants in such a way as to secure maximum safety for human beings and the

	environment, see Appendix1. Nuclear power companies in Sweden jointly established the Swedish Nuclear Fuel and Waste Management Company (SKB) in the 1970s.
SMHI	Swedish Meteorological and Hydrological Institute

Reference list

[1] 2010/635/Euratom - Commission recommendation of 11 October 2010 on the application of Article 37 of the Euratom Treaty

[2] SSMFS 2008:1 - Swedish Radiation Safety Authority's Regulations and General Advice concerning Safety in Nuclear Facilities

[3] Förstudie Nyköping. Jordarter, bergarter och deformationszoner. PRD-96-013. Bergman, T., Isaksson, H., Johansson, R., Lindén, A. H., Persson, C. och Stephens, M. (1996). Svensk kärnbränslehantering AB

[4] SKB's waste manual for low and intermediate level waste (in Swedish). Document ID 1195328. http://www.skb.se/publication/2480178/R-15-15.pdf 2018-08-21

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(The Swedish Civil Contingencies Agency's Regulations on Transport of Dangerous goods by Road)

[6] IMDG. TSFS 2015:66 - Transportstyrelsens föreskrifter och allmänna råd om transport till sjöss av förpackat farligt gods https://www.transportstyrelsen.se/TSFS/TSFS%202015_66k.pdf 2018-08-21
(The Swedish Transport Agency's Regulations and General Advice on the Transport of Packaged Dangerous Goods by Sea)

[7] SSMFS 2018:3. Strålsäkerhetsmyndighetens föreskrifter om undantag från strålskyddslagen och om friklassning av material, byggnadsstrukturer och områden. https://www.stralsakerhetsmyndigheten.se/contentassets/fd378df462fa47a58935551d27bace50/vagledning-med-bakgrund-och-motiv-till-stralsakerhetsmyndighetens-foreskrifter-ssmfs-2018_3-om-undantag-fran-stralskyddslagen-och-om-friklassning-av-material-byggnadsstrukturer-och-omraden.pdf 2018-08-21
(The Swedish Radiation Safety Authority's Regulations concerning exemption from the radiation protection regulations and concerning clearance of materials, buildings and land)

[8] SSM, Beslut om tillståndsvillkor för avveckling av Ågesta, SSM2017-2293-1, 2017-06-29 (Decision regarding licence conditions for decommissioning of the Ågesta reactor)

[9] Utsläppsanalys Ågesta inför nedmontering och rivning, Resurs-920 – 002, 2017-11-08, L Bäckstöm, A Fermvik
(Emission analysis of emissions during dismantling and demolition of Ågesta)

[10] IAEA-TECDOC-1162, Generic procedures for assessment and response during a radiological emergency, International Atomic Energy Agency (IAEA), August 2000

[11] T-NA 10-76 – Dosberäkningsprogram- DoseCalc rev 5, 2017-02-28, Vattenfall AB
(Report describing the code structure of the dose calculation program DoseCalc)

[12] T-CKV 2009-050, Methodology Handbook for Realistic Analysis of Radiological Consequences, J Möller, May 2010, version 2

[13] Strålsäkerhetsmyndigheten (SSM), Föreläggande avseende analys av radiologiska omgivningskonsekvenser för kärnkraftsreaktorerna Forsmark 1, Forsmark 2 och Forsmark 3, SSM 2008/1945, Beslut 2009-04-06
(Injunction regarding analysis of radiological area consequences)

[14] Berglund, JÅ. et.al. Friklassning vid nedmontering och rivning av kärntekniska anläggningar. R-16-13. Svensk Kärnbränslehantering AB, 2016
[15] PREDO2 Introduction QP.50000-63714825 v2.0, 2015-12-18, Vattenfall AB
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[17] PREDO2 Results Studsvik/SVAFO QP.50000-87996375 v2.0, inkl. elektroniska appendix, 2017-02-08, Vattenfall AB
[18] ADR-S 2019, Myndigheten för samhällsskydd och beredskaps föreskrifter om transport av farligt gods på väg och i terräng, MSBFS 2018:5
(The Swedish Civil Contingencies Agency Regulations on the transport of dangerous goods by road and terrain)

Appendix 1 – The Swedish system for the disposal of spent nuclear fuel and radioactive waste

A law was enacted in Sweden in the 1970s stipulating that anyone who produces electricity using nuclear power must also manage and dispose of the waste. The nuclear power companies in Sweden therefore jointly established the Swedish Nuclear Fuel and Waste Management Company, SKB, with the task of managing and disposing of all radioactive waste from Swedish nuclear power plants.

Figure A1-1 below shows the Swedish system for radioactive waste disposal. The system for dealing with Swedish radioactive waste comprises a number of facilities that together provide a safe chain. The first links in this chain were already in place in the early 1980s, others still have to be constructed. The radioactivity level of the waste determines how it is managed. Radioactive waste from sources other than nuclear power plants such as that produced in hospitals and industry must also be safely disposed of.

Transport by sea
Waste from nuclear power stations is transported by SKB's specially built vessel M/S Sigrid.

Central Interim Storage Facility for Spent Nuclear Fuel (Clab)
Today all spent nuclear fuel produced by Swedish nuclear power stations so far, is in interim storage in Clab outside Oskarshamn. It is stored in pools located in rock vaults 25–30 meters underground and is under continuous surveillance and control. Clab has been operating since 1985.

