Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Report

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

Increased storage of spent nuclear fuel at Clab in Sweden

2023:07

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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, Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management), SKB. SSM has controlled that the general data provides the necessary information and that it complies with the guideline of the most recent recommendations of the application of Article 37 of the Euratom Treaty.

Abstract

The purpose of this report is for Sweden to provide the European Commission with general information on increasing storage from a maximum of 8,000 tonnes to a maximum of 11,000 tonnes of spent nuclear fuel from Swedish nuclear power plants in the central interim storage facility for spent nuclear fuel (Clab) on the Simpevarp Peninsula in Oskarshamn. The report follows the guideline set out in Annex I on the recommendation for applying Article 37 of the Euratom Treaty (2010/635/Euratom). The report shows that an increase of the interim storage will not risk leading to radioactive contamination of water, soil or airspace in another EU Member State.

The licensee for Clab is Svensk Kärnbränslehantering AB (SKB). Commissioned in 1986, the facility consists of a receiving section at ground level and a storage section. The storage section consists of two rock caverns located more than 30 metres below ground, connected by a water-filled transport channel. Each rock cavern contains storage pools where the spent nuclear fuel is interim-stored with approximately eight metres of water cover. The increase in storage entails a gradual increase in the activity inventory and decay heat. The space, cooling of decay heat and maintenance of adequate radiation safety are accommodated within the framework of the current Clab facility. This will enable a gradual increase from 8,000 tonnes to 11,000 tonnes of spent nuclear fuel to be carried out in the existing facility with retained activities. The current limit of 8,000 tonnes will be reached at the beginning of 2024, after which a licence for increased storage will need to be obtained.

The information presented on radioactive discharges to air and water, during normal operation or events during interim storage of spent nuclear fuel, shows that there will be no discharges that would result in measurable dose levels in other Member States. According to the guideline in Annex I, no reporting of effective dose is required in other Member States provided that reporting is provided of doses to the reference group in the vicinity of the installation. This applies if the assessed maximum exposure levels from discharge under normal conditions for adults and children in the vicinity of the installation are below 0.01 mSv per year or below 1 mSv in the event of unplanned discharge and there are no other exposure pathways, such as, food exports. Doses close to the facility due to discharges to air and water is well below 0.01 mSv per year under normal conditions and well below 1 mSv in the event of an unplanned discharge. Therefore, it is not relevant to report calculations of doses to persons outside Sweden's borders. The data, assessment methods and assumptions used in the calculations have been chosen conservatively to ensure that the results do not underestimate discharges and doses.

This report is based on investigations that form the basis for completed and ongoing licensing in Sweden. The conclusion from the studies is that discharges under normal conditions and possible events are only marginally affected by interim storage of 11,000 tonnes in relation to the current situation with interim storage of 8,000 tonnes. This means that both existing discharges of radioactivity and those from increasing the interim storage are well below the specified doses to persons in the vicinity of the facility and do not pose a risk to any other Member State. In addition, radioactive operational waste from the activities will remain unchanged and take place with previously commissioned facilities for waste management and final disposal.

Contents

Introduction

SKB manage all radioactive waste and spent nuclear fuel from Swedish nuclear power plants. SKB is a subsidiary of Vattenfall AB and is jointly owned by the companies that operate the Swedish nuclear power plants. The system for managing all radioactive waste is divided into two main parts: one part for low-level and intermediate-level waste, where the SFR (final repository for short-lived radioactive waste) is currently in operation, and one part for spent nuclear fuel, where Clab (central interim storage facility for spent nuclear fuel) is in operation. SKB also owns the ship M/S Sigrid for the transportation of radioactive waste and spent nuclear fuel. This waste system is to be extended and supplemented so that in due course it can take care of the final disposal of all radioactive waste and spent nuclear fuel produced during the operation and decommissioning of the Swedish nuclear power reactors, see Figure 0-1.

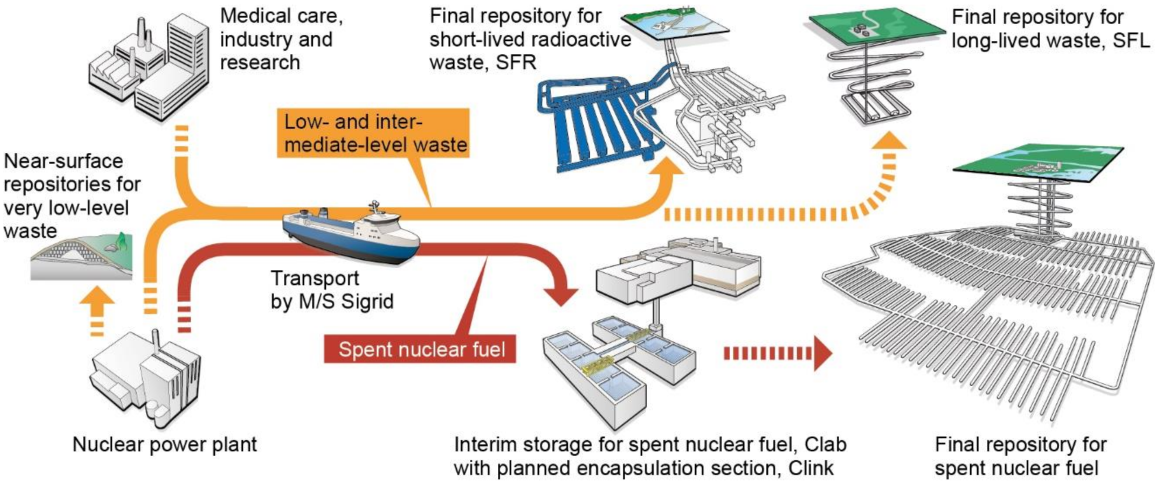

Figure 0-1. The Swedish system for spent nuclear fuel and radioactive waste.

In accordance with the Euratom treaty Article 37[1], this report constitutes a notification to the European Commission on increasing the maximum allowed quantity of stored spent nuclear fuel in Clab from 8,000 tonnes to 11,000 tonnes[2]. The report covers the points set out in Annex I to 2010/635/Euratom: The Commission recommendation of 11 October 2010 on the application of Article 37, where Annex I is to be applied to activities under paragraph 6 *Storage of irradiated nuclear fuel in installations intended for this purpose*.

Spent nuclear fuel from the Swedish nuclear power plants will be interim-stored at Clab prior to future final disposal in the final repository for spent nuclear fuel. The fuel is stored under water in pools in two rock caverns located about 30 metres below the ground surface. In 1979, the Government granted SKB a licence for the construction of Clab, which then consisted of a rock cavern for storage. In 1985, the Government granted a licence for the operation, including the receiving and storage of spent nuclear fuel. In 1998, the Government granted a licence to extend Clab with a second rock cavern and to store a maximum of 8,000 tonnes of spent nuclear fuel. This storage quantity was based on the decision of the Swedish Parliament at the time that Swedish nuclear power would be finally decommissioned in 2010 and on the quantity of spent nuclear fuel

[1] Treaty establishing the European Atomic Energy Community (2012/C 327/01)
[2] The weights refer to the quantity of uranium, and for mixed oxide fuel (MOX) also plutonium, in the unirradiated nuclear fuel.

that was expected to arise. Several of Sweden’s nuclear power reactors have continued to operate after that time, which has led to a larger quantity of spent nuclear fuel needing to be interim-stored until all spent nuclear fuel has been finally disposed of in the Final Repository for Spent Nuclear Fuel.

The additional quantity of spent nuclear fuel will be received, handled and stored in the same way as currently. The increase in storage entails a gradual increase in the activity inventory and decay heat. The space, cooling of decay heat and maintenance of adequate radiation safety are accommodated within the framework of the current Clab facility. This means that the gradual increase from 8,000 tonnes to 11,000 tonnes of spent nuclear fuel will be managed in the existing facility with retained operation.

In 2021, the Government granted SKB a licence to increase the maximum allowed quantity of nuclear fuel for interim storage in Clab from 8,000 tonnes to 11,000 tonnes. Before storage is allowed to exceed 8,000 tonnes, the Land and Environment Court must grant a licence and the Swedish Radiation Safety Authority (SSM) must approve the safety analysis report for storage of 11,000 tonnes spent nuclear fuel in Clab.

1 The site and its surroundings

1.1 Information about the area

Clab is located on the Simpevarp Peninsula in Oskarshamn municipality, near the coast of the Baltic Sea, see Figure 1-1. The facility is situated about 20 kilometres north-east of central Oskarshamn and about 8 kilometres north-east of the village Figeholm, see Figure 1-2. The area around Simpevarp is sparsely populated and consists of smaller villages. The shortest distances to the nearest Member States and their major cities are presented in Table 1-1.

Table 1-1. Clab's siting in relation to other Member States.

Member State	Distance to boundary [km]	Urban area	Population [million]	Distance to city [km]
Denmark	260	Copenhagen	2.0	320
Latvia	270	Riga	0.7	450
Estonia	320	Tallinn	0.6	520
Germany	360	Berlin	4.4	580
Finland	350	Helsinki	1.1	570
Lithuania	310	Vilnius	0.6	610
Poland	300	Warsaw	3.2	640

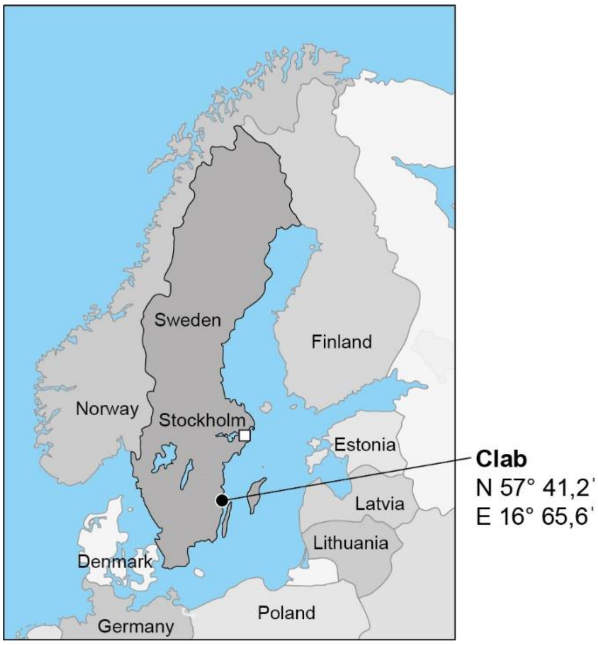

Figure 1-1. Siting of Clab in relation to surrounding countries. Distances to nearby countries are listed in Table 1-1.

Figure 1-2. Oskarshamn municipality with a detailed map of the Simpevarp Peninsula.

In addition to Clab, there is a nuclear power reactor (O3) in operation and two reactors (O1 and O2) that are permanently shut down on the same industrial site. Furthermore, there are facilities for service and operation of the nuclear power plant, near-surface repository for very low-level waste and an interim storage facility for low-level waste. These facilities are owned by OKG AB. There is also a harbour owned by SKB on the Simpevarp Peninsula. It is used for maritime transport of spent nuclear fuel to Clab and radioactive waste from Clab and OKG to SFR by SKB's ship M/S Sigrid.

1.2 Geology

This section provides a review of the site geology with a focus on the nature of the bedrock. The unconsolidated, mostly Quaternary, sediments and deposits that cover areas of the rock will not be mentioned as the facility is built directly on and in the bedrock.

1.2.1 Regional – Oskarshamn Region

Oskarshamn Municipality is situated in what is called Småland lithotectonic unit, which is dominated by igneous rocks formed 1810-1770 million years ago during and after the youngest phase of the Svecokarelian mountain-building event that occurred 2000 to 1800 million years ago (Wahlgren and Stephens 2020). These rocks are part of the first generation of the Transscandinavian Igneous Belt (TIB), which extends from south-eastern Sweden and onwards into southern Norway. TIB rocks contain varying proportions of the mineral's quartz, plagioclase and alkali feldspar and are classified according to their modal and chemical composition. The TIB rock types in the Oskarshamn region are for the most part plutonic (intrusive igneous rocks) and are specifically granites to monzodiorites, a group of rock types in south-eastern Sweden that is commonly referred to as Småland-granite. Småland-granites vary in colour from grey to red with a grain size ranging from medium to coarse. Both evenly grained (equigranular) and porphyritic variants occur. In the latter case, the rock type has a fine-grained groundmass and contains larger mineral grains (phenocrysts) consisting of feldspar (SKB 2000).

Together with the Småland-granites, associated, but subordinate, fine-grained, usually porphyritic, volcanic rocks occur as well as basic intrusive rocks such as diorite and gabbro. A distinctive feature of the area's bedrock is narrow dykes or irregular small fractures of fine-grained granite. The fine-grained rock types have a consistently higher abundance of fractures and are more water-bearing than the coarser rock types (Bergman et al. 1999, section 2.2.2). The area is intersected by a network of low-grade ductile, brittle-ductile and brittle deformation zones, which have undergone repeated brittle reactivation after the Svecokarelian orogeny (Wahlgren and Stephens 2020).

North and south of the area around the Simpevarp Peninsula there are two distinct granite bodies, called Götemar- and Uthammar-granite, which were intruded into the approx. 1800-million-year-old TIB rocks about 1450 million years ago, (Friese et al. 2012 and references therein). The granites have an evenly grained texture with a coarse grain size, but may also be found as medium- and fine-grained varieties. These granites show no signs of ductile deformation and have only been subjected to brittle deformation.

1.2.2 Local – Simpevarp Peninsula

Rock types

The bedrock in the site area located on the Simpevarp Peninsula is completely dominated by three categories of plutonic TIB rock types, see Figure 1-3:

- Fine-grained dioritoid with an unevenly grained (inequigranular) texture and large phenocrysts of hornblende and plagioclase,
- Medium-grained quartz monzodiorite (quartz monzonite to monzodiorite) with an equigranular to slightly porphyritic texture,
- Medium-grained Ävrö granite (granite to quartz monzodiorite), usually with a porphyritic texture.

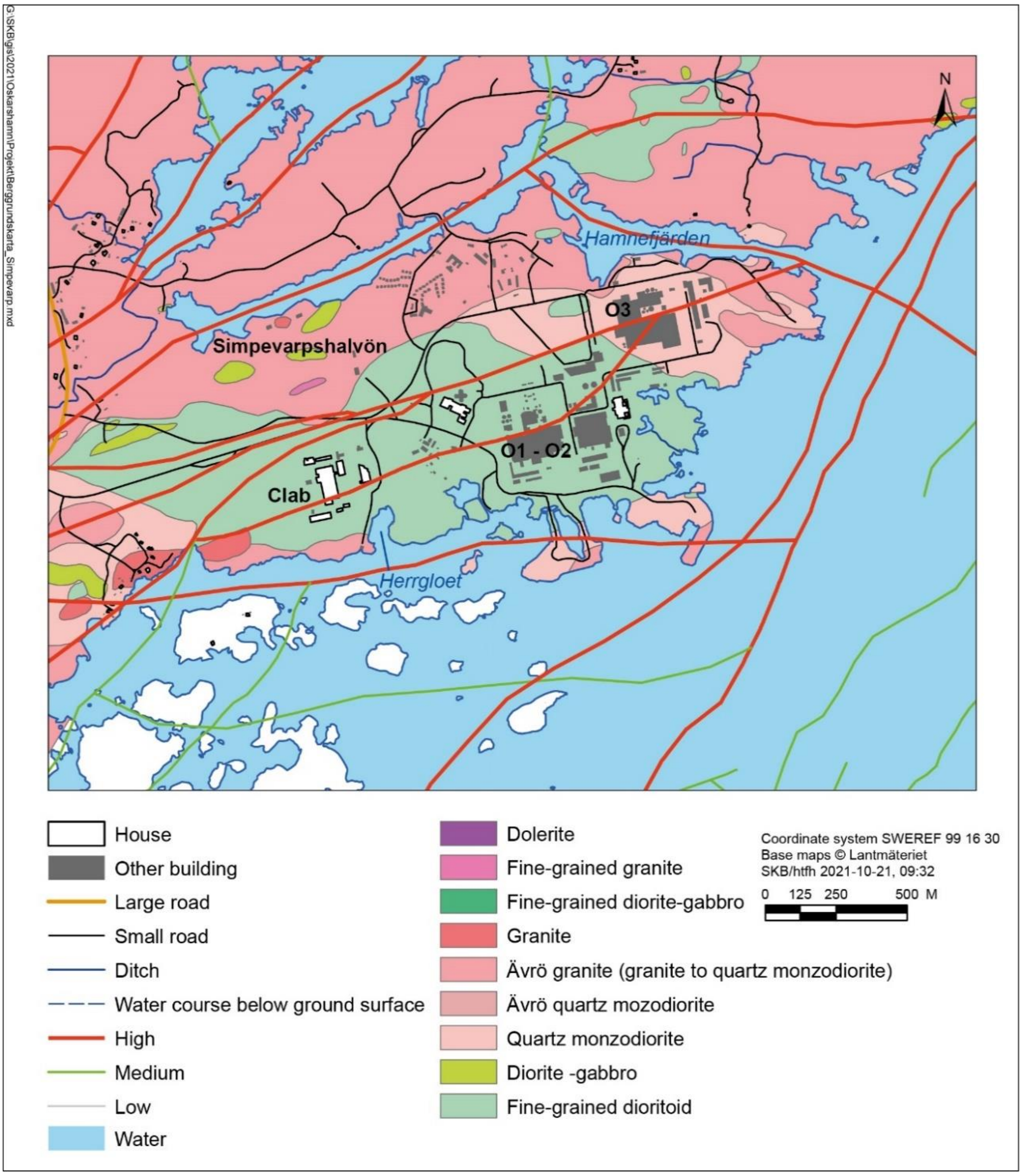

Figure 1-3. Geological map of the Simpevarp Peninsula. High, medium, low refers to the confidence level of deformation zones.