Clab is not a final repository, so after interim storage, the waste will be moved to the Spent Fuel Repository that SKB plans to construct at Forsmark.

Final Repository for Short-lived Radioactive Waste (SFR)
This is where operational waste from nuclear power plants, which includes used protective clothing, replaced components and filtering materials that have been used to decontaminate reactor water, is deposited. Radioactive waste from hospitals, industry and research is also disposed of here. The repository is located at Forsmark in bedrock about 50 meters below sea level.

A licence application has been submitted to the authorities in order to extend SFR, primarily to make room for decommissioning waste.

Final Repository for Spent Nuclear Fuel at Forsmark
The planned Spent Fuel Repository forms the last link in the chain when it comes to dealing with spent nuclear fuel. It will be deposited there in sealed copper canisters placed in rock vaults and surrounded by bentonite clay at a depth of 500 meters in the rock.

Encapsulation plant at Oskarshamn
After interim storage the spent nuclear fuel will be sealed into canisters and SKB plans to construct an encapsulation plant at Oskarshamn. The canisters will be made of copper with inserts of nodular cast iron and will each contain about 2 tons of waste.

Final Repository for Long-lived Radioactive Waste (SFL)
SKB is also planning a final repository for long-lived radioactive waste, SFL. This project has not, however, progressed as far as the others.

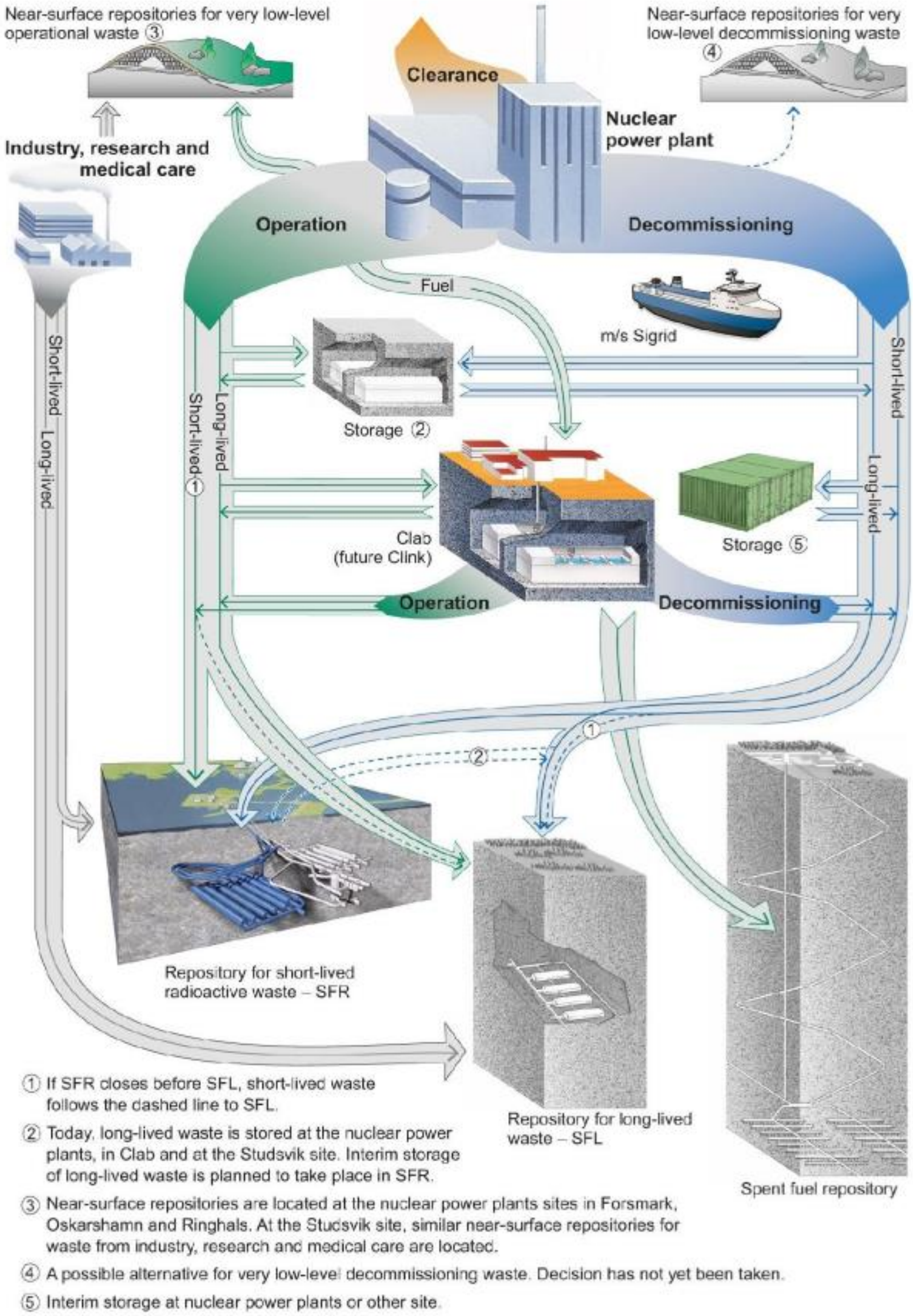


Figure A1-1 The Swedish system for the disposal of radioactive waste.

Appendix 2 - Clearance levels

The information in this appendix has been excerpted and translated from the Swedish Radiation Authority’s regulation concerning clearance of materials, buildings and land, SSMFS 2018:3.

SSMFS 2018:3 Appendix 2, Values for exemption or clearance levels

Applies to materials other than radioactive contaminated soil or sediment that has been excavated, unless samples are collected. (+) designates parent nuclides. See table below.

Radio-nuclide	Level (Bq/g)
H-3	100
Be-7	10
C-14	1
F-18	10
Na-22	0,1
Na-24	1
Si-31	1 000
P-32	1 000
P-33	1 000
S-35	100
Cl-36	1
Cl-38	10
K-40	1
K-42	100
K-43	10
Ca-45	100
Ca-47	10
Sc-46	0,1
Sc-47	100
Sc-48	1
V-48	1
Cr-51	100
Mn-51	10
Mn-52	1
Mn-52m	10
Mn-53	100
Mn-54	0,1
Mn-56	10
Fe-52 (+)	10
Fe-55	1 000
Fe-59	1
Co-55	10
Co-56	0,1
Co-57	1
Co-58	1
Co-58m	10 000
Co-60	0,1
Co-60m	1 000
Co-61	100
Co-62m	10
Ni-59	100
Ni-63	100
Ni-65	10
Cu-64	100
Zn-65	0,1
Zn-69	1 000
Zn-69m (+)	10
Ga-72	10
Ge-71	10 000
As-73	1 000
As-74	10
As-76	10
As-77	1 000
Se-75	1
Br-82	1
Rb-86	100
Sr-85	1
Sr-85m	100
Sr-87m	100
Sr-89	1 000
Sr-90 (+)	1
Sr-91 (+)	10
Sr-92	10
Y-90	1 000
Y-91	100
Y-91m	100
Y-92	100
Y-93	100
Zr-93	10
Zr-95 (+)	1
Zr-97 (+)	10
Nb-93m	10
Nb-94	0,1
Nb-95	1
Nb-97m (+)	10
Nb-98	10
Mo-90	10
Mo-93	10
Mo-99 (+)	10
Mo-101 (+)	10
Tc-96	1
Tc-96m	1 000
Tc-97	10
Tc-97m	100
Tc-99	1
Tc-99m	100

Radio-nuclide	Level (Bq/g)	Radio-nuclide	Level (Bq/g)	Radio-nuclide	Level (Bq/g)
Ru-97	10	Te-131m (+)	10	Pr-142	100
Ru-103 (+)	1	Te-132 (+)	1	Pr-143	1 000
Ru-105 (+)	10	Te-133	10	Nd-147	100
Ru-106 (+)	0,1	Te-133m	10	Nd-149	100
Rh-103m	10 000	Te-134	10	Pm-147	1 000
Rh-105	100	I-123	100	Pm-149	1 000
Pd-103 (+)	1 000	I-125	100	Sm-151	1 000
Pd-109 (+)	100	I-126	10	Sm-153	100
Ag-105	1	I-129	0,01	Eu-152	0,1
Ag-108m (+)	0,1	I-130	10	Eu-152m	100
Ag-110m (+)	0,1	I-131	10	Eu-154	0,1
Ag-111	100	I-132	10	Eu-155	1
Cd-109 (+)	1	I-133	10	Gd-153	10
Cd-115 (+)	10	I-134	10	Gd-159	100
Cd-115m (+)	100	I-135	10	Tb-160	1
In-111	10	Cs-129	10	Dy-165	1 000
In-113m	100	Cs-131	1 000	Dy-166	100
In-114m (+)	10	Cs-132	10	Ho-166	100
In-115m	100	Cs-134	0,1	Er-169	1 000
Sn-113 (+)	1	Cs-134m	1 000	Er-171	100
Sn-125	10	Cs-135	100	Tm-170	100
Sb-122	10	Cs-136	1	Tm-171	1 000
Sb-124	1	Cs-137 (+)	0,1	Yb-175	100
Sb-125 (+)	0,1	Cs-138	10	Lu-177	100
Te-123m	1	Ba-131	10		
Te-125m	1 000	Ba-140	1	Hf-181	1
Te-127	1 000	La-140	1	Ta-182	0,1
Te-127m (+)	10	Ce-139	1	W-181	10
Te-129	100	Ce-141	100	W-185	1 000
Te-129m (+)	10	Ce-143	10	W-187	10
Te-131	100	Ce-144 (+)	10	Re-186	1 000