The fine-grained dioritoid dominates the southern parts of the Simpevarp Peninsula where Clab's storage section is situated. The rock is grey with diffuse vein-like aggregates that cause an inhomogeneous coarsening of the grain size and an inequigranular texture. The contact gradually transitions between the dioritoid and the surrounding rock, but may be abrupt locally. An increase in temperature due to the intrusion of the quartz monzodiorite and the Ävrö-granite (see below) is interpreted as a cause of the local grain size thickening in the dioritoid (SKB 2005). The dioritoid has previously been classified as a volcanic rock type with an andesitic to dacitic composition that supposedly recrystallised, giving it a granitic character (Wikman and Kornfält 1995, Bergman et al. 1999, SKB 2002). However, it was concluded through later site investigations that this rock type, except for being fine-grained, does not show any typical characteristics that would indicate volcanic origin (SKB 2005). It has therefore been classified as dioritoid.

The eastern part of the Simpevarp Peninsula, where O1, O2 and O3 are situated, see Figure 1-3, is dominated by grey to greyish-red, medium-grained quartz monzodiorite with an even-grained texture. Ävrö-granite dominates the northern part of the Simpevarp Peninsula and denotes a group of more or less porphyritic rock types that vary in composition from quartz monzodiorite to granite. Ävrö-granite is reddish-grey to greyish-red, medium-grained and feldspar phenocrysts are 1-2 cm in size. Typical for Ävrö-granite is the occurrence of centimetre to decimetre sized basic and intermediate enclaves. Diorite and gabbro are found as small volumes spread over the Simpevarp Peninsula. Also, smaller bodies of red to greyish-red, medium to coarse-grained granite are found in the western parts of the peninsula and as diffuse small volumes in the Ävrö-granite. The rock mass on the peninsula is permeated by younger fine-grained granite (aplite) and in some cases also by coarse-grained pegmatite, in the form of dykes or irregular streaks (Bergman et al. 1999, section 4.1.3).

The ore potential in the area is judged to be very low. The only potential that exists is for quarrying of building and decorative stone from the Götemar- and Uthammar-granites in the north and south for (SKB 2005, Section 13.2.1).

Deformation zones

The Simpevarp Peninsula is restricted to the north and south by steeply dipping regional deformation zones that stretch NE-SW and east-west with a trace length of up to tens of kilometres. The central part of the peninsula is intersected by smaller, kilometre-long deformation zones from a few metres to tens of metres thick and stretching NE-SW. One of these is a brittle-ductive zone with a thickness of about ten metres that lies directly south of Clab.

It has been possible to build the facilities on the Simpevarp Peninsula consistently in good quality rock with low to moderate inflow rates. Most of the deformation zones that have been encountered have a relatively insignificant thickness (Bergman et al. 1999, Section 4.1.3) with orientation in the east-west or NE-SW direction and dipping steeply (SKB 2005, Section 11.2.2).

Rock stress and rock mechanics data

The rock types that occur at Clab's site have a fine grain spread, which gives different fracture frequencies (SKB 2000). Fine-grained rock types can lead to an increased fracture frequency and thereby an increased water flow. During the construction and extension of Clab, rock stress measurements were performed in two boreholes (Klasson et al., 1997, Stanfors et al. 1998, section 7.4). The measurements yielded similar results for the magnitude of the horizontal stresses, but not for their orientation. The most reliable measurements point to a NW-SE orientation of the maximum horizontal stress. The shallow depth of Clab's rock caverns means that the stresses are low (around 6 and 3 MPa for the maximum and minimum horizontal stresses, respectively). The vertical stress measurements are not unequivocal and are therefore assumed to correspond to the vertical overburden pressure (Stanfors et al. 1998).

In conjunction with rock stress measurements and the rock mechanics analyses done prior to the construction of Clab, a number of rock mechanics parameters have been determined (Bergman et al. 1999). Rock mechanics data was also obtained later in conjunction with the drilling of two deep boreholes on the Simpevarp Peninsula (Lanaro and Fredriksson 2005). The rock samples used for the later measurements came from a greater depth than those used in connection with construction of the facility, which means that data from these measurements is not directly comparable.

In general, the bedrock within the site area is judged to have good properties from a mechanical stability perspective (SKB 2000).

1.3 Seismology

This section presents the present-day seismic activity in Oskarshamn and the surrounding areas, as well as probabilities of future earthquakes and ground shaking. Furthermore, the seismic resistance design of the facility is described.

An earthquake is a rapid movement along a fault plane that occurs when stresses built up in the Earth’s crust are released when the rock’s stability criterion is reached. Earthquakes usually occur on already existing discontinuities, such as faults, deformation zones or along boundaries between geological units, since it is easier for stresses to utilise existing discontinuities than to create a new one. An empirical relationship between magnitude and number of earthquakes (the Gutenberg-Richter relationship) has been observed in several locations around the world.

1.3.1 Regional and local seismic activity

Tectonic stress conditions in Sweden

The majority of the world’s earthquakes occur along the boundaries of the large tectonic plates. Sweden is located far from a plate boundary, the closest being the Mid-Atlantic Ridge. Furthermore, Sweden is situated on a very old, stable part of the Earth’s crust, the Baltic Shield, which means that activity is generally lower than in younger surrounding areas. Based on the knowledge of present-day stress conditions, known geological structures and observed seismic activity, it is highly unlikely that Sweden would experience a large, magnitude 8-9 earthquake within the next 100 years (Böðvarsson et al. 2006).

In Sweden, stresses at earthquake-relevant depth, i.e. deeper than about one kilometre, are dominated by tectonic stresses from the Mid-Atlantic Ridge, a fact that has been observed both seismically (Slunga 1991) and in deep boreholes (Stephansson et al. 1991, Lund and Zoback 1999). Borehole measurements show that the stress state can vary considerably both in intensity and in orientation, but that there is a tendency for horizontal stresses to be greater than vertical stresses (Stephansson et al. 1991).

In the present day, post-glacial rebound caused by the retreat of the most recent ice sheet is Sweden’s dominant deformation process with vertical movements up to about one centimetre per year (Johansson et al. 2002). Despite the large movements, the rebound does not significantly affect the present-day stress state in the Earth’s crust, since the vertical movement occurs without resistance. Plate tectonics, on the other hand, dominate the stress pattern, which is clearly shown in the analysis of the focal mechanisms of Swedish earthquakes (Slunga 1991).

Earthquakes in Sweden

In Sweden, there are very rarely earthquakes that damage buildings or other structures. Small earthquakes, however, occur daily (Böðvarsson et al. 2006) and on a longer timescale it is not entirely unlikely that a larger earthquake could occur. A period of increased seismicity occurred in connection with stress changes due to the retreat of the last ice sheet about 9,000 years ago. During this period, magnitude M8 earthquakes were triggered in northern Scandinavia along glacially induced faults. A magnitude MS 5.4 (S-wave magnitude) earthquake that occurred in 1904 at the Koster Islands (on the west coast of Sweden) is the largest known earthquake registered in Sweden in modern times (both in historic (Wahlström 1990) and instrumental (Slunga 1991, Böðvarsson et al. 2006, FENCAT 2007) earthquake catalogues).

Sweden's seismic activity is currently measured by the Swedish National Seismic Network (SNSN) (Lund et al. 2021). The data measured shows significant geographic variation, and four areas with different activity levels can be distinguished, see Figure 1-4. These areas can in part be linked to different geological discontinuities. The highest seismic activity is observed in northern Sweden and along the north-eastern coast. Earthquakes occur there mainly along the aforementioned glacially induced faults. Another area of relatively high seismicity is south-western Sweden, where seismicity is limited eastwards by the so-called Protogine zone (Slunga 1991), which in very simple terms represents the boundary between rocks affected by the older Svecocarelian orogeny to the east and the younger Sveconorwegian orogeny to the west. In southern Sweden, seismicity is related to what is known as the Sorgenfrei-Tornqvist zone (Slunga 1991), which is an inverted graben structure whose deformation history began towards the end of the Palaeozoic era. North-western and south-eastern Sweden are the two areas with the lowest seismic activity, according to observations at present.

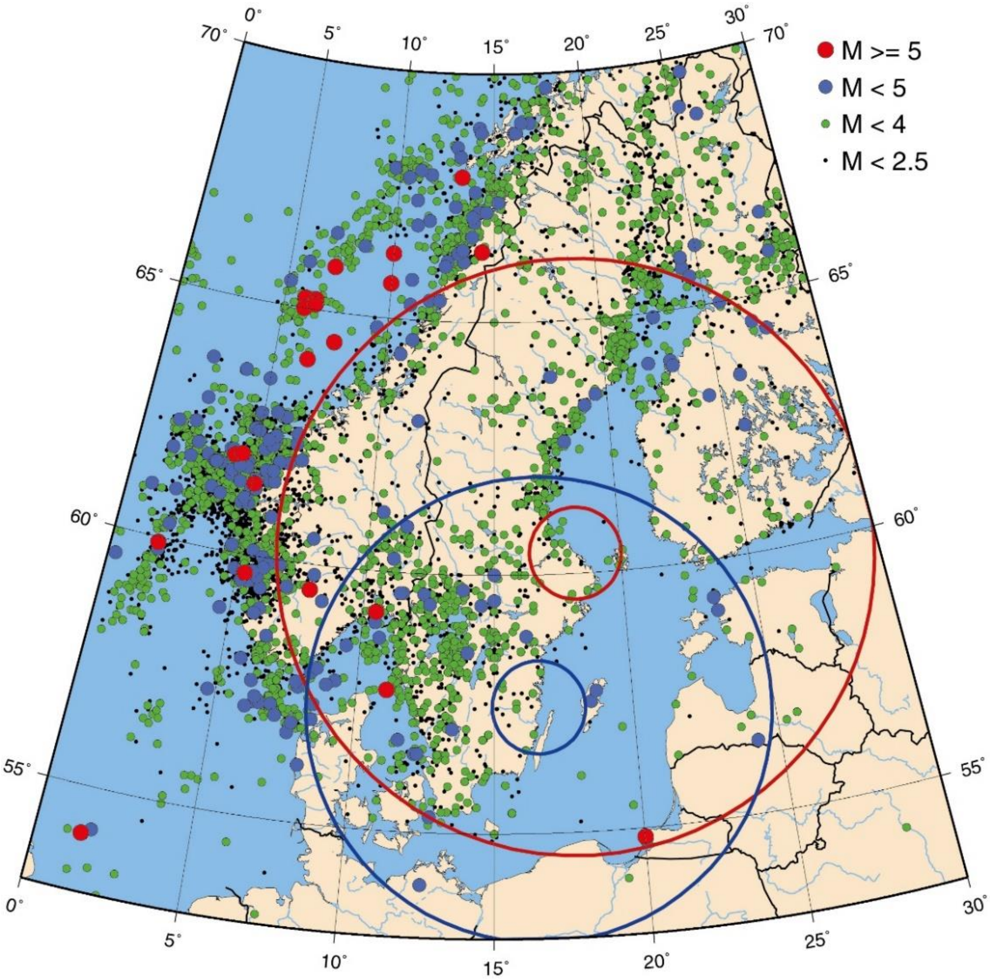

Figure 1-4. Seismic activity in Sweden and neighbouring countries between 1904 and 2006. The blue circles show distances of 100 km and 500 km from Simpevarp. The red circles show distances of 100 km and 650 km from Forsmark. "M" stands for magnitude on the Richter Scale. Figure from (Böðvarsson et al. 2006).

Earthquakes in the Oskarshamn area

The present-day seismicity within a 500 km radius around Oskarshamn is shown in Figure 1-5. As can be seen in Figures 1-4 and 1-5, seismic activity was very low in south-eastern Sweden during the reported time. As a result, a statistical analysis of the earthquake frequency in the area around Oskarshamn is very uncertain. Since there is much to suggest that there is substantial episodicity in Swedish seismic activity (Slunga 1991, Kijko et al. 1993), it is unclear whether the relative calm in south-eastern Sweden is a lasting phenomenon. However, no glacially induced faults have been found in the Oskarshamn area (Lagerbäck et al. 2004, 2005, 2006).

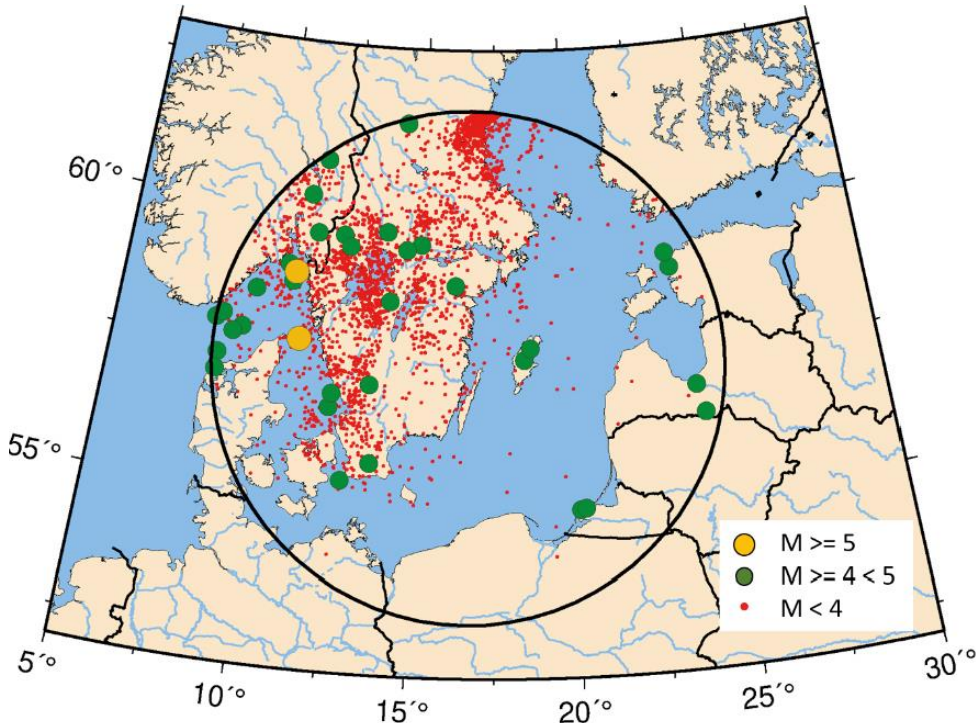

Figure 1-5. Seismic activity within a 500-kilometre radius around Oskarshamn between 1375 and 2020. Data is a combination of homogenized catalogues (SNSN 2007, FENCAT 2007, EMEC 2021).

1.3.2 Probability of earthquakes and ground motion in the Oskarshamn area

Probability of earthquakes in the Oskarshamn area

The probability of earthquakes in the Oskarshamn area has been calculated according to the methodology in (Böðvarsson et al. 2006) with a combination of earthquake catalogues over the periods of 1904 to 2007 (FENCAT 2007) and 2000 to 2007 (SNSN 2007) homogenised according to Slunga et al. (1984). Previously, there has not been enough data from the Oskarshamn area to produce a statistically significant result. This is due to the fact that SNSN has not had stations running in south-western Sweden for a sufficient period of time. The probability of earthquakes in the Oskarshamn area has therefore been based on data from the majority of Sweden (the large red circle with a radius of 650 kilometres in Figure 1-4) and a b-value of b=0.81 in the Gutenberg Richter relationship equation,3 which is used to calculate the probability of earthquakes.