Radio-nuclide	Level (Bq/g)	Radio-nuclide	Level (Bq/g)	Radio-nuclide	Level (Bq/g)
Re-188	100	Ra-223 (+)	1	Np-240	10
Os-185	1	Ra-224 (+)	1	Pu-234	100
Os-191	100	Ra-225	10	Pu-235	100
Os-191m	1 000	Ra-226 (+)	0,01	Pu-236	1
Os-193	100	Ra-227	100	Pu-237	100
Ir-190	1	Ra-228 (+)	0,01	Pu-238	0,1
Ir-192	1	Ac-227 (+)	0,01	Pu-239	0,1
Ir-194	100	Th-226	1 000	Pu-240	0,1
Pt-191	10	Th-227	1	Pu-241	10
Pt-193m	1 000	Th-228 (+)	0,1	Pu-242	0,1
Pt-197	1 000	Th-229	0,1	Pu-243	1 000
Pt-197m	100	Th-230	0,1	Pu-244 (+)	0,1
Au-198	10	Th-231	100	Am-241	0,1
Au-199	100	Th-232 (+)	0,01	Am-242	1 000
Hg-197	100	Th-234 (+)	10	Am-242m (+)	0,1
Hg-197m	100	Pa-230	10	Am-243 (+)	0,1
Hg-203	10	Pa-231	0,01	Cm-242	10
Tl-200	10	Pa-233	10	Cm-243	1
Tl-201	100	U-230	10	Cm-244	1
Tl-202	10	U-231	100	Cm-245	0,1
Tl-204	1	U-232 (+)	0,1	Cm-246	0,1
Pb-203	10	U-233	1	Cm-247 (+)	0,1
Pb-210 (+)	0,01	U-234	1	Cm-248	0,1
Bi-206	1	U-235 (+)	1	Bk-249	100
Bi-207	0,1	U-236	10	Cf-246	1 000
Bi-210	10	U-237	100	Cf-248	1
Po-203	10	U-238 (+)	1	Cf-249	0,1
Po-205	10	U-239	100	Cf-250	1
Po-207	10	U-240 (+)	100	Cf-251	0,1
Po-210	0,01	Np-237 (+)	1	Cf-252	1
At-211	1 000	Np-239	100	Cf-253	100

Radio-nuclide	Level (Bq/g)	Radio-nuclide	Level (Bq/g)	Radio-nuclide	Level (Bq/g)
Cf-254	1	Es-254 (+)	0,1	Fm-254	10 000
Es-253	100	Es-254m (+)	10	Fm-255	100

Decay products that have been taken into account when determining values for radionuclides marked with (+) are listed in the table below.

Parent nuclide	Decay product(s)
Fe-52	Mn-52m
Zn-69m	Zn-69
Sr-90	Y-90
Sr-91	Y-91m
Zr-95	Nb-95
Zr-97	Nb-97m, Nb-97
Nb-97m	Nb-97
Mo-99	Tc-99m
Mo-101	Tc-101
Ru-103	Rh-103m
Ru-105	Rh-105m
Ru-106	Rh-106
Pd-103	Rh-103m
Pd-109	Ag-109m
Ag-108m	Ag-108
Ag-110m	Ag-110
Cd-109	Ag-109m
Cd-115	In-115m
Cd-115m	In-115m
In-114m	In-114
Sn-113	In-113m
Sb-125	Te-125m

Parent nuclide	Decay product(s)
Te-127m	Te-127
Te-129m	Te-129
Te-131m	Te-131
Te-132	I-132
Cs-137	Ba-137m
Ce-144	Pr-144, Pr-144m
Pb-210	Bi-210, Po-210
Ra-223	Rn-219, Po-215, Pb-211, Bi-211, Tl-207, Po-211
Ra-224	Rn-220, Po-216, Pb-212, Bi-212, Tl-208
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214
Ra-228	Ac-228
Ac-227	Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207, Po-211
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208

Parent nuclide	Decay product(s)
Th-232	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208
Th-234	Pa-234m, Pa-234
U-232	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208
U-235	Th-231

Parent nuclide	Decay product(s)
U-238	Th-234, Pa-234m, Pa-234
U-240	Np-240m, Np-240
Np-237	Pa-233
Pu-244	U-240, Np-240m, Np-240
Am-242m	Np-238
Am-243	Np-239
Cm-247	Pu-243
Es-254	Bk-250
Es-254m	Fm-254

Appendix 3 from SSMFS 2018:3 - Clearance levels for oil and other hazardous waste to be sent for incineration or disposal

Radionuclide	Clearance level (Bq/g)
H-3	1 000
Be-7	100
C-14	100
Na-22	1
P-32	1 000
P-33	1 000
S-35	1 000
Cl-36	10
K-40	10
Ca-45	1 000
Ca-47	10
Sc-46	1

Radionuclide	Clearance level (Bq/g)
Sc-47	100
Sc-48	1
V-48	1
Cr-51	100
Mn-52	1
Mn-53	10 000
Mn-54	1
Fe-55	1 000
Fe-59	1
Co-56	1
Co-57	10

Radionuclide	Clearance level (Bq/g)
Co-58	1
Co-60	1
Ni-59	1 000
Ni-63	1 000
Zn-65	10
Ge-71	10 000
As-73	1 000
As-74	10
As-76	10
As-77	1 000
Se-75	10