Due to the low seismicity in the Oskarshamn area, it is statistically uncertain to calculate earthquake probabilities within smaller circles with current data. The probability for circles with radii of 100 and 10 kilometres are therefore calculated by means of a normalization per area of the result from a circle with a larger radius in which Oskarshamn is included, even though the centre is situated further north in Sweden, see Figure 1-4. The results for the 100 km radius show that the

[3] log(N)=a-bM, where M is the magnitude and N the number of earthquakes greater than the magnitude M. The slope of the logarithmic function, b-value, indicates how the number of small earthquakes relates to the number of large earthquakes. The seismic activity is usually characterized by a calculation of the b-value in a given area and for a given period of time.

probability of a magnitude 5 earthquake occurring within 100 years is 9% and that the probability of a magnitude 6 earthquake is 1.5%. If the radius is reduced to 10 kilometres, the probability of magnitude 5 and 6 earthquakes occurring within 100 years decreases to 0.1% and 0.01% respectively, see (Böðvarsson et al. 2006).

Updating previous calculations with newer data (SNSN data from 2000-2020, FENCAT data from 1375-2014 and EMEC data from 1900-2014 in a 500 km radius around Oskarshamn, see Figure 1-5) results in b-values between 0.88-0.93. The use of higher b-values would result in lower probabilities for earthquakes. However, the differences between older and newer calculations are judged to be within the margin of error. Therefore, the previously stated results are considered equivalent. Conclusions drawn previously regarding the likelihood of earthquakes occurring are thus unchanged.

Maximum movements caused by earthquakes

Earthquakes cause two types of deformation: static, permanent deformation of the bedrock, and dynamic, temporary, deformation in form of a propagating elastic wave. The static deformation declines relatively quickly from the hypocentre of the earthquake, while the dynamic deformations propagate much further.

In (Böðvarsson et al. 2006) static deformations are estimated in a simple elastic model of the Earth's crust for a fictional magnitude 5 earthquake with properties similar to the largest of recent times earthquakes that occurred close to Sweden (Kaliningrad 2004). The results show that a magnitude 5 earthquake at a realistic depth, three kilometres and deeper, results in relatively small static displacements at the ground surface (max. 1.5 mm) and that they decrease with the depth of the earthquake.

Dynamic deformations propagate in the form of seismic waves and can cause damage to buildings and structures further away from the epicentre of the earthquake. The damage caused depends partly on the amplitude and frequency of the waves, partly on the structure itself and how it is connected to the ground or rock. The most common measure of the damaging effects of an earthquake is the maximum acceleration to which the solid rock may be subjected, which is known as Peak Ground Acceleration (PGA), often specified as fractions of the acceleration of the Earth's gravity field (g = 9.81 m/s2). According to (Böðvarsson et al. 2006), a magnitude 5 earthquake at a depth of 12 kilometres with properties similar to those in the Kaliningrad 2004 earthquake generates a maximum ground acceleration of PGA = 0.05 g in crystalline rock when applying vibration models for Swedish rock (Slunga et al. 1984). A study of earthquake risk in Scandinavia using probability-based methods (Wahlström and Grünthal 2001) concluded that there is a 90% probability that PGA will not exceed 0.01 -0.015 g in 50 years in the Oskarshamn area. With a probability of 0.01 per year, the PGA can reach 0.007 g and with a probability of 10-5 per year, 0.15 g in the Oskarshamn area according to calculations (Slunga 1978). A certain PGA value can be caused by a large earthquake at a farther distance or a moderate earthquake at a shorter distance. It is, however, mainly earthquakes with a magnitude above 6.0 that determine the maximum expected ground accelerations in Oskarshamn (Slunga 1978).

The probability of earthquakes and expected ground accelerations depend on the b-value used. In Böðvarsson et al. (2006), a b-value of 0.8 has been used, while a b-value of 0.69 was used by Slunga (1978). The latter gives a slightly higher probability, but the differences are deemed to be within the margin of error.

1.3.3 Seismic resistance design

The building and its storage pools, fuel canisters, handling machine, and fuel elevator in the receiving section, are designed to withstand the loads that can arise during an E4 earthquake4 without damaging the fuel (SKBdoc 1865662). The auxiliary feed water is also dimensioned to remain intact after an E4 earthquake. The earthquake dimensioning is carried out as follows:

- **Rock caverns and storage pools.** Due to the stiffness of the surrounding rock and the low strength of an E4 earthquake, the impact of the earthquake on the rock cavern would be very moderate. The storage pools are, with regard to temperature movements, set up on plain bearings. These have been adapted to earthquakes (sufficiently high friction values) so that no sliding or resonance oscillation of the storage pools will occur. The impact that an earthquake can have on the storage pools is thus small.
- **Fuel canisters including storage racks.** The equipment is designed for an E4 earthquake.
- **Auxiliary feed water.** The upper sections of piping have been cast into the concrete structure. The lower sections of piping lie on pipe supports. Earthquake loads are a technical design requirement for the equipment in question and are included as load cases in the technical design requirement for mechanical devices and buildings.
- **Handling machine in the storage section.** It is a requirement that the handling machine in the storage section does not fall during an E4 earthquake and damage the storage pools or fuel. The machine is designed so that it cannot fall more than approx. 0.1 m before it is stopped by the pool walls if it were to detach from the overhead crane track. It can therefore neither damage the pool nor the fuel, and no further action needs to be taken for the handling machine. The same applies to the trolley when it is run in the transport channel. Earthquake loads are a technical design requirement for the equipment in question and are included as load cases in the technical design requirements for buildings.
- **Fuel elevator turntable with lifting equipment.** Lifting equipment for the elevator car is placed on the turntable. The turntable’s bearing arrangement is designed to minimise the impact from an earthquake on the lifting equipment. Earthquake loads are a technical design requirement for the equipment in question and are included as load cases in the technical design requirements for buildings.
- **Underground buildings.** In the event of an E4 earthquake, the damage will be limited so that the criticality safety and cooling of fuel in the receiving section is maintained. Earthquake loads are included as load cases in the technical design requirements for buildings.

1.4 Hydrology

1.4.1 General

Clab is situated on the Simpevarp Peninsula near the pronounced brackish Baltic Sea, see Figure 1-1. The salinity of the Baltic Sea at the site is about 0.65%. The Baltic Sea is characterised by its fjord-like characteristics with narrow, shallow inlet and extensive fresh water inflow.

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[4] Event class E4 is defined as unlikely events with an event frequency interval of $10^{-4} > f \geq 10^{-6}$ per year. This also includes a number of overall events that, irrespective of event frequency, are analyzed in order to verify the robustness of a nuclear facility. The relevant event for an earthquake in E4 is an earthquake with a PGA of 0.1 g and an annual frequency of 10^{-5}.

The average ground level on the Simpevarp Peninsula is six metres above sea level. The average ground level on SKB's Simpevarp 1:9 property, where Clab is located, is nine metres above sea level.

With its location on the Baltic Sea, the site is not affected by tides, storms that cause tides or flash flooding. The location of the facility, enclosed by the islands of Tallskär, Långskär, Granholmen and others (Figure 1-6), limits sea wave height and the effects of sea waves are negligible. There are no dam installations in the vicinity of the site that can affect safety.

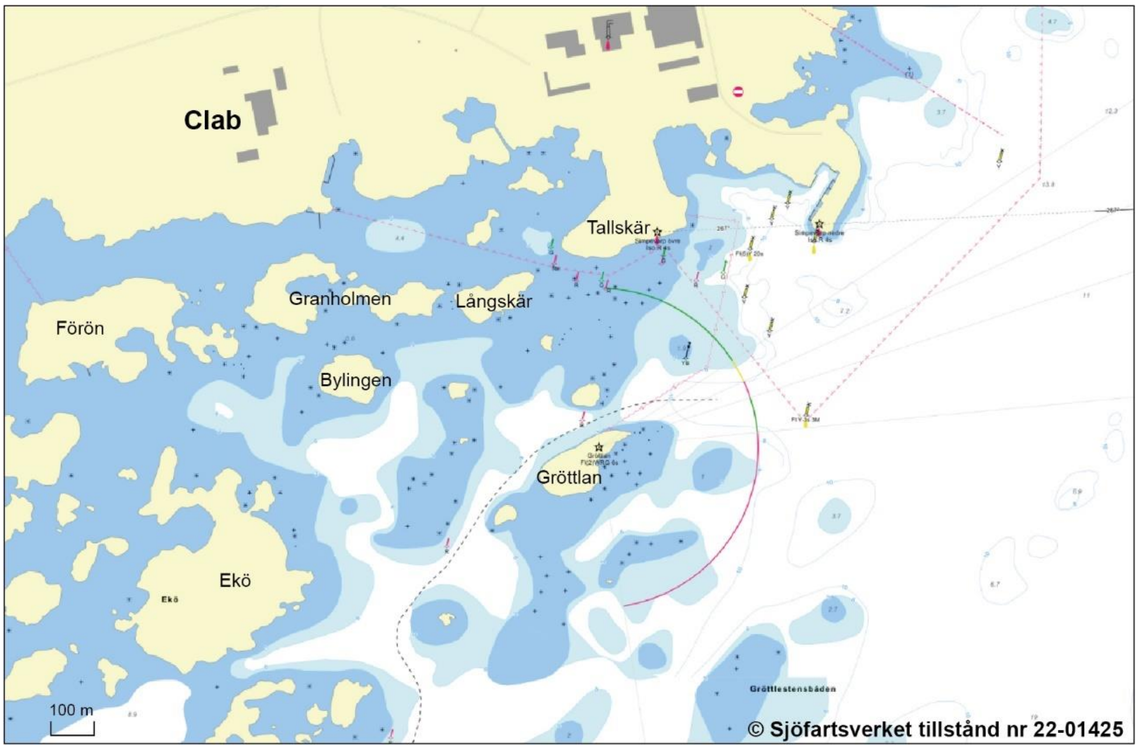


Figure 1-6. Clab's location on the coast of the Baltic Sea.

1.4.2 Water levels

The variation in water level in the Baltic Sea is governed by inflows and outflows through the Öresund and Danish Belts, and by inflowing watercourses. The volume of flows through the strait is controlled by air pressure variations and associated wind conditions. The strongest inflows to the Baltic Sea result from west to northwest winds, and corresponding outflows result from winds from east to northeast. Sustained high pressure over the Baltic Sea generally results in low water levels.

The water levels are also affected locally by the wind. This means that coasts with onshore winds temporarily have higher water levels, which can be noticeable in high winds. Extensive storms that cause high water levels in this way often give rise to a standing wave. Water that has been sheared up towards a coast flows back and raises the water level on the opposite coast. This wave can continue to strike back and forth for several days, but declines in intensity due to friction. Throughout the Baltic Sea, from north to south, standing waves have a period of four days and may continue for weeks. Other standing waves may form between the Gulf of Finland and the south-western Baltic Sea with a period of about 27 hours (SMHI 2009). Long and shallow bays are more significantly affected by wind and standing waves as the water masses are forced into an increasingly narrow and shallow area, causing the water level in turn to be even higher.

Oskarshamn's water level has been tracked since 1960 and, to a great degree, represents the water level outside the Oskarshamn plant. The highest water level, measured in January 2017, was +116 cm above the average water level. The lowest water level was measured at -82 cm below the average water level in March 1972. Table 1-2 shows the forecast maximum and minimum water levels at the site for a recurrence period of 100 years.

Table 1-2. Forecast maximum and minimum water levels for a recurrence period of 100 years (cm).

Recurrence period [years]	100
Maximum water level above the average water level [cm] at the installation site	118
Minimum water level below the average water level [cm] at the installation site	-90

1.4.3 Currents

The surface current depends largely on the wind and changes direction. The rotation of the Earth causes weak anti-clockwise circulation. This results in a weak, average, southbound current along the Swedish coast. The most important factor for current direction is wind (SKBdoc 1865659). During the period 1975-1976, current measurements were carried out in an area close to OKG’s nuclear power plant. The results of these tests showed parallel coastal currents with typical velocities of about 10 cm/s. For short periods, velocities of about 50 cm/s were measured. The directional distribution of the current was in good agreement with the directional distribution of the wind, see section 1.5. During the period, measurements showed that 55% of the current was northbound and 45% southbound. During the same period, the wind blew west to east 52% of the time. Currents were also measured in the area outside Simpevarp from October 2004 to April 2005. These measurements also showed that the current velocity is, for the most part, slower than 10 cm/s.

The direction of deeper currents may deviate from the direction of the surface current, especially when the wind affects whether the surface current travels to or from land. There are instances of stable currents travelling in the same direction for several days, as well as cases where the current changes direction more than once per day.

1.4.4 Sea water temperature

The highest measured natural water temperatures in the area outside the site are +27°C for surface water, +22°C at a depth of 10 metres, and +20°C at a depth of 20 metres. These are the highest values measured during the period of 1969-1998. The maximum temperatures are not maintained for long, but rather for a few days at a time.

The lowest surface water temperatures are between +1°C down to the freezing point, which is about -0.6°C and at a depth of 20 metres, no lower than +0.5°C. The duration of these temperatures is from January to March.

1.4.5 Ice freeze-up and ice conditions

In the coastal area at Simpevarp, ice freeze-up normally occurs in the beginning of February and at the earliest in the beginning of January. Ice break-up normally occurs at the end of March and at the latest at the end of April. Ice thickness is normally between 15 and 20 centimetres, and at most as deep as 45 centimetres. The solid ice that forms during harsh winters does not pose a problem for supplying cooling water to the site as the thickness of the ice cover rarely exceeds one metre during harsh winters.

Frazil ice can arise in the event of strong wind in connection with freezing temperatures and open water. The water temperature at these times is about 0°C. Ice crystals form in the water surface and are carried, due to turbulence, several metres deep in the water. The ice crystals clump together and may stick to structures below the water surface. In gale winds, the ice crystals can be carried down to a depth of ten metres. Strong ice crystals can then form on the grates of the cooling water intake, which is at these depths. This reduces the throughput area and can cause a difference in level across the inlet grid. The greatest risk of frazil ice is from the beginning of January to the middle of March. The conditions for frazil ice exist at least a few days each winter.

If a thin ice rind forms in the archipelago, the ice easily breaks up in the event of strong winds from land. A compacted belt of grease ice, also known as a grease ice ridge, is formed at the edge of the fast ice boundary. The water-laden grease ice can be pushed down to a depth of 6-7 metres. The phenomenon is most common in bays or inlets facing the sea and lacking protective shallows or small islands. Since Clab is encompassed by several islands, it is relatively protected from this phenomenon.

1.4.6 Marine life

In the summer, large quantities of algae, algae blooms, occur in the surface water when the air and water temperatures are favourable. The prevailing winds control where algae blooms appear near land.

The greatest number of fishes are found in the autumn. Large amounts of fish may be present, but not enough to block an intake channel. However, it may be enough to cause clogging in the screening system and cooler. The high influx of fish lasts 1-5 days. Jellyfish are carried in with easterly winds and can remain for about a week, generally in the autumn.

Mollusc attachment occurs in intake channels. In the event of a flow interruption, the molluscs die from lack of oxygen. When the facility is returned to normal operation, the shells are transported further into the systems. Molluscs can also be transported into the systems in their larvae stage as they pass freely through the screening system. The mollusc larvae then settle on areas to grow. If necessary, the heat exchangers are flushed clean of these.

Plant matter can be carried toward the coast in the event of strong wind from land.

1.4.7 Groundwater conditions

The Simpevarp Peninsula is constructed of rock types with low water flow and the movement of groundwater is probably limited to the bedrock weak zones.

Surveys have indicated that the rock has a low flow of water. The groundwater level is at or slightly higher than the surface of the Baltic Sea.

1.5 Meteorology

Meteorological data for the site is evaluated based on four weather stations located 22 kilometres south-west (Oskarshamn), 38 kilometres north (Västervik), 85 kilometres south (Kalmar) and kilometres east (the northern tip of the island Öland) of Clab, see Figure 1-7. The weather station in Oskarshamn gives the best indication of conditions in Simpevarp. For local weather monitoring, there is a meteorology mast on the Simpevarp Peninsula. This mast is used for measuring wind direction, wind speed, temperature and air pressure. The weather stations are owned and operated by the Swedish Meteorological and Hydrological Institute (SMHI), and the meteorology mast by OKG.