Radionuclide	Clearance level (Bq/g)	Radionuclide	Clearance level (Bq/g)	Radionuclide	Clearance level (Bq/g)
Br-82	1	Cd-115m (+)	100	Ce-141	100
Rb-86	100	In-111	10	Ce-143	10
Sr-85	10	In-114m (+)	10	Ce-144 (+)	100
Sr-89	100	Sn-113 (+)	10	Pr-143	1 000
Sr-90 (+)	10	Sn-125	10	Nd-147	100
Y-90	1 000	Sb-122	10	Pm-147	1 000
Y-91	100	Sb-124	1	Pm-149	1 000
Zr-93	100	Sb-125 (+)	10	Sm-151	1 000
Zr-95 (+)	1	Te-123m	10	Sm-153	100
Nb-93m	1 000	Te-125m	1 000	Eu-152	1
Nb-94	1	Te-127m (+)	100	Eu-154	1
Nb-95	10	Te-129m (+)	100	Eu-155	100
Mo-93	100	Te-131m (+)	10	Gd-153	100
Mo-99 (+)	10	Te-132 (+)	1	Tb-160	1
Tc-96	1	I-125	10	Dy-166	100
Tc-97	100	I-126	10	Ho-166	100
Tc-97m	100	I-129	1	Er-169	1 000
Tc-99	10	I-131 (+)	10	Tm-170	100
Ru-97	10	Cs-129	10	Tm-171	1 000
Ru-103 (+)	10	Cs-131	1 000	Yb-175	100
Ru-106 (+)	10	Cs-132	10	Lu-177	100
Rh-105	100	Cs-134	1	Hf-181	10
Pd-103 (+)	1 000	Cs-135	100	Ta-182	1
Ag-105	10	Cs-136	1	W-181	100
Ag-108m (+)	1	Cs-137 (+)	10	W-185	1 000
Ag-110m (+)	1	Ba-131	10	Re-186	1 000
Ag-111	100	Ba-140	1	Os-185	10
Cd-109 (+)	100	La-140	1	Os-191	100
Cd-115 (+)	10	Ce-139	10	Os-193	100

Radionuclide	Clearance level (Bq/g)
Ir-190	1
Ir-192	1
Pt-191	10
Pt-193m	1 000
Au-198	10
Au-199	100
Hg-197	100
Hg-203	10
Tl-200	10
Tl-201	100
Tl-202	10
Tl-204	100
Pb-203	10
Pb-210 (+)	0,1
Bi-206	1
Bi-207	1
Bi-210	100
Po-210	0,1
Ra-223 (+)	10
Ra-224 (+)	10
Ra-225	10
Ra-226 (+)	0,1
Ra-228 (+)	0,1
Ac-227 (+)	0,1
Th-227	10
Th-228 (+)	1

Radionuclide	Clearance level (Bq/g)
Th-229 (+)	1
Th-230	1
Th-231	1 000
Th-232 (+)	0,1
Th-234 (+)	100
Pa-230	10
Pa-231	0,1
Pa-233	10
U-230 (+)	10
U-231	100
U-232 (+)	1
U-233	10
U-234	10
U-235 (+)	10
U-236	10
U-237	100
U-238 (+)	10
Np-237 (+)	1
Np-239	100
Pu-236	1
Pu-237	100
Pu-238	1
Pu-239	1
Pu-240	1
Pu-241	10
Pu-242	1

Radionuclide	Clearance level (Bq/g)
Pu-244 (+)	1
Am-241	1
Am-242m (+)	1
Am-243 (+)	1
Cm-242	10
Cm-243	1
Cm-244	1
Cm-245	1
Cm-246	1
Cm-247 (+)	1
Cm-248	1
Bk-249	100
Cf-246	100
Cf-248	10
Cf-249	1
Cf-250	1
Cf-251	1
Cf-252	1
Cf-253 (+)	10
Cf-254	1
Es-253	10
Es-254 (+)	1
Es-254m (+)	10

Decay products that have been taken into account when determining values for radionuclides marked with (+) are listed in the table below.

Parent nuclide	Decay product(s)
Sr-90	Y-90
Zr-95	Nb-95m
Mo-99	Tc-99m
Ru-103	Rh-103m
Ru-106	Rh-106
Pd-103	Rh-103m
Ag-108m	Ag-108
Ag-110m	Ag-110
Cd-109	Ag-109m
Cd-115	In-115m
Cd-115m	In-115m
In-114m	In-114
Sn-113	In-113m
Sb-125	Te-125m
Te-127m	Te-127
Te-129m	Te-129
Te-131m	Te-131
Te-132	I-132
I-131	Xe-131m
Cs-137	Ba-137m
Ce-144	Pr-144, Pr-144m
Pb-210	Bi-210, Po-210
Ra-223	Rn-219, Po-215, Pb-211, Bi-211, Tl-207, Po-211
Ra-224	Rn-220, Po-216, Pb-212, Bi-212, Tl-208

Parent nuclide	Decay product(s)
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214
Ra-228	Ac-228
Ac-227	Th-227, Fr-223, Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207, Po-211
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208
Th-229	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Tl-209, Pb-209
Th-232	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208
Th-234	Pa-234m, Pa-234
U-230	Th-226, Ra-222, Rn-218, Po-214
U-232	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208
U-235	Th-231
U-238	Th-234, Pa-234m, Pa-234
Np-237	Pa-233
Pu-244	U-240, Np-240m, Np-240
Am-242m	Np-238
Am-243	Np-239
Cm-247	Pu-243
Cf-253	Cm-249
Es-254	Bk-250
Es-254m	Fm-254

Appendix 4 from SSMFS 2018:3 - Clearance levels for buildings.

Clearance levels for use refers to buildings to be cleared for continued use, and Clearance levels for dismantling refers to buildings cleared provided that they are dismantled.

Radi-onu-clide	Clearance level	Clearance level for
H-3	100	100
C-14	10	100
Na-22	10	100
S-35	10	1
Cl-36	1	1
K-40	100	100
Ca-45	10	1
Sc-46	10	100
Mn-53	100	100
Mn-54	10	100
Fe-55	100	100
Co-56	10	100
Co-57	100	1
Co-58	100	100
Co-60	10	10
Ni-59	1	1
Ni-63	100	1
Zn-65	10	100
As-73	10	100
Se-75	100	1
Sr-85	100	1
Sr-90	1	1
Y-91	10	1
Zr-93	10	10
Zr-95	10	100

Radi-onu-clide	Clearance level	Clearance level for
Nb-	10	1
Nb-94	10	100
Mo-93	1	10
Tc-97	1	10
Tc-	1	10
Tc-99	1	1
Ru-	100	1
Ag-	10	100
Ag-	10	100
Cd-	1	100
Sn-	100	1
Sb-	10	100
Sb-	10	100
Te-	100	1
Te-	1	100
I-125	1	100
I-129	100	100
Cs-	10	100
Cs-	10	100
Cs-	10	100
Ce-	100	1
Ce-	100	1
Pm-	10	100
Sm-	100	100
Eu-	10	100

Radi-onu-clide	Clearance level	Clearance level for
Eu-	10	100
Eu-	100	1
Gd-	100	1
Tb-	10	100
Tm-	10	100
Tm-	10	1
Ta-	10	100
W-	1	10
W-	10	10
Os-	100	100
Ir-192	100	1
Tl-204	10	10
Pb-	10	10
Bi-207	10	100
Po-	100	1
Ra-	10	10
Ra-	10	100
Th-	1	10
Th-	1	10
Th-	10	10
Th-	1	10
Pa-	1	1
U-232	1	10
U-233	10	100
U-234	10	100

Radionuclide	Clearance level	Clearance level for
U-235	10	100
U-236	10	100
U-238	10	100
Np-	10	100
Pu-	10	100
Pu-	10	10
Pu-	1	10
Pu-	1	10
Pu-	100	1
Pu-	10	10

Radionuclide	Clearance level	Clearance level for
Pu-	10	10
Am-	10	10
Am-	10	10
Am-	10	10
Cm-	10	1
Cm-	10	100
Cm-	10	100
Cm-	1	10
Cm-	10	10
Cm-	10	10

Radionuclide	Clearance level	Clearance level for
Cm-	1	10
Bk-	1	10
Cf-	10	100
Cf-	1	10
Cf-	10	100
Cf-	1	10
Cf-	10	100
Cf-	10	100
Es-	10	100

Decay products that have been taken into account when determining values for radionuclides marked with (+) are listed in the table below.

Parent nuclide	Decay product(s)
Sr-90	Y-90
Zr-95	Nb-95, Nb-95m
Ru-106	Rh-106
Ag-108m	Ag-108
Ag-110m	Ag-110
Cd-109	Ag-109m
Sn-113	In-113m
Sb-125	Te-125m
Te-127m	Te-127
Cs-137	Ba-137m
Ce-144	Pr-144, Pr-144m
Pb-210	Bi-210
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214
Ra-228	Ac-228
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208, Po-212
Th-229	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Tl-209, Po-213, Pb-209
U-235	Th-231
U-238	Th-234, Pa-234m, Pa-234
Np-237	Pa-233
Pu-244	U-240, Np-240m, Np-240
Am-242m	Np-238, Am-242
Am-243	Np-239
Cm-247	Pu-243
Es-254	Bk-250

SSMFS 2018:3 Appendix 5 - Rules for the application of exemption and clearance levels

1. When applying exemption and clearance levels, the sum of fractions of the clearance levels for the radionuclides present must be less than or equal to 1, i.e. the following summation formula shall be applied:

$$\sum_{i=1}^{n} \frac{c_i}{c_{Ni}} \leq 1$$

Where:

c_i is the total activity of nuclide i in becquerels or per mass unit in kilobecquerel per kilogram (kBq/kg) or per unit area in kilobecquerel per square meter (kBq/m²),

c_{Ni} is the exemption or clearance level for nuclide i and n is the number of nuclides occurring.

2. The activity concentration of radioactive substances in materials subject to clearance is calculated as a mean value for the entire quantity, with a maximum of 1 000 kilograms.