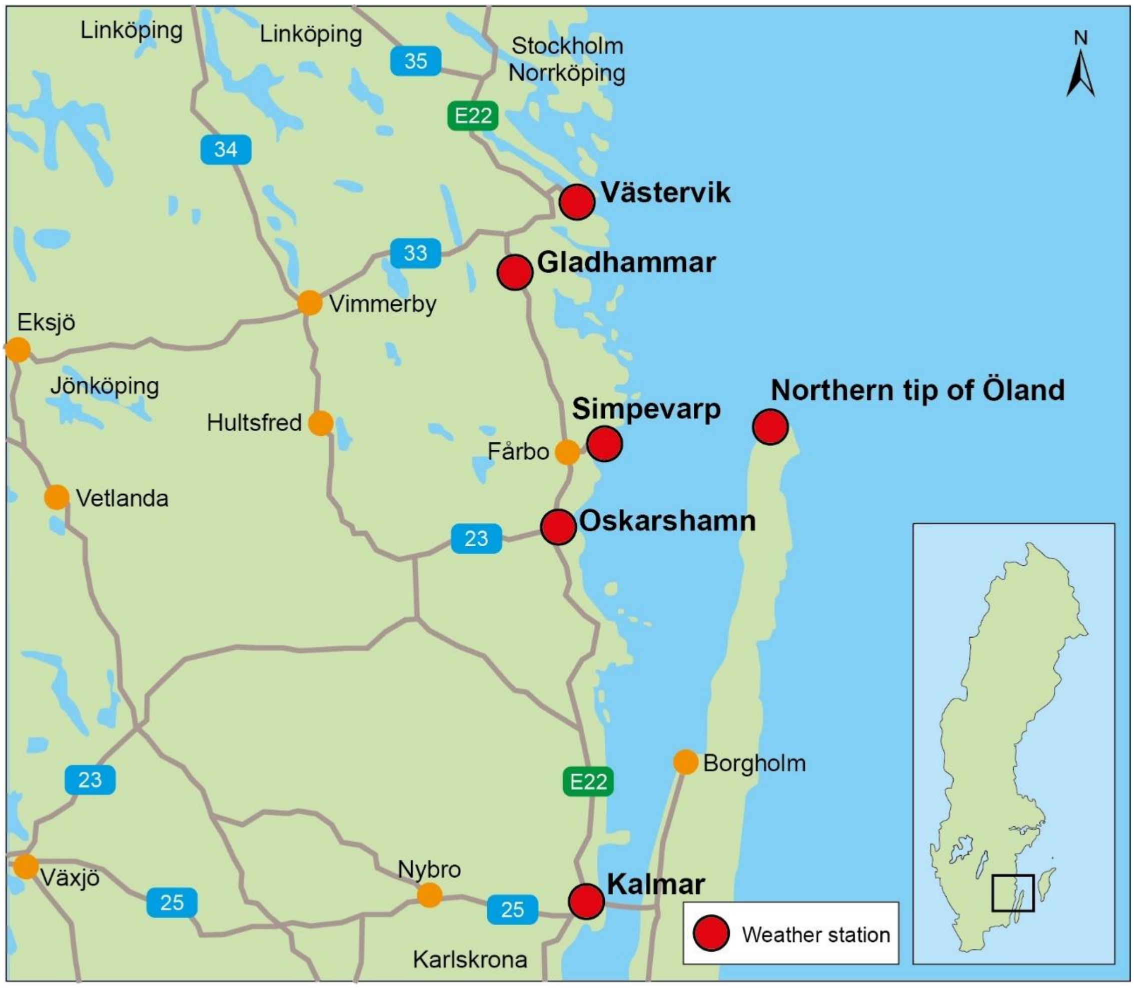


Figure 1-7. Meteorological data weather stations.

1.5.1 Wind

Both the wind direction and wind speed often show large and rapid fluctuations around an average value, i.e. that the wind is gusty. The measurement stations used for wind data are those on the northern tip of the island Öland and in Kalmar, where data for wind roses is observed every third hour with 10-minute average wind at a height of ten metres above ground. Both wind roses, Figure 1-8, show a clear majority of winds from south to west. Wind speeds above 15 m/s rarely occur, but when they do, the wind is generally from the west. The measurement station on the northern tip of the island Öland is exposed and the wind speeds are higher there than in Simpevarp, which is topographically protected, above all, from westerly winds (SKBdoc 1717385).

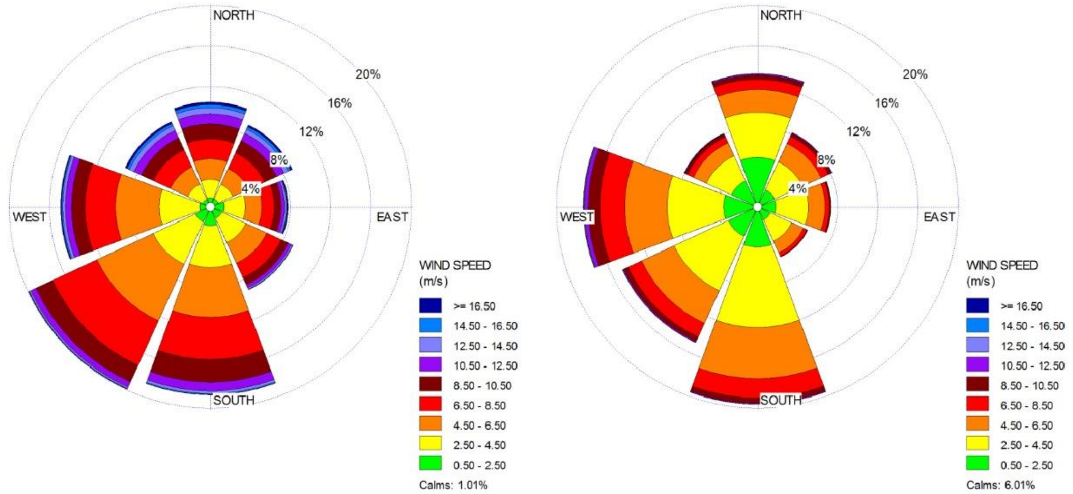


Figure 1-8. Wind rose from the northern tip of the island Öland 1961-2017 (left) and from Kalmar 1961-2005 (right) (SKBdoc 1717385).

Using data from the northern tip of the island Öland and a description of the terrain at Simpevarp, Simpevarp's wind frequencies are calculated, see Table 1-3. The calculations show that Simpevarp is protected from strong westerly winds.

Table 1-3. Calculated wind frequencies (% of the time) for Simpevarp divided into wind directions and wind speed classes (SKBdoc 1717385).

Wind speed [m/s]	N	NE	E	SE	S	SW	W	NW	Total
0.5–2.5	3.5	2.5	1.7	1.7	2.4	4.9	5.1	3.7	**25.5**
2.5–4.5	3.3	3.2	2.5	2.8	5.1	7.2	4.8	3.5	**32.4**
4.5–6.5	1.9	2.3	2	2.4	5	5.2	2.5	2	**23.3**
6.5–8.5	0.83	1.2	1.2	1.3	2.9	2.2	0.91	0.89	**11.4**
8.5–10.5	0.29	0.46	0.56	0.51	1.1	0.57	0.25	0.32	**4.1**
10.5–12.5	0.07	0.14	0.21	0.16	0.26	0.09	0.05	0.1	**1.1**
12.5-–14.5	0.04	0.04	0.07	0.04	0.04	0	0	0.02	**0.25**
14.5–16.5	0.01	0.01	0.02	0.01	0.01	0	0	0	**0.06**
Total	**9.8**	**9.9**	**8.3**	**8.9**	**16.8**	**20.0**	**13.6**	**10.5**	**98.0**

The maximum wind speeds at Simpevarp have been calculated for two different elevations above ground. The estimated maximum winds have a recurrence time of 100 years. The results are presented in Table 1-4, and for comparison, values are presented that are exceeded once per year (recurrence time 1 year). Average wind means a mean value over ten minutes, while gusts are a mean value over three seconds.

Table 1-4. Calculated maximum wind speeds at Simpevarp with recurrence times of 1 and 100 years, at two elevations above ground (SKBdoc 1717385).

Elevation above ground [m]	Wind speed [m/s] Recurrence time 1 year		Wind speed [m/s] Recurrence time 100 years	
	Average wind speed	Gust	Average wind speed	Gust
10	17.9	28.5	24.7	39.5
50	25.4	35.1	35.2	48.7

1.5.2 Temperature

The air temperature for the Oskarshamn measurement station has been measured since 1961, and in Figure 1-9 observed maximum and minimum temperatures per month since 1961 are shown, as well as mean temperature, mean maximum temperature and mean minimum temperature for the period 1991-2017. The calculated minimum and maximum temperatures with 100 years' recurrence time are shown in Figure 1-9, and in Table 1-5.

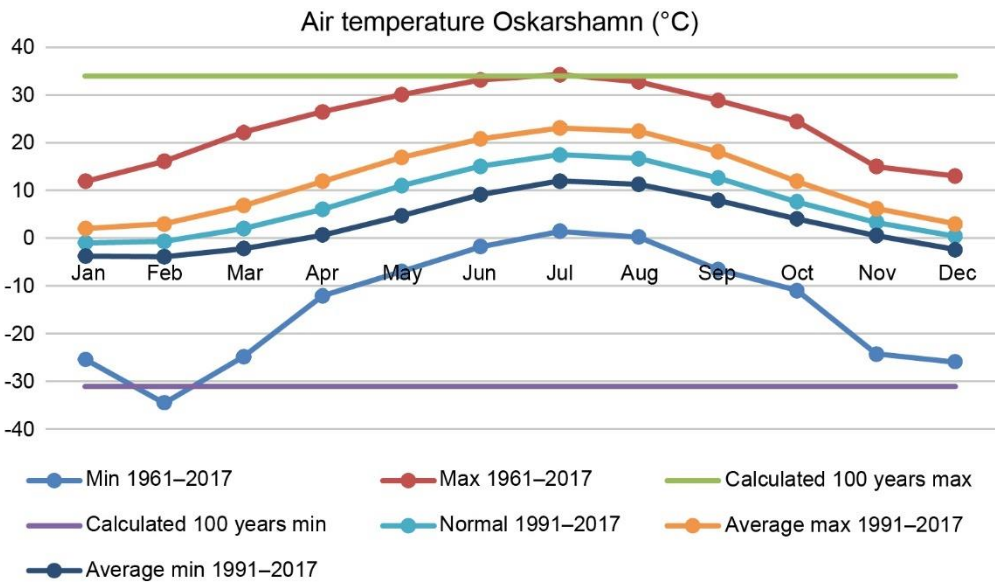


Figure 1-9. Air temperature for Oskarshamn's measurement station (SKBdoc 1717385).

Table 1-5. Calculated maximum and minimum temperature with a recurrence time of 100 years. 95% confidence intervals are indicated by the values in parentheses (SKBdoc 1717385).

Measurement station	Maximum temperature °C 100 year recurrence time	Minimum temperature °C 100 year recurrence time
Oskarshamn	34.0 (32.6; 34.7)	-31.1 (-34.0; -27.1)
Northern tip of the island Öland	30.5 (29.1; 31.2)	-20.4 (-23.9; -16.1)
Västervik and Gladhammar	34.1 (32.9; 34.6)	-30.8 (-33.9; -26.7)
Kalmar	34.5 (32.3; 36.0)	-27.3 (-29.5; -24.3)

1.5.3 Precipitation

The normal precipitation during a month for Oskarshamn's measurement station varies between 30 and 70 mm, see Figure 1-10. The largest precipitation volumes during a day mainly occur during the summer months and usually in connection with thunderstorms. The highest daily precipitation for Oskarshamn during the period 1961-2017 is 99 mm, and for Västervik during the period 1876-2017 is 112 mm. Table 1-6 shows calculated precipitation quantities during different durations and recurrence times.

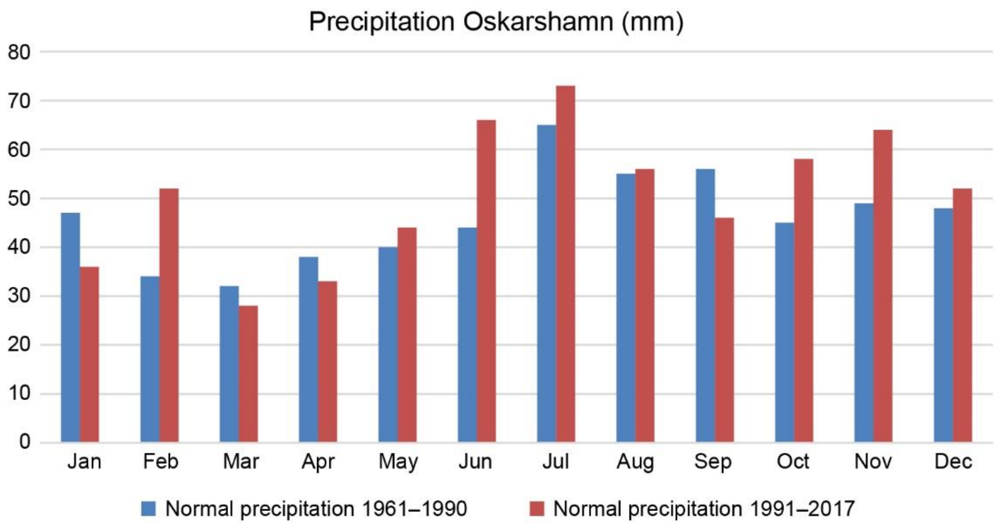


Figure 1-10 Normal precipitation [mm] per month for the Oskarshamn measurement station (SKBdoc 1717385).

Table 1-6. Calculated precipitation volumes for different durations and recurrence times. (SKBdoc 1717385). The values per hour and per 15 minutes are highly uncertain for longer recurrence times, since the measurement series for short-term precipitation started in the 1990s and are thus short. These values are marked with ~.

	Daily Oskarshamn	Per hour Gladhammar	Per 15 minutes Gladhammar
100 years	79 mm	~28 mm	~39 mm
2 years	32 mm	11 mm	7 mm

1.5.4 Extreme weather

Tornadoes can occur anywhere in the country. They are always very local in nature and the diameter of the intensive vortex is usually about a hundred metres. Once a tornado has formed, it is relatively long-lasting. There are several cases described where it has been possible to follow a tornado's devastation for a few kilometres. On average, about 5 km^2 per year is estimated to be affected by a tornado with a wind speed of at least 75 m/s, but wind speeds of just over 100 m/s have occurred. The average number of tornadoes is estimated to be ten per year in Sweden. The probability of a random site being affected during a year is then 1 in 100,000 (SKBdoc 1717385).

During thunderstorms, lightning is the visible part of electrical discharges. It consists of air that is so strongly heated that it becomes luminous. When the voltage differences in a cloud become so great that they exceed the insulating capacity of the air, a discharge occurs. The standard value for normal lightning (SKBdoc 1839602) assumes that 10% of all lightning carries a greater risk than normal lightning. At nuclear power plants, it is customary to use a definition of normal lightning that assumes that 2% of all lightning can be expected to result in major impact, which is also applied to Clab.

Heat and cold periods in Sweden are measured by SMHI (SKBdoc 1674672). The highest temperature recorded in Sweden is 38°C (Ultuna, Uppland, 9 July 1933 and Målilla, Småland, 29 June 1947). Temperatures around 36-37°C have been recorded on several occasions in different locations. The highest recorded monthly mean temperature is 21.9 °C (Karlstad, July 1901 and Linköping, July 1914). There are no major local differences, which means that these measurements are applicable to large parts of Sweden. The lowest temperature recorded in Sweden is -53°C (Vuoggatjålme, Lapland, 2 February 1966). In the southern parts of Sweden (Götaland and Svealand), the lowest recorded temperature is around -40°C (Västmanland, 24 January 1875). The lowest recorded monthly mean temperature is -27.2°C (Vittangi, Lapland, February 1985). Unlike high temperatures, the geographical variation of low temperatures can be great due to local topography.

SMHI has calculated extreme daily precipitation for Simpevarp (SKBdoc 1472964). The analysis is based on time series of the highest measured daily precipitation for each individual year. Data from two weather stations (Oskarshamn and Västervik) in the vicinity of the facilities have been analysed for Simpevarp. The results show an extreme daily precipitation of 90-100 mm for a recurrence time of 100 years and 120-140 mm for a recurrence time of 1,000 years. Extreme short-term precipitation for Simpevarp has been estimated to be about 40 mm during an hour for the recurrence time of 100 years (SKBdoc 1472964), based on calculated values.

In winter, the Småland coast is often exposed to heavy snowfall in connection with persistent north-east wind over an ice-free sea. In January 1985, a "snow firehose" occurred on the coast of Småland. The sea was open and there was a significant drop in temperature in the atmosphere, which caused heavy snowfalls that were driven in over land by a north-easterly wind. At the weather station in Oskarshamn, the snow depth was measured at 110 cm and in Misterhult, situated about 10 kilometres north-west of Simpevarp, about 130 cm was measured.

An ice storm is a storm with sleet or freezing rain, which freezes into ice when it reaches the ground and other surfaces. This can cause severe slippery conditions and extensive damage. Everything is covered with heavy, shear ice. Vehicles can be covered by an ice crust that prevents them from running. Poles, masts, cables, trees, bridges and buildings that are burdened by the ice crust can fall and cause damage, block accessibility or cause interruptions in power supply and telecommunications. Ice sheet growth has been estimated for different recurrence times (SKBdoc 1726798). Since there are few events in the observation material, there is great uncertainty regarding estimates of ice growth. Forecasted ice growth is presented in Table 1-7 as a function of the recurrence time for the two cases of sleet, as well as wet snow and decreasing temperature.