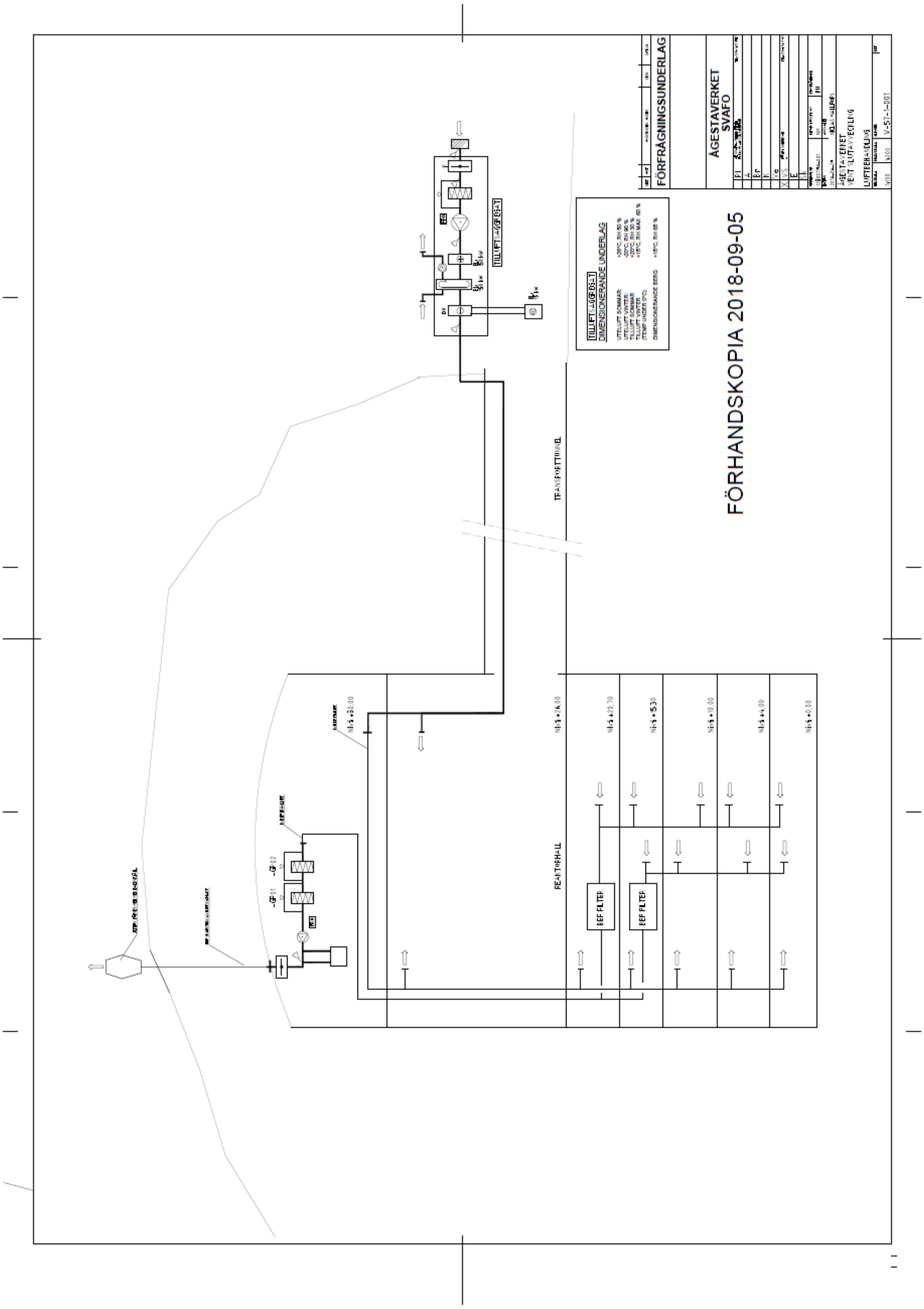
3. The clearance levels for buildings to be released for free use shall be applied to each square metre of the surfaces. When clearing buildings for dismantling the clearance levels shall be applied to surfaces with a maximum area of 10 square meters. Radioactive substances below surfaces are to be attributed to such surface and included when comparison is made with the clearance levels.

4. Decay products listed in the appendices of parent nuclides marked with (+) need not be included if their level of activity is lower than or the same as the level of activity of the parent nuclide.

5. If a radioactive substance without a specified clearance level occurs, the Swedish

Radiation Safety Authority must be contacted for a decision on which clearance level to apply. For nuclides with half-lives shorter than 1 day, 0.1 becquerel per gram may be used as a default value for both exemption and clearance.

Appendix 3 Detailed flow diagram of ventilation system during dismantling and segmentation



Appendix 4 Analysis of usage of dose factors from the Predo model for the Studsvik site for estimation of doses to the public from Ågesta

Dose factors from the PREDO model for the Studsvik site [1, 2] are used for estimation of doses to the public from aerial discharges from Ågesta during normal operation. The release point “fictive” in the model has a discharge height of 20 m above ground and is used for all aerial discharges from the Studsvik site, except those from the facilities R2 and HA (the discharge heights are larger for these). The aerial discharge at Ågesta takes place at approximately 20 m height above ground, since the discharge point is on a hill rising approximately 20 m above the surrounding environment and the chimney will be at least 5 m high.

South-westerly winds (i.e. wind direction towards north-east) are prevailing both at Studsvik and Ågesta, and although the Studsvik site is situated close to the sea, the average wind speed is also similar for both sites.

The PREDO-model for “fictive” is based on eight different dose contributions from six different objects (distances between discharge point and the objects are given in brackets)

	Outdoor occu-pancy	Indoor occupancy	Drinking water	Garden food	Crops	Meat and milk	Forest food	Aquatic food
Residential building with garden plot (ca. 650 m)	X	X		X				
Cropland (ca. 1 km)	X	X			X			
Pasture land (ca. 650 m)	X					X		
Forest (ca. 350 m)	X						X	
Lake (drinking water) (ca. 5 km)			X					
Lake (aquatic food) (ca. 6 km)								X

At distances more than a few hundred meters from the discharge point (assuming average weather and a discharge height of about 20 m) the activity concentration in air decreases with the distance from the discharge point and thus the dose contributions also decrease with this distance. Compared to Studsvik the distance is greater between the discharge point at Ågesta and the cropland and pasture land. Also hunting (part of forest food) is most likely less common near Ågesta compared to near Studsvik, and it is probably carried out at a greater distance from the discharge point. The prevalent wind direction also needs to be considered and towards north east (the prevalent wind direction at Ågesta) the distances to cropland, pasture land and residential buildings with garden plots are significantly larger than these distances in the PREDO-model for Studsvik.