Table 1-7. Ice growth [mm] with recurrence time for two weather situations. 95% confidence intervals are indicated by the values in brackets.

Recurrence time	10 years	100 years
Sleet (mm)	1.52 (0.74: 2.75)	3.63 (0.99: 9.09)
Wet snow and falling temperature	11 (9: 15)	28 (16: 46)

1.6 Natural resources and foodstuffs

1.6.1 Water utilisation

The nearest protected area for drinking water is in Fårbo, 11 kilometres from Clab. Since 1983, drinking and process water for OKG, and subsequently also for Clab, has been taken from lake Götemaren through a pipe to a water supply plant operated by OKG, see Figure 1-2. The Söråmagasinet dam is used for back-up water supply of drinking and process water for OKG and Clab. This reservoir meets SKB's and OKG's overall water needs for about five months during normal operation. The wastewater from Clab is divided into active water (water that may contain radioactive substances), sanitary water and surface water. Active wastewater is treated in a purification plant at Clab before it is transported via the cooling water tunnels to Hamnefjärden, see Figure 1-2. Surface water in the Simpevarp area is only used on a small scale as drinking water for humans and to some extent for livestock. Neither groundwater nor surface water in the Simpevarp area has any impact on water used in any adjacent Member State.

The Baltic Sea is an inland sea consisting of brackish water, which can be used for irrigation or for drinking water for humans or pets to a limited extent after desalination or other measures. According to the Swedish National Board of Fisheries, there were twelve licensed fishermen in Oskarshamn municipality in 2009, all of whom conducted small-scale, near-coastal fishing. Since then, the number of professional fishermen has decreased as a result of reduced fish stocks, which in turn has led to reduced catch quotas. According to statistics from the Swedish Agency for Marine and Water Management (successor to the Swedish National Board of Fisheries), there has been a gradual reduction in the Swedish fishing fleet in following years.

1.6.2 Food production

The land is primarily used for forestry in the Simpevarp area. Arable land in the area is primarily used to produce feed and grazing for domesticated animals. The number of agricultural animals in Oskarshamn municipality is presented in Table 1-8. The level of agricultural activities is low in the area around Simpevarp. Oskarshamn municipality has 180 agricultural companies (2020), most of which are on less than 30 hectares of arable land. This represents less than 5% of the municipality's land, which is below the average proportion of agricultural land in Sweden.

Table 1-8. Number of farm animals in Oskarshamn municipality in 2020 according to the Swedish Board of Agriculture's statistics. (jordbruksverket.se, 25/11/2021).

Animals	Number
Cows for rearing calves	893
Heifers, bulls and steers	1,288
Calves, under 1 year	1,444
Lambs	562
Rams and ewes	751
Pigs for slaughter, 20 kg and above	31

No large quantities of food are produced in the region and area around Simpevarp. Based on this, the quantity of food that is exported from the area is deemed to be negligible. There is no specific data available on exports of food produced in the area or region to other Member States.

1.7 Other activities in the vicinity of the site

Clab is located on the same industrial site as OKG's three nuclear power reactors. O1 and O2 are permanently shut down while O3 is in operation, see Figure 1-2. In connection with this, there is an oil storage facility with tanks containing diesel and a hydrogen gas factory. Vessels pass through the channel around Simpevarp. Tankers maintain a greater distance than eight kilometres, which constitutes the necessary safety distance (SKBdoc 1436265).

In the event of an incident at nuclear power reactor O3, the shift supervisor at Clab is immediately informed in accordance with the governing event instructions for reactor O3. There is an action list and checklist at Clab that is applied in such an event. This means that Clab immediately manages the facility and personnel with regard to the incident at O3. The primary measure is to ensure that the facility is in a safe state. Filtering is controlled to ensure that no radioactive discharge from the O3 incident enters the facility. If necessary, the crisis organisation is activated, see chapter 7. Other non-nuclear facilities owned and operated by SKB in the vicinity are contacted to ensure that relevant measures can be adopted.

2 The installation

2.1 Main features of the installation

2.1.1 Facility and operations

Clab consists of a receiving section at ground level and a storage section consisting of rock caverns more than 30 metres below the ground surface, see Figure 2-1. In addition, there are buildings above ground for the activities required to operate the facility, see Figure 2-2. Transport tunnels lead down from the ground surface to the storage section and a fuel elevator connects the receiving section with the storage section (SKBdoc 1865661). The storage section consists of two rock caverns at a distance of about 40 metres from each other, connected by a water-filled transport channel. Each rock cavern is approximately 120 metres long and contains four storage pools and one reserve pool. The receiving section at ground level contains pools of water and handling equipment for transport casks and spent fuel.

The water in the pools is heated by the decay heat from the spent nuclear fuel. The heat is cooled by sea water via heat exchangers. Sea water is introduced via an intake building south of Clab, see Figure 2-2, and transferred via pipes and filters to the heat exchanger. After passage through the heat exchanger, the heated water is fed back into the sea via a ground and culvert pipe to Hamnefjärden north-east of Clab, see Figure 1-2. The flow of cooling water is adapted to the cooling demand and temperature of the sea water. The cooling chain is designed to remove decay heat from an inventory of 11,000 tonnes of spent nuclear fuel. The pool water section of the cooling chain contains filters and ion exchangers to purify pool water from impurities. Similarly, other contaminated water in the facility is purified via several different purification systems. After sampling to ensure purification, purified water is returned to the systems or discharged to the sea.

The main processes in Clab consist of receiving, handling and interim storage of spent nuclear fuel.

Receiving entails spent nuclear fuel arriving at the port of Simpevarp from the nuclear power plants by the ship M/S Sigrid. The fuel is transported in transport casks, which are specially designed and licensed for transporting spent nuclear fuel. Further transport from the port and within the industrial site is carried out by terminal vehicles. The terminal vehicle is also used for direct transport of spent nuclear fuel from OKG. Transport casks containing fuel are received in the receiving section where a receiving inspection is carried out.

Clab is designed to receive 300 tonnes of spent nuclear fuel per year, which will not change with increased interim storage. The quantity of fuel received from the nuclear power plants varies from year to year, but is always less than 300 tonnes. The largest annual quantity is received from final shutdown of nuclear power reactors, but is also less than 300 tonnes per year (SKBdoc 1608273).

Handling of the received spent nuclear fuel is carried out in the receiving section, where the transport cask containing fuel is cooled by water to a predetermined temperature. The transport cask is then placed in a storage pool and the fuel is lifted out and placed in a fuel canister that is carried down to the storage section by the fuel elevator. This is done in an elevator cage with just over half a metre of water coverage over the fuel. The storage canister containing fuel is then moved to a predetermined position in one of the storage pools. All fuel handling takes place under water.

The fuel is **interim-stored** with about eight metres of water coverage in pools in the rock caverns. In addition to spent nuclear fuel, core components from the nuclear power plants are also stored.

These core components mainly consist of control rods from boiling water reactors (BWRs) and other core components and occupy about a tenth of the total quantity of storage positions in Clab.

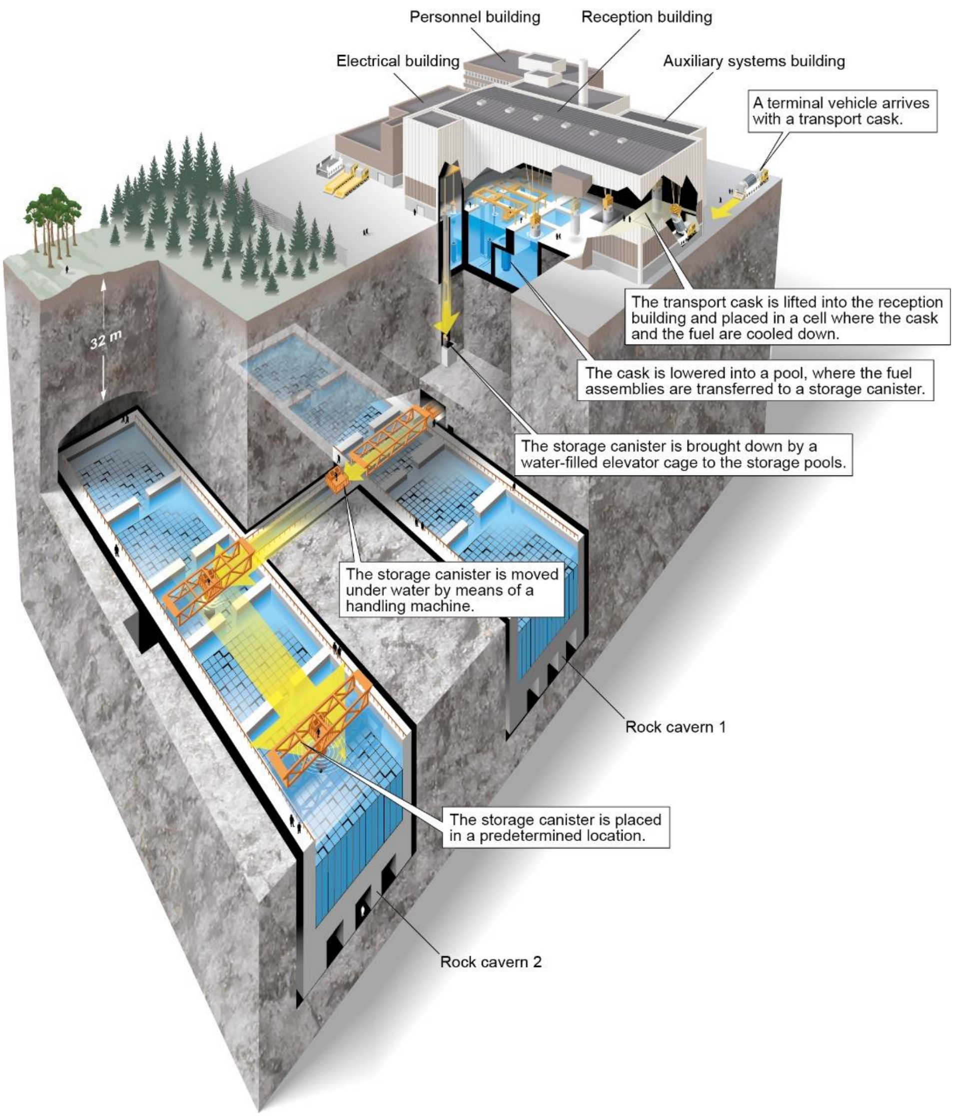


Figure 2-1. Clab main building with receiving section and storage section in two rock caverns for spent nuclear fuel.

Figure 2-2. Clab's above-ground buildings.

2.1.2 Safety regulations

Clab is a nuclear facility subject to the Nuclear Activities Act (1984:3) and the Radiation Protection Act (2018:396). In addition, the licence stipulations submitted to SKB for Clab apply. The Nuclear Activities Ordinance (1984:14) and the Radiation Protection Ordinance (2018:506) describe how the laws are to be applied and which mandates the relevant authorities have. With the support of this, the Swedish Radiation Safety Authority issues regulations that govern the design of the facility and the activities carried out in it. The regulations[5] that are fully or partly applied for Clab are:

General regulations

- SSMFS 2008:1 "The Swedish Radiation Safety Authority's Regulations and General Advice on Safety in Nuclear Facilities".
- SSMFS 2018:1 "The Swedish Radiation Safety Authority's Regulations on Basic Rules for Licensable Practices with Ionising Radiation".

Activity-specific regulations:

- SSMFS 2008:3 "The Swedish Radiation Safety Authority's Regulations and General Advice on Control of Nuclear Material etc."
- SSMFS 2008:12 "The Swedish Radiation Safety Authority's Regulations and General Advice on Physical Protection of Nuclear Facilities".
- SSMFS 2008:13 "The Swedish Radiation Safety Authority's Regulations on Mechanical Devices in Certain Nuclear Facilities".

[5] Regulations 2022-01-01

- SSMFS 2008:17 “The Swedish Radiation Safety Authority’s Regulations and General Advice on the Design and Construction of Nuclear Power Reactors”[6].
- SSMFS 2008:23 “The Swedish Radiation Safety Authority’s Regulations on Protection of Human Health and the Environment in connection with Discharges of Radioactive Substances from certain Nuclear Facilities”.
- SSMFS 2008:24 “The Swedish Radiation Safety Authority’s Regulations on Radiation Protection Managers at Nuclear Facilities”.
- SSMFS 2008:26 “The Swedish Radiation Safety Authority’s Regulations on Radiation Protection of Individuals Exposed to Ionising Radiation at Nuclear Facilities”.
- SSMFS 2008:38 “The Swedish Radiation Safety Authority’s Regulations on Archiving at Nuclear Facilities”.
- SSMFS 2014:2 “The Swedish Radiation Safety Authority’s Regulations on Preparedness in Nuclear Facilities”.
- SSMFS 2018:3 “The Swedish Radiation Safety Authority’s Regulations on Exemptions from the Radiation Protection Act and on Clearance of Materials, Building Structures and Areas”.
- SSMFS 2018:10 “The Swedish Radiation Safety Authority’s Regulations on Radon at the Workplace”.

Activities involving ionising radiation are based on three fundamental principles established in the Radiation Protection Act (2018:396) and recommended by the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA). These principles entail that the activity must be justified, optimised and that dose limits must be used to limit radiation doses.

Radiological emergencies and discharges are prevented by customising the basic construction to include several barriers. This is done in accordance with section 4 of the Nuclear Activities Act (1984:3). The purpose of the barriers is to prevent the dispersion of the facility's radioactive substances. If a barrier is breached, the next barrier takes over, see section 2.5. The integrity of the barriers is protected by safety functions. The facility also has an adapted defence-in-depth system. The defence-in-depth system is an application of several overlapping levels of technical equipment, organisational support and manual measures to protect the facility's barriers and maintain their effectiveness, as well as to protect the surroundings if the barriers do not function as intended. If one level in the defence-in-depth system does not work as intended, the next level should take over and deal with or limit the consequences of the conditions that may arise. Independence between defence-in-depth levels is sought.

2.2 Ventilation systems and the treatment of gaseous and airborne wastes

Ventilation systems for controlled areas maintain the supply and circulation of air in the storage halls and other controlled areas. The flow paths of radioactive substances are presented in Figure 3-1. Ventilation takes place through the supply of outdoor air and cooling and dehumidification of circulating air and the removal of exhaust air via the chimney. All exhaust air from controlled areas is led through the chimney where aerosols are collected and radioactive substances are detected. The air in controlled areas is controlled so that air passes from areas with less risk of

[6] The regulation concerns only Nuclear Power Reactors but it is applied by SKB with regard to sections 2, 21 and 22 concerning safety and event categorisation respectively.

airborne activity to rooms with a greater risk of airborne activity. To further reduce the risk of dispersion of activity in the facility, the ventilation system has a subdivision into subsystems with filtration (SKBdoc 1069245). In the chimney, air is propelled by fans to the aerosol and carbon filters. Exhaust air from areas/process systems where significant amounts of activity can become airborne, is filtered through droplet separators, air heaters, fine filters and HEPA filters. The handling and final disposal of solid radioactive waste arising from the purification of air is described in Chapter 5.

2.3 Liquid waste treatment

Process water and water from floor drainage in controlled areas are purified from particles and ions with filters and ion-exchangers (SKBdoc 1190346, SKBdoc 1190359). The particles consist of crud, that is, chalk river unidentified deposits that have detached from the surfaces of the fuel assemblies in the pools. Used filters and ion exchange resins are transported via receiving tanks for storage in six tanks with a storage volume of 38 m^3 in each, or directly on for concrete-embedment. In the embedment facility, filters and ion exchange resins are dewatered and then solidified in concrete moulds. A lid is cast on the solidified waste. When the mould has been completed, it is transported to a storage position prior to transport within the industrial area from Clab to OKG. Sludge and sediment from sumps are transferred to OKG’s waste station. The management and final disposal of solid radioactive waste from the purification of water is described in Chapter 5.

2.4 Solid waste treatment

Treatment and final disposal of solid radioactive waste is described in Chapter 5.

2.5 Containment

According to SSMFS 2008:1, there must be a basic structure adapted for each facility in which multiple barriers must be included. The purpose of the barriers is to prevent the dispersion of the facility's radioactive substances. If a barrier is breached, the next barrier takes over.

The barriers in Clab consist of the spent nuclear fuel. The first barrier consists of the fuel pellet. The purpose of the pellet is to contain fissile material and fission products in a crystalline structure with the prevention of criticality and with heat transfer to the cladding. The second barrier consists of the fuel cladding, whose function is to remove heat and contain fission gases and radioactive substances. During storage of the spent nuclear fuel in Clab, it is mainly the integrity of the fuel cladding that must be protected. The temperature of the fuel pellets does not reach such levels during storage that their integrity is jeopardised. Some fuel rods are encapsulated by packaging that constitutes a substitute for the fuel cladding barrier.

2.6 Decommissioning and dismantling

Decommissioning of a nuclear facility includes the measures taken by the licensee, after final shutdown of a facility, to dismantle and demolish all or parts of the facility and to reduce the quantity of radioactive substances in the ground and remaining buildings to such levels that permit clearance of the facility. Under the Nuclear Activities Act, the licensee of a nuclear facility is responsible for safely decommissioning and demolishing the facility. This is specified in the Swedish Radiation Safety Authority’s regulations. Before a nuclear facility is constructed, there must be a plan for the future decommissioning of the facility. Thus, in accordance with regulations, there is a plan for the decommissioning of Clab (SKBdoc 1532641).

According to current plans (in 2022), the last Swedish nuclear power reactors will be decommissioned in 2045 and interim storage of spent nuclear fuel will continue until 2075. This is to allow the last fuel core to decay for 30 years before final disposal. When Clab has been emptied of spent nuclear fuel, decommissioning according to SKB's strategy will be carried out without delay.

The plan for decommissioning is based on the overall strategy of carrying out work in a safe, efficient and environmentally sustainable way. Where relevant, established methods for dismantling and demolition of radioactive systems and structures will be applied. Experience from dismantling and decommissioning other nuclear facilities, primarily the Swedish nuclear power reactors, will be used to plan the work. Methods that minimise the spread of contamination will be prioritised. Throughout decommissioning, the plans for the execution and chronology of work operations will be optimised based on a joint ALARA and BAT perspective in order to minimise dose and maximise efficiency. Waste from decommissioning of the facility will be divided into categories based on dose rate. A system for clearance will be applied for the waste that has activity levels below applicable clearance limits. Other radioactive waste will be managed and disposed of according to the same principles as applied to the waste that arises during operation of the facility, see Chapter 5. The planned final state following decommissioning and dismantling of Clab is a cleared industrial site that can be used for non-nuclear facilities and activities.

3 Release from the installation of airborne radioactive effluents in normal conditions

The facts linked to discharge of radioactivity in general are presented here, regardless of whether it is to air or water. Facts specifically linked to discharge to air are presented here and facts specifically linked to discharge to water are presented in Chapter 4.

3.1 Authorisation procedure in force

In August 2021, the Swedish Government decided to grant SKB a licence under the Nuclear Activities Act and permissibility under the Environmental Code to increase the storage capacity in Clab from 8,000 tonnes to 11,000 tonnes, following a statement from SSM and the Land and Environment Court. After this decision, the Court shall issue a licence with conditions to SKB in accordance with the Environmental Code. Before SKB can commence routine operation of the facility according to the new licence, SSM will have to approve a preliminary safety analysis report (PSAR) and thereafter an updated safety analysis report (FSAR) and a supplementary safety analysis report (SAR) for Clab with 11,000 tonnes of spent nuclear fuel. The Swedish Radiation Safety Authority also has the opportunity to set up special conditions or regulations for governing operations.

3.1.1 Legislation regarding nuclear activity

The framework for nuclear activities is mainly provided by the Nuclear Activities Act (1984:3) and the Radiation Protection Act (2018:396) with associated ordinances. SSM's tasks are specified in Ordinance (2008:452) with instructions for the Swedish Radiation Safety Authority. SSM has developed regulations (SSMFS) to provide a more detailed framework for nuclear power plants and other nuclear facilities.

The Swedish Radiation Safety Authority monitors that nuclear activities in Sweden are carried out in a safe manner by issuing regulations and licence conditions, as well as through inspections, checks and reviews of nuclear safety and radiation protection. SSM's goal is to protect humans and the environment from the harmful effects of ionising radiation by applying best available technology (BAT) and optimisation of radiation protection (ALARA). The key provisions related to this objective are:

- SSMFS 2008:1: The Swedish Radiation Safety Authority's Regulations and General Advice on Safety in Nuclear Facilities.
- SSMFS 2008:23: The Swedish Radiation Safety Authority's Regulations on Protection of Human Health and the Environment in connection with Discharges of Radioactive Substances from certain Nuclear Facilities.
  The provisions specify some of the definitions and parameters on how to perform the dose calculations used in this report.
- SSMFS 2018:1 The Swedish Radiation Safety Authority's Regulations on Basic Rules for Licensable Practices with Ionising Radiation.

In Sweden there are no discharge limits specified in becquerel (Bq), but in its regulations, SSM has set criteria for discharge to air and water during normal operation which pertain to restrictions on permissible exposures in the form of doses to persons in the vicinity. According to the authority's regulations concerning discharges (SSMFS 2008:23), the radiation effective dose to the general public from one year's air and water discharge of radionuclides collectively from all facilities located within the same geographically defined area must not exceed 0.1 mSv. However, by optimising the facility and its operations and applying the ALARA principle, it is ensured that the doses to the general public are even lower.

For Clab, this means that doses resulting from discharges from OKG NPPs and Clab together are restricted by this requirement. According to the Radiation Protection Ordinance (SFS 2018:506), the total dose contribution from all societal activities that involve ionising radiation to individuals from the general public who do not work with ionising radiation may not exceed an effective dose of 1 mSv per year. This serves as a basis for acceptance criteria for normal operation and expected events. Normal operation is defined as the operation and disruptions within the established conditions and limitations that are set out in a nuclear facility's safety-related technical specifications (STF). Expected events include events that can be expected to occur during the service life of the facility, including events with a frequency of $\geq 10^{-2}$ per year. Events with a lower frequency are presented in Chapter 6.

3.1.2 Monitoring of discharges

According to SSM's regulations, discharges must be monitored to the greatest extent possible and reasonable. Monitoring shall be customised to the activities that are carried out, the expected radionuclides and the prevailing conditions. A plan for how discharge is limited and monitored and how the plant systems are adapted to this purpose shall be prepared and submitted to the Swedish Radiation Safety Authority. The plan shall describe the monitoring of discharge of radioactive substances into the environment. The monitoring results shall be regularly reported to the authority. Environmental monitoring for Clab is presented in Chapter 8.

3.1.3 Environmental impact assessment

Under both the Environmental Code and the Nuclear Activities Act, environmental impact assessment (EIA) is mandatory documentation in nuclear facility licence applications. The Environmental Code sets out requirements on what the EIA must contain and on EIA consultation procedures.

The operator (applicant) is obliged to consult with the relevant central authorities, county administrative boards, municipalities, residents of the area and other stakeholders about the EIA's limitations and content at an early stage in preparing the EIA. The EIA shall describe the direct and indirect effects of the planned activities and its associated activities. The EIA contains a site description of the activity and its environs and descriptions of the technology to be used. The EIA also describes the impact on people, animals, plants, land, water, air, climate, landscape and cultural environment. In addition, the impact on the management of land, water and the physical environment is described in general, as well as the management of materials, natural resources and energy.

Large nuclear facilities, such as in the case of increased storage in Clab, require a government decision on permissibility under the Environmental Code and a licence under the Nuclear Activities Act. The permissibility decision under the Environmental Code is prepared by the Land and Environment Court, which disseminates the EIA and other application documents broadly, including to the Swedish Radiation Safety Authority and other central authorities, the county administrative boards and municipalities concerned, as well as organisations and individuals who are assumed to be impacted. The Court also conducts an open main hearing in which the EIA is discussed. When this is completed, the Land and Environment Court issues an opinion to the Government, which, e.g., states whether the EIA can be approved. When the Government has made a decision on permissibility, the case is returned to the court for a decision on licences and stipulations for the applied-for activity. A new main hearing is held at this stage, which once more gives the parties concerned the opportunity to propose and discuss licence stipulations, which will result in the Land and Environment Court notifying the judgment after the hearing.

3.2 Technical aspects

The calculations of activity discharge from Clab are based on a maximum quantity of 300 tonnes of fuel received per year. The activity discharge calculations are conservative in that the time that the added activity is allowed to decay before discharge is underestimated in relation to the actual operating case. This in turn leads to an overestimation of activity from short-lived nuclides in the calculated values compared with the actual discharges. The calculated discharges thus constitute a reasonable upper discharge limit from the facility with regard to inventory and annual receipt of fuel. All spent nuclear fuel is handled under water, which means that discharge from Clab of radioactivity to air will be via aerosols. A schematic diagram of the activity flow in the facility is presented in Figure 3-1. Table 3-1 presents calculated discharges to air during a year of annual storage of 300 tonnes of spent nuclear fuel with an inventory of up to 11,000 tonnes (SKBdoc 1865624).

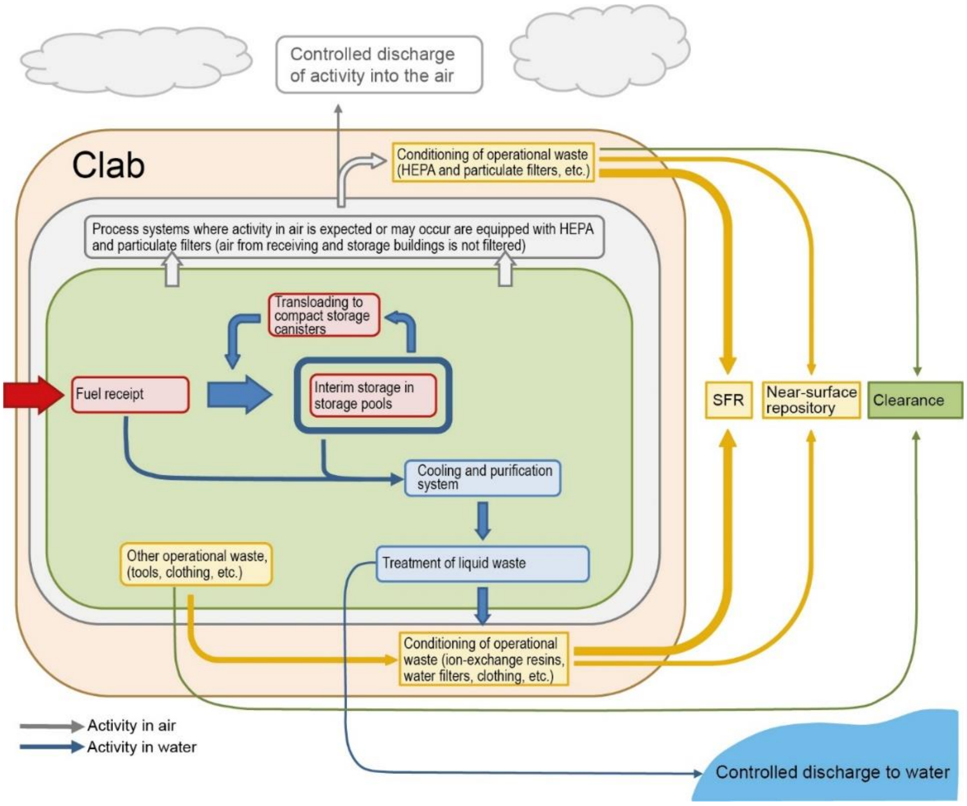


Figure 3-1. Flow paths of radioactive substances in Clab during normal operation.

Table 3-1. Calculation of realistic annual discharge to air with 300 tonnes of fuel received per year up to 11,000 tonnes of total inventory.

Calculated discharge to air	
Nuclide	**[Bq/year]**
Co-60	3.8E+06
Ni-63	2.6E+06
Kr-85	1.1E+10
I-129	1.1E+02
Cs-137	3.1E+05
Pu-238	3.4E+04
Pu-239/Pu-240	1.6E+04
Am-241	1.2E+04
Am-243	1.1E+04
Cm-242	2.2E+04
Cm-243/Cm-244	7.1E+03

Radioactive nuclides in the systems at Clab come from spent nuclear fuel and its structural materials and from core components. Most of the radioactivity in the facility comes from the fuel assemblies where the radioactive substances are mainly bound to the fuel pellets. Radioactivity as induced activity is present in the structural materials and core components of the fuel assemblies.

The fuel consists almost exclusively of uranium dioxide fuel from a boiling water reactor (BWR) and a pressurised water reactor (PWR). In the fuel, inventories of fission products and actinides comprise activity sources that can be discharged to systems in Clab in the event of damage to the fuel cladding. The activity discharge depends on the quantity of failed fuel that is received, handled and stored at the facility. Known failed fuel is placed in boxes to limit discharge from these during storage and handling.

On the surface of the fuel, there are corrosion products that have adhered to the fuel assemblies, crud, that can detach during receipt and storage. Detachment of crud from spent fuel in receipt and storage in pools is of great importance for the dispersion of radioactive substances in the facility and activated corrosion products are dominant in terms of importance for the radiological status of the facility.

The fuel's structural material and core components have induced activity. Activity discharge from this can take place by corrosion detachment. The hydrochemical environment of the storage pools means that the discharge of radioactive nuclides from the fuel’s structural material and core components is negligible in comparison with the corresponding discharge from fuel crud. Nuclide Sb-125, which is triggered by alloy materials, is an exception.

Radioactive nuclides can be discharged from control rods with fractures. This means that tritium can be discharged from BWR control rods during the storage period. However, most of the tritium has been discharged before the control rod arrives at Clab, and the possible remaining discharge after receiving at Clab has a low radiological impact on the facility. Activity discharge from leaking PWR control rods has some radiological impact on the facility's activity discharge, mainly due to silver isotopes.

The ventilation in Clab is designed so that all outgoing air from the controlled side goes via the chimney. The exhaust air from all subsystems is collected at the base of the chimney. The air is filtered through equipment that measures activity and air flow before it leaves the facility, see section 2.2. After filtration and monitoring, small quantities of radioactive substances are discharged into the air from the facility. See also section 3.3 on monitoring discharges to air.

3.3 Monitoring of discharges

Discharge of air is monitored by continuously measuring activity in the air flow in the chimney (SKBdoc 1186311). Monitoring is carried out by directing some of the air flow into sampling loops over an aerosol filter. In addition, the activity of individual subsystems is measured before the exhaust air is collected in the chimney (SKBdoc 1179134, SKBdoc 1186321).

Beta and gamma detectors are placed in measuring loops in the chimney (SKBdoc 1186311). The signal from the beta and gamma detectors is monitored continuously. An alarm is sent when the measurement value exceeds the set limits. Radioactivity is measured by measuring the concentration in the air, which means that the prevailing air flow is also measured to determine activity discharge to the surroundings. Activity in filters is measured at regular intervals in the laboratory when the filters are changed. Filters are normally replaced once a week, but depending on the discharges measured, they may be changed at other intervals. Information on discharge through the chimney is presented in an annual report to the Swedish Radiation Safety Authority.

For Clab, the level for event warning alarms for detectors that measure beta radiation in the chimney is currently 900 kBq per second. Beta radiation alarms cover changes in discharge to the air caused by an increase in radioactive discharge for whatever reason during normal operation or in the case of an event. If necessary, the alarm limit is reviewed in line with established instructions (SKBdoc 1887605). In the event of an alarm, disruption instructions are followed. These state that it is necessary to investigate if there is work in progress at the facility that may be causing increased activity. Radiation protection personnel are contacted for support and checks are made of whether there are elevated activity levels in systems or rooms.

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

Dose to representative persons during normal operation are calculated with PREDO – PREdiction of DOses from normal releases of radionuclides to the environment (Vattenfall, 2015a). PREDO is a software platform for radiological risk assessment consisting of transport models for air dispersion, terrestrial transport and marine transport in addition to a dose calculations part. PREDO calculates doses to different age groups from the public as a result of radionuclide dispersion in the environment. With PREDO nuclide specific dos conversion factor, are calculated for a unit discharge rate of one Bq for each of the radionuclides assumed to potentially be discharged from a facility. The dose conversion factors is then used for estimating annual doses to the public based on discharges from the facility. The PREDO platform has been reviewed and approved by the Swedish Radiation Safety Authority for Clab. The releases of radioactive substances to the air from the Clab site during normal operation and its radiological consequences are assessed by modelling concentrations in environmental media along identified human exposure pathways and resulting doses to humans. Different types of ecosystems in the terrestrial environment entail specific conditions and human activities that will lead to exposure situations.