Based on this the dose contributions from food consumption (e.g. crops, meat (farmed and hunted) and milk) are deemed overestimated when the model is applied at Ågesta and it is thus considered conservative.

To find out the relevance of the overestimation of dose through food consumption, the dose contributions for key radionuclides of relevance at Ågesta must be considered. For Studsvik, dose factors for six different types of families have been established; "average family", "farmer (general) family", farmer (dairy producer) family", "fisherman family", "hunter family" and "vegetarian family". Which group receives the highest dose depends on which radionuclides are discharged. For "fictive" and "R2" discharge points "vegetarian family" receives the highest doses in the Studsvik model, based on historic discharge data. Dose contributions for the most important radionuclides (based on inventory and dose factors) at the decommissioning of Ågesta are presented in the table below for "vegetarian adult.

Nuklid	Max dose factor for vegetarian[1] (Sv/year per Bq/year) **Fel! Hittar inte referenskälla.**	Activity inventory in Ågesta (Bq) [3]	Dos contribution (vegetarian adult) [2]			
			External exposure	Inhalation	Ingestion water and milk	Ingestion solid food
H-3 (tritium)	7,0E-20	4,2E+13	0 %	16 %	51 %	33 %
Ni-59	8,7E-18	5,3E+11	0 %	1 %	0 %	99 %
Co-60	6,1E-16	2,7E+11	79 %	0 %	0 %	21 %
Ni-63	1,9E-17	4,6E+13	0 %	1 %	0 %	99 %
Sr-90	1,3E-15	6,5E+09	0 %	1 %	1 %	98 %
Ag-108m	1,4E-15	1,9E+12	92 %	0 %	0 %	8 %
Cd-113m	9,0E-16	5,9E+10	0 %	0 %	0 %	100 %
Cs-137	5,0E-16	1,4E+10	42 %	0%	1 %	56 %
Eu-152	3,3E-16	1,3E+10	90 %	0 %	0 %	10 %
Am-241	1,7E-14	2,6E+08	0 %	38 %	0%	62 %

[1] Highest value for "adult", "child" or "infant"

This shows that for several radionuclides, ingestion of solid food is the largest contributor to dose. This is also the case for "child" and "infant". The PREDO-model "fictive" discharge point at Studsvik can thus be considered conservative for aerial discharges at Ågesta.

For C-14, the dose factor estimated for the release point Ustore at the nuclear fuel manufacturing facility in Västerås, exceed the dose factor for the Studsvik site by an order of two [4]. However, the main contribution to the dose factor for C-14 is the consumption of crops [4], and the distances between the release point and the selected croplands are even shorter than corresponding distances for the Studsvik site [5]. Hence, the dose factor for C-14 is expected to be lower for Ågesta than for the fuel manufacturing facility and consequently the Studsvik dose factor is used also for C-14. In addition, C 14 accounts only for 0.02 % of the estimated committed effective dose for Ågesta decommissioning, so even if the highest overall dose factor in the PREDO project would be used (from the fuel manufacturing facility), the estimated effective dose would still be 5.2×10^{-10} Sv.

One aspect to look at more closely is the potential dose from inhalation of H-3 to non-nuclear workers in the vicinity of the Ågesta discharge point. In the PREDO-model "farming adult" is assumed to have an outdoor occupancy of 7,2 hours per day, which is three times more than ”vegetarian adult”. The dose factor is however only 10 % higher for ”farming adult”, which means that inhalation typically is not the main dose contributor to the overall dose from H-3. In fact, infants have higher dose factor than adults, despite lower outdoor occupancy. At Ågesta members of other organisations present on the industrial site housing the Ågesta reactor can be working part of the working day within the vicinity of the discharge point, but the time present there is deemed to be considerably less than the outdoor occupancy of ”farming adult” (50 h per week). So, although the distance between the discharge point and the exposed person can be smaller than at Studsvik, the fact that inhalation is not the most significant exposure pathway and that the time spent in the vicinity is lower, it is deemed acceptable to use the dose factors in PREDO also for H-3.

Based on the assessment above, the PREDO-model for Studsvik “fictive” is considered appropriate to use for aerial discharges at Ågesta.

[1] PREDO2 Site Report Studsvik/SVAFO QP.50000-63726184 v2.0, 2017-02-07, Vattenfall AB

[2] PREDO2 Results Studsvik/SVAFO QP.50000-87996375 v2.0, inkl. elektroniska appendix, 2017-02-08, Vattenfall AB

[3] 10-0057R rev 2 Ågesta – Assessment of radioactivity at decommissioning, ALARA

[4] PREDO2 Results Westinghouse QP.50000-88024748 v2.0, inkl. elektroniska appendix, 2017-02-08, Vattenfall AB

[5] PREDO2 Site Report Westinghouse QP.50000-63744911 v2.0, 2017-02-07, Vattenfall AB

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

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

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