Specific areas (locations) of an ecosystem type, called land use object, where the highest impact from a source is expected, is identified for the site, specifically as a part of the exposure pathway analysis (Vattenfall 2017a). The land use object identification governs the site-specific model set up. It will decide how many and which areas in the terrestrial environment that are potentially most affected by the releases and where a subsequent exposure of humans can take place, i.e. which areas that are of most importance for the dose assessment calculations. The components of the site-specific model are; calculations of transport from release point to receptors (identified land use objects), subsequent activity concentrations in environmental media in the land use objects and resulting doses to potentially exposed humans in the areas. Specific parameter values used for calculations of site specific dose conversion factors for garden, cropland, pasture land, forest and lake parameters as well as inhalation and ingestion rates are presented in (Vattenfall 2017a). Selected land use objects show highest contaminant air concentrations among land use objects of the same ecosystem type, these are considered conservative in addition to representative.

The model for assessing terrestrial doses following airborne releases is composed of source, transport, receptor and dose blocks, see figure 3-2. The model calculates radionuclide transport and accumulation between and in these blocks and resulting doses to humans.

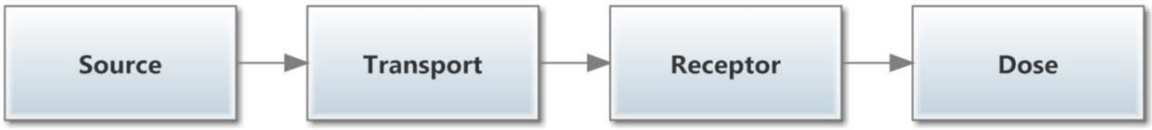


Figure 3-2. The model components of the PREDO terrestrial model.

For Clab the source of atmospheric release is the facility's chimney. A transport block consists of a combination of the release point and selected receptors. The radionuclide air concentration and deposition rate in the given receptor following atmospheric release, dispersion and transport from the given release point, considering ingrowth and decay of radionuclides during the transport from release point to receptor is calculated. Humans are exposed to the risk of radionuclide exposure and resulting doses when they are residing in a receptor and eating products from it. A dose block calculates doses to humans living near/utilizing the areas near the site resulting from identified exposure pathways in the different receptors and the radionuclide concentrations in different media found in the receptors.

Representative persons included consist of the age groups infants (0-5 years old), children (6-15 years old) and adults (16-70 years old), and they belong to the following families (Vattenfall 2015a and references therein):

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

Dose factors for airborne releases for the average representative family and for the most exposed representative family are presented in (Vattenfall 2017b).

More details regarding models and results concerning dose conversion factors for normal operating discharges to air can be found in (SKBdoc 1865626, SKBdoc 1989563, SKBdoc 1876512, Vattenfall 2015a, Vattenfall 2015b, Vattenfall 2017a, Vattenfall 2017b).

3.4.2 Evaluation of concentration and exposure levels

Environmental inspections are carried out around nuclear facilities on the Simpevarp Peninsula in accordance with the Swedish Radiation Safety Authority's regulations, see Chapter 8. This radioecological environmental monitoring continuously provides figures of the occurrence of different radionuclides in Clab's vicinity. OKG takes samples, performs analyses and reports annually. The reporting includes the results from plant sample, milk sample, water and sediment measurements in line with the radioecological environmental monitoring programme (SKBdoc 1865626, SKBdoc 1934157).

The results of the environmental inspections are based on the total discharges from OKG, currently reactor O3, and Clab, together with entirely external discharges. The latter in the form of Cs-137 from the Chernobyl accident in 1986. The measurements of discharges to water and air from these sources comprise a small fraction of the discharges from Clab of the measured values in the surrounding environment. The evaluation of the radiological consequences for biota shows that the calculated dose rate is well below 10 µGy/h, which is the comparison value used as a limit for detectable effects on biota. This also means that no effects are anticipated at the population level.

According to completed calculations and analyses of the discharges of radioactive substances and dose to critical groups from today's Clab, there would only be a marginal effect when the interim storage is increased to up to 11,000 tonnes of spent nuclear fuel. This is because the discharges are largely caused by the *handling* of spent nuclear fuel, which on an annual basis remains unchanged with increased storage. Dose to the critical group for storage of 11,000 tonnes of spent nuclear fuel from the discharges to air indicated in Table 3-1 has been calculated with dose conversion factors, see Section 3.4.1. Results from these calculations are presented in Table 3-2 (SKBdoc 1865626, 1989563).

According to realistic calculations, the dose contribution from interim storage amounts to $5.5 \cdot 10^{-7}$ mSv per year and in conservative calculations $6.2 \cdot 10^{-6}$ mSv with 11,000 tonnes of spent nuclear fuel stored. The calculated doses from the current storage of a maximum of 8,000 tonnes of spent nuclear fuel are of the same magnitude.

Table 3-2. Calculated dose to representative person in the average family, in the age group of infants, from annual discharge of activity to air.

	Conservative estimation	**Realistic estimation**
Dose (mSv)	$5.5\ 10^{-7}$	$6.2 \cdot 10^{-6}$

Dose according to the same calculation method based on measured discharges, between the years of 2011 and 2021 with a maximum storage quantity of fuel of about 7,500 tonnes, varies from $2.2 \cdot 10^{-7}$ mSv to a maximum of $7.7 \cdot 10^{-7}$ mSv (SKBdoc1989563). The annual discharges from Clab during the period 2011-2021 are considerably lower than the regulatory authorities' dose constraint of 0.1 mSv.

Since the start of Clab, there has been a generally decreasing trend in the air discharge of actinides. This is mainly due to the nuclear power plants' current stringent approach (ALARA programme that includes fuel damage strategy) to fuel damage. This leads to a decrease in the concentration of actinides in the crud on the fuel received at Clab. Increased interim storage in Clab will not lead to any significant changes in the inventory of free activity in the facility and will therefore only have a small impact on the discharges of radioactive substances to the surrounding environment.

The dose to a representative person from the public in the vicinity of Clab from discharge to air is well below 10 µSv per year even when conservatively estimated. Calculations of doses to persons outside Sweden's borders are therefore not relevant and have thus not been calculated, in accordance with specification in Appendix I to 2010/635/Euratom.

3.5 Radioactive airborne discharge from other installations

Coordination between Clab and OKG's reactor O3 is described in Section 1.7. In the event of an O3 event with a risk of radioactive discharge, Clab is informed immediately and measures are implemented in accordance with an established action and checklist. This means that filtering of ventilation is initiated and ventilation to buildings is switched off if necessary. The facility is brought into a safe state and a decision is made on whether or not to evacuate.

4 Release from the installation of liquid radioactive effluences in normal conditions

The facts linked to discharge of radioactivity in general regardless of whether it is to air or water are presented in Chapter 3. Facts specifically linked to discharge to water are presented here.

4.1 Authorisation procedure in force

See section 3.1 for the current licensing procedure.

4.2 Technical aspects

The prerequisites for calculating discharges, the origin of the radioactive substances, their composition, physical-chemical forms, the handling of these substances, discharge methods and discharge paths are presented in Section 3.2.

Table 4-1 presents calculated discharges to water during a year with an inventory of 11,000 tonnes of spent nuclear fuel and with a storage of 300 tonnes per year (SKBdoc 1865624).

Table 4-1. Calculations of realistic annual discharges to water with 300 tonnes of fuel received per year up to 11,000 tonnes of total inventory.

Calculated discharge to water	
Nuclide	**[Bq/year]**
H-3	9.7E+08
Mn-54	5.9E+04
Fe-55	1.4E+06
Co-60	1.8E+07
Ni-59	1.8E+04
Ni-63	5.8E+07
Ag-108m	3.1E+05
Ag-110m	1.6E+05
Sb-125	6.4E+06
Sr-90	2.1E+04
Cs-137	1.0E+07
Pu-238	2.2E+03
Pu-239/Pu-240	3.7E+02

Calculated discharge to water	
Nuclide	**[Bq/year]**
Am-241	2.6E+03
Cm-242	5.9E+03
Cm-243/Cm-244	1.1E+03

The water that cools the fuel in the transport cask and the water that cools and purifies the receiving and storage pools is transferred to the system for process water treatment, see Section 2.3. After purification, the water is transported to tanks where it is analysed. When an acceptable activity level is ensured, much of the treated water is reused. The surplus is discharged via a cooling water channel to Hamnefjärden (SKBdoc 1190363), see Figure 1-2. A schematic illustration of the activity flow in the facility is presented in Figure 3-1. Small amounts of radioactive substances are discharged with the water that is not reused. This is discharged from the facility after water purification and inspection. See section 4.3 on monitoring discharges to water. The calculated annual dose to representative persons of different age groups from discharges of radionuclides via water is lower than the equivalent for air discharges. Annual doses from discharges to water have also decreased due to modernisation of purification systems, which has led to a higher recycling of water, i.e. lower discharges of radionuclides and thereby lower doses to surroundings.

4.3 Monitoring of discharges

The sampling system is designed to take samples where the chemical composition is as representative as possible for process water in the systems or system components being sampled (SKBdoc 1865624). Before sampling from a system or system component, the medium is so well mixed that its chemical composition is uniform throughout the system/system component. Most sampling points are equipped with sampling probes that make it possible to take isokinetic samples of flowing water and thereby avoid taking samples of the more or less stagnant water film, which may be present on the system walls or pipe surfaces in a water-filled system. In tanks where water is collected before discharge to the receiving body, samples are taken for determination of the total quantity of alpha-, beta- and gamma-emitting substances (SKBdoc 1190363, SKBdoc 1220463).

Nuclide-specific alpha radiation is measured with an alpha spectrometer. The total alpha and beta radiation is measured with a scintillation detector. Gamma radiation is measured with an HPGe detector consisting of a germanium crystal. Beta radiation is measured with a scintillator after specially preparing the samples.

After completed analyses, surplus water is discharged to the recipient if the activity level is below the established target values of $\leq 10^{-9}$ mSv/m^3 for total gamma activity, $\leq 10^{-10}$ mSv/m^3 for total alpha activity and values for beta-emitting isotopes, each of which in relation to dose to critical group (SKBdoc 1061854). If the activity content is higher, the water is returned to the purification system. This is repeated until approved levels are reached.

4.4 Evaluation of transfer to man

4.4.1 Models, including where appropriate generic models, and parameter values used to calculate the consequences of the releases

Doses from discharges to the marine environment to representative persons from the public during normal operation is calculated with the software PREDO (Vattenfall, 2015a). With PREDO nuclide specific dose conversion factors for each of the radionuclides assumed to potentially be discharged from a facility are calculated using a similar kind of basic method as for discharges to air, see Section 3.4.1. The marine model is based on a box modelling approach to cope with the need for large space and time scale calculations (Vattenfall 2015c). The dispersion of radionuclides takes place via neighbouring boxes and across a vertical water column where the following dispersion mechanisms are considered:

- horizontal and vertical water exchanges between boxes;
- adsorption on suspended sediments;
- depletion of activity in suspended materials in equilibrium with the water phase activity;
- exchange of radionuclides between water column and bottom through the molecular diffusion and bioturbation phenomena.

A more detailed composition of the water column and its sediment layers, as well as its interaction with neighbouring volumes is shown in Figure 4-1. The boxes describing the water column containing suspended matter are subdivided into a number of vertical layers. For each water column layer temporal variations in the nuclide concentration, the exchange with adjacent boxes due to advection, sediment settling and turbulent diffusion processes are considered. Furthermore, the transfer of activity from suspended to bottom sediment due to suspended sediment settlement, radioactive sources and radioactive decay is considered. Temporal variations in the three sediment layers located under the water column are described considering the transfer of radioactivity between water column and sediment, and radioactive decay. The transfer of radioactivity from the upper sediment layer to the water column is described by diffusion in the interstitial water and by bioturbation. Radioactivity in the upper sediment layer migrates downwards by diffusion and by burial at a rate taken as the same at which particles settle from the overlying water. The upward transfer of radioactivity from the middle sediment layer to the top sediment layer occurs only by diffusion. Burial causes an effective loss of radioactivity from the middle to the deep sediment layers, from which no upward migration occurs. The transfer of radionuclides to marine organisms is described considering the food web structure and the trophic level of the organisms.

Activity entering the water column is transported by currents and turbulent diffusion and lost to bottom sediments through sorption on suspended particles which then settle out. The exchange of activity between the upper layer of the sediment and the water column is described as diffusion and bioturbation. Activity in the upper sediment layer may diffuse downward but there is also an effective downward transfer via the continued sedimentation at the top of the sediment layers. Return of activity from the middle sediment to the top sediment occurs only through diffusion. The effective loss of activity from middle sediment to deep sediment arises from the continued deposition of sediment.

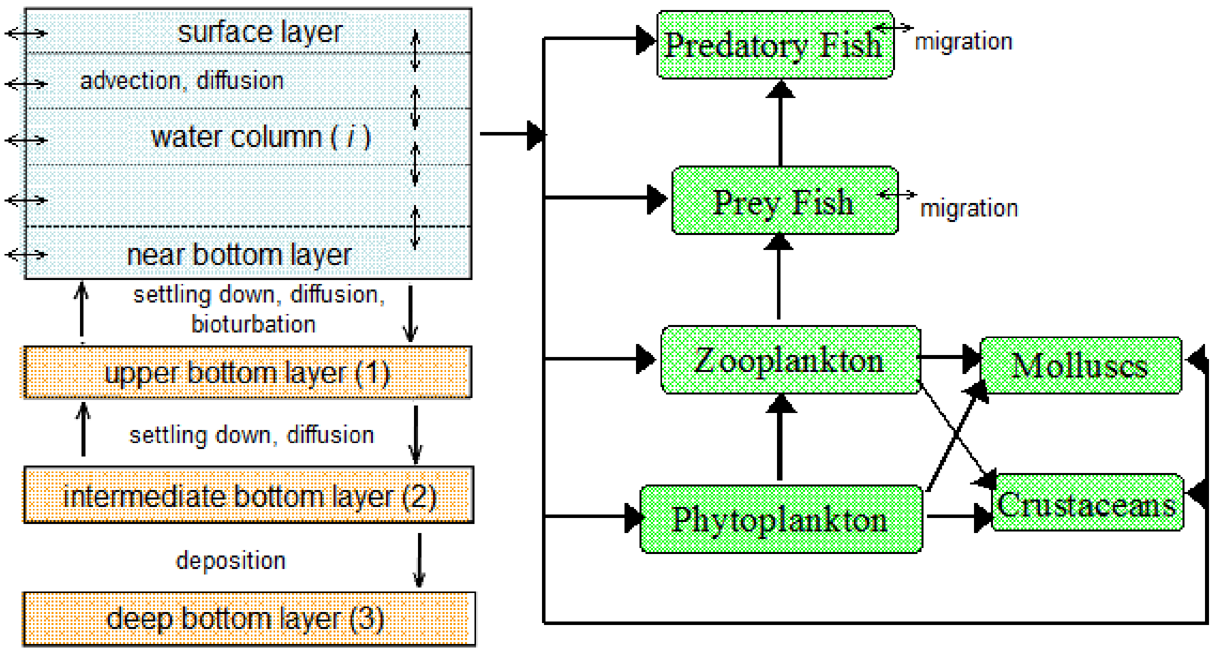


Figure 4-1. Schematic diagram of the activity transfer processes in each box of the model (Vattenfall 2015c).

The calculated annual dose to representative persons from the various family types and different age groups, from discharges of radionuclides via water has been lower than the equivalent for air discharge. Annual doses from discharge to water have decreased due to efficiency improvements, which has led to lower discharge of radionuclides and thereby lower doses. Dose factors for aquatic releases for the average representative family and for the most exposed representative family are presented in (Vattenfall 2017b).

More details regarding models and results concerning dose conversion factors for normal operating discharges to water can be found in (SKBdoc 1865626, SKBdoc1989563, SKBdoc 1876512, Vattenfall 2015a, Vattenfall 2015c, Vattenfall 2017a, Vattenfall 2017b).

4.4.2 Evaluation of concentration and exposure levels

Environmental inspections are carried out in accordance with the Swedish Radiation Safety Authority's regulations concerning the nuclear facilities on the Simpevarp Peninsula, see Chapter 8 and Section 3.4.2.

According to performed calculations and analyses, discharges of radioactive substances and dose to a critical group currently from Clab are only marginally affected by the fact that interim storage is increased to a maximum of 11,000 tonnes of spent nuclear fuel. This is because the discharges are largely caused by the *receipt* of spent nuclear fuel, which on an annual basis remains unchanged with increased storage. Dose to the critical group for storage of 11,000 tonnes of spent nuclear fuel from the discharges to water indicated in Table 4-1 has been calculated with dose conversion factors, see Section 4.4.1. The results from these calculations are presented in Table 4-2 (SKBdoc 1865626, SKBdoc 1989563).

According to realistic calculations, the dose contribution from *interim storage* of spent nuclear fuel amounts to $2.2 \cdot 10^{-6}$ mSv per year and in conservative calculations, $2.2 \cdot 10^{-5}$ mSv with 11,000 tonnes storage of spent nuclear fuel. The calculated doses from the current storage of a maximum of 8,000 tonnes of spent nuclear fuel are of the same magnitude.

Table 4-2. Calculated dose to representative person in the average family, in the age group of infants, from calculated annual discharges of activity to water.

	Conservative estimation	Realistic estimation
Dose (mSv)	$2.2 \cdot 10^{-6}$	$2.2 \cdot 10^{-5}$

According to the same calculation method based on measured discharge during the years 2011 to 2021, the dose varies from $0.1 \cdot 10^{-6}$ mSv to a maximum of $4.9 \cdot 10^{-6}$ mSv (SKBdoc1989563). The annual discharges from Clab during the period 2011-2021 are considerably lower than the regulatory authorities' dose restriction.

Dose close to the facility to a representative person in a critical group from discharges to water is well below 10 µSv per year even when conservatively estimated. Calculations of doses to persons outside Sweden's borders are therefore not relevant and have thus not been calculated, in accordance with specification in Appendix I to 2010/635/Euratom.

4.5 Radioactive discharges into the same receiving waters from other installations

Water is discharged via a cooling water channel to Hamnefjärden, see Figure 1-2. Cooling water from the O3 nuclear power reactor is also discharged to Hamnefjärden. Coordination between Clab and O3 is described in Section 1.7. Managing in the case of an O3 event with a risk of radioactive discharge is presented in section 3.5.

5 Disposal of solid radioactive waste from the installation

The operational waste[7] that Clab gives rise to is handled and packaged for subsequent transport to the intended final repository in accordance with the waste management plan (SKBdoc 1357561). The operational waste arises as a natural part of the handling and interim storage of spent nuclear fuel and core components during operation and maintenance of Clab. Operational waste is in solid form or otherwise solidified. Where possible, the waste is cleared immediately or after decontamination. Radioactive operational waste from Clab is managed in part by OKG as detailed in Section 5.1.

5.1 Solid radioactive waste

Operational waste from Clab is divided into the following categories:

- Compactible waste.
- Non-compactible waste.
- Large components.
- Oil.
- Concrete and construction waste.
- Ion exchange resins, filter aids and concentrates.
- Sludge and sediment.
- Operational waste from primary systems.
- Other operational waste.

Each category of waste is disposed of in near-surface repository or in SFR depending on the surface dose rate, activity content and number of long-lived radionuclides.

Compactible waste consists largely of plastic, rags, clothing and mineral wool. The amount varies, but is normally 2-20 tonnes per year. The activity content of the waste is low or very low and is mainly short-lived. The waste is transported to OKG, where it is compacted in a low-level waste handling facility.

Short-lived, very low-level waste with a surface dose rate below 0.5 mSv/h is deposited in OKG's near-surface repository on the Simpevarp Peninsula according to OKG's procedures for this. Short-lived, low-level waste with a higher surface dose rate than 0.5 mSv/h is disposed of in SKB's final repository for short-lived waste, SFR, in Forsmark, to which it is transported by the M/S Sigrid vessel. If necessary, the waste can be interim-stored in rock caverns for active waste at OKG as it awaits transport.

Non-compactible waste consists mainly of metals, but may also contain construction waste, electrical cables and similar. The amount is on average about two tonnes per year. Scrap metal can be sent to Cyclife Sweden to be purified from activity via melting and then cleared. Other waste is packaged in waste containers for storage and final disposal according to the same limits for radioactivity as the compactible waste.

For **large components** that do not fit in standard waste containers or weigh more than 20 tonnes, specific plans are prepared for handling and final disposal when the need arises.

[7] Operational waste refers to the radioactive waste that arises in the process of managing and storing spent nuclear fuel and used core components.

Oil from controlled areas constitutes a volume of 1-2 m^3 per year. Oil that cannot be cleared immediately is sent to OKG for purification and then returned to Clab for clearance. Thereafter, it is treated in accordance with rules for conventional waste.

Concrete and construction waste arise in connection with plant modifications in a controlled area. The waste can often be cleared. If this is not possible, it is handled as non-compactible waste, as described above.

Ion-exchange resins, filter aids and concentrates arise in connection with the purification of water. The annual amount of granular ion-exchange resins amounts to 4 m^3, while the annual amount of powdered ion-exchange resins and inert filter aids amounts to 400 kg. The waste is embedded in concrete moulds and then transported to OKG's rock cavern for waste. There the moulds are interim-stored for later transport by the M/S Sigrid to SFR for final disposal.

Sludge and sediment arise in pump sumps in controlled areas. This waste amounts to about 50 kg/year. The sludge has a surface dose rate of 0.1-5 mSv/h. It is placed in concrete tanks and dewatered. The resulting drainage water is dealt with in the water purification systems, see Section 2.3. The concrete tanks are interim-stored in OKG's rock cavern for waste and transported from there by the M/S Sigrid to SFR for final disposal.

Operational waste from primary systems predominantly consists of filters and components from systems that handle fuel transport casks. This waste amounts to about 300 kg per year with an activity content between 100 GBq and 30 TBq. Due to the level of radioactivity, it must be handled and packaged in a hot cell. The waste is placed in a mould and then transported out from the hot cell for casting in the mould. It is then handled the same as ion-exchange resins.

Other operational waste that arises in a controlled area consists of paint and chemical residues, batteries, radioactive preparations and smoke alarms. Waste that is not contaminated is cleared. Enclosed radiation sources are removed from their casing and deposited in moulds. The very few remaining amounts of waste are handled after sorting and categorisation in accordance with the details above.

5.2 Radiological risks to the environment

Sweden has a system for final disposal of spent nuclear fuel and radioactive waste, see Introduction, Figure 0-1. Management and final disposal of radioactive operational waste from Clab takes place within the Swedish system and thereby has no impact on any other country. Radioactive waste arising from the operation of Clab that cannot be cleared, is disposed of in near-surface repository or in SFR. Production of radioactive waste is minimised as well as adapted to existing disposal and clearance alternatives. Radioactive waste is sorted and deposited according to the limits established with respect to radioactivity for the near-surface repository at Simpevarp and SFR in Forsmark.

Waste containing radionuclides with a short half-life and with a surface dose rate below 0.5 mSv/h is disposed of in the near-surface repository on Simpevarp. This is operated under the ownership and licensing of OKG. It is designed with external and soil drainage. Drainage water that may arise is collected for sampling and purification, if applicable. The near-surface repository is required to be under institutional control for 30 years after the last deposition is made.

The final repository for short-lived, low- and intermediate-level waste (SFR) has been in operation since 1988. It is situated in the same area as the Forsmark nuclear power plant, see Figure 5-1. It is a hard rock facility consisting of four waste vaults and a silo located 60-140 metres beneath the seabed. Waste that does not meet the surface dose rate or half-life for final disposal requirements for storage in the near-surface repository is placed in SFR. This final repository has been tested and approved in accordance with current regulations for radiation safety and the environment. These tests have been conducted both on operation when waste is deposited and after final closure.

Analyses show that the radiation safety satisfies the criteria that apply for final repositories by a good margin (SKBdoc 1096063). The waste is transported enclosed in packaging with a transportation system specially developed and managed for radioactive waste and spent nuclear fuel.

Handling and deposition of waste from Clab is reviewed on an ongoing basis and minor adjustments are made. Areas with potential for improvement are reviewed and changes are implemented where relevant. This applies both to the limitation of the quantity of waste that is produced and to management and inspections.

5.3 Off-site arrangements for the transfer of waste

SKB has an agreement with OKG that entails that a large part of the management and certain disposal of radioactive waste is carried out by OKG. The surface dose rate of the waste is measured at Clab. Concrete embedment of liquid waste such as ion-exchange resins and filters is also carried out there. Low-level, combustible waste is sent by SKB's ship M/S Sigrid from Clab to Cyclife Sweden in Studsvik for incineration, see Figure 5-1. Once incinerated, the ash is sent back and is then handled in accordance with Section 5.1. OKG conducts nuclide-specific measurements of the waste and conditions and packages solid waste for final disposal. Short-lived, very low-level waste is disposed of in OKG's near-surface repository. Other radioactive waste that cannot be disposed of in near-surface repository is interim-stored at OKG before being transported by sea to SFR. This final repository and transportation system are owned and operated by SKB. All operational waste from Clab is owned by SKB, which thereby is responsible for its management and final disposal.

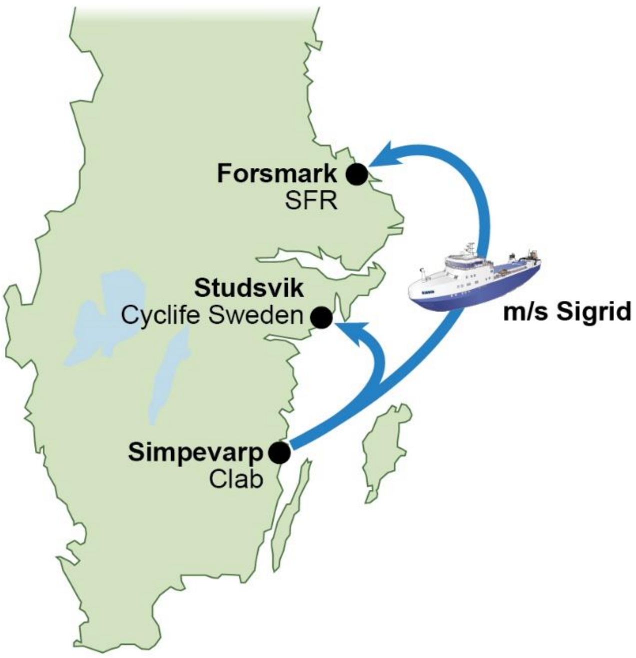


Figure 5-1. Geographical location of Cyclife Sweden and SFR in relation to Clab.

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

Clearance entails that the rules in the Radiation Protection Act (2018:396) need not be applied since the risks of radioactive contamination are so insignificant that they are regarded as negligible. The requirements for clearance concerning exemptions from the Radiation Protection Act and for clearance of materials, buildings and areas are specified in SSMFS 2018:3. The Swedish Radiation Safety Authority requires the operator to measure and document that radioactive contamination is below the limit values for clearance. Radioactive contaminants shall be removed if this can be done by simple means. Materials may be cleared directly by the operator. The clearance process is monitored by the Swedish Radiation Safety Authority in on-site inspection and review of the operators' governing documents and annual reports. Buildings and areas must be cleared from regulatory control if an activity involving ionising radiation is decommissioned or relocated. The regulatory authority decides on clearance. Materials, buildings and areas that cannot have been contaminated by radioactive substances do not need to be cleared. The operator applies to the Swedish Radiation Safety Authority for clearance from regulatory control. The authority then reviews the application and makes a decision. In most cases, the authority will conduct its own on-site measurements as a cross-check of the operator's application documentation.

The clearance level for radioactive contamination on an external material and, where appropriate, internal surfaces, calculated as a mean value over 0.03 square metres, is:

- for tritium, nickel-59 and nickel-63 a total of 40 MBq per square metre,
- for carbon-14, chlorine-36, iron-55 and technetium-99 a total of 4 MBq per square metre,
- for other beta- and gamma-emitting radionuclides, a total of 40 kBq per square metre, and
- for alpha-emitting radionuclides a total of 4 kBq per square metre.

For objects with a total area of less than 0.03 square metres, 0.03 square metres may be used as a condition for the mean value calculation. This also applies to personal items, tools and equipment that will continue to be used for their original purpose and that can only have been contaminated on the surfaces accessible for measurement. The clearance levels for the concentration of radioactive substances specified in SSMFS 2018:3 apply to oil that is handed over for incineration and other hazardous waste that is handed over for incineration or disposal. For routine operation of Clab, waste streams for clearance are small. In the event of changes to the facility, larger waste streams may arise for clearance. This means that the quantity and type of waste that is cleared varies from year to year depending on what changes are made to the facility. Examples from recent years are when a total of about 11 tonnes of metal, electronics, plaster and plastic were cleared in 2020 and a total of about 5 tonnes of metal, electronics and epoxy were cleared in 2019.

More details regarding clearance levels for different materials are presented in SSMFS 2018:3 and its appendices. SKB's management system (SKBdoc 1064139) governs the application of regulations on clearance for Clab.

6 Unplanned releases of radioactive effluents

According to SSM regulation SSMFS 2008:1, the capacity of the facility's barriers and defence-in-depth systems that exist to prevent radiological emergencies and mitigate the consequences should they nevertheless occur must be analysed using deterministic methods. The regulation also states that in addition to this deterministic analysis, the safety of the facility should be analysed using probabilistic methods in order to provide as comprehensive a picture of safety as possible. The current safety analysis report for Clab with 8,000 tonnes of stored nuclear fuel has been approved by the Swedish Radiation Safety Authority.

The major features of the work process for preparing the safety assessment are:

1. Inventory and selection of external events.
2. Mapping and event classification of internal events.
3. Identification of overarching events that cover other events within the analysis area.
4. Analysis of events/sequences within each analysis area according to the developed methodology:
    a. Handling incidents.
    b. Impact on cooling.
    c. Criticality.
    d. Flooding.
    e. Fire.
    f. Radiological impact on the surroundings.
5. Risk assessment of incidents.
6. Probabilistic safety assessment.

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

External events are caused by natural phenomena or human activities outside the facility. The identification of external events begins with a compilation of all potentially relevant events. The Swedish Radiation Safety Authority's regulations and IAEA standards (SKBdoc 1470546) provide guidance on identifying external events. External events are divided into air-based (A), ground-based (G) and water-based (W) events, which reflect their origin and facilitate mapping.

A selection has been made based on the compilation of external events to eliminate events without significant impact on the facility. The selection analysis (SKBdoc 1479102) is based on established and justified selection criteria that are generally accepted both with respect to simple external events and multiple external events. After the selection analysis, a number of events remained for detailed analysis with regard to their strength, frequency and uncertainties.

Internal events have been identified at different levels of detail according to the methodology that is based on international standard ISO 31010 (SKBdoc 1470552). Each event has been divided into event classifications based on the occurrence frequency of each event. This was done by systematically mapping the various errors that can give rise to an initiating event, i.e. an analysis on the component level, or by formulating a number of basic guidelines based on general assessments of the frequency of certain types of errors. The event classification of internal events is based on the methodology for this, see (SKBdoc 1470555).

In cases where studied, identified events and sequences had the same or a milder impact on the fuel cladding or pool integrity as another event or sequence, an analysis was performed for the initiating events that representatively or restrictively cover all other initiating events within each event class.

After review of all events that emerged while preparing the safety assessment, the events that can lead to unplanned discharges have been identified. These are handling incidents that in turn lead to an impact on/damage to fuel cladding or containers with radioactive material, as well as events that can affect cooling and in turn lead to boiling in storage or receiving pools (SKBdoc 1483954).

No initiating events related to criticality, fire or flooding and leading to radiological environmental consequences have been identified (SKBdoc 1483954).

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 specified a reference accident scenario as it is the licensee of the nuclear facility who is responsible for doing so. The Swedish Radiation Safety Authority reviews the accident scenarios described and handled in the licensee’s safety analysis report.

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

Due to the inventory increasing from 8,000 tonnes to 11,000 tonnes, events that could give radiological consequences to the surroundings have been analysed. The analyses show that the scenario that delivers the highest dose are events that lead to boiling in the storage pools. These events are classified as unlikely with a frequency of $10^{-4} > f \geq 10^{-6}$ per year.

The scenario of boiling in storage pools has been analysed conservatively and, with the increase in inventory, delivers a dose of 1.1 mSv to an adult who is assumed to be outdoors at a distance of one kilometre, and 0.4 mSv at a distance of two kilometres. This means that discharge does not lead to consequences outside the near vicinity, nor to exposure to a critical group outside the near vicinity. The borderline of the nearest Member State (Denmark) lies 260 kilometres away, see Table 1-1.

6.3.1 Accidents entailing releases to atmosphere

There are no specific calculation premises for a nuclear facility like Clab but SKB has applied the methodology developed for nuclear power plants for selected events in Clab (SKBdoc 1483954). The Swedish nuclear power plants have jointly developed the Methodology Handbook for Realistic Calculations (SKBdoc 1738417) based on the regulatory authorities’ calculation premises for nuclear power plants in (SSM 2009a, 2009b, 2009c). The Swedish Radiation Safety Authority states that both conservative and realistic calculations must be carried out. In addition, the methodology describes both the production of an external source term and how to carry out dispersion calculations (SSM 2009a, 2009b, 2009c). According to the Swedish Radiation Safety Authority, the licensee must apply the U.S. National Regulatory Commission (NRC) Regulatory Guide 1.183 for conservative analyses. When applying the methodology to Clab boiling events have only been analysed using conservative approaches.

The methodology for calculating release, discharge and dispersion of activity to the environment and its radiation dose consequence can be divided into several parts, see Figure 6-1.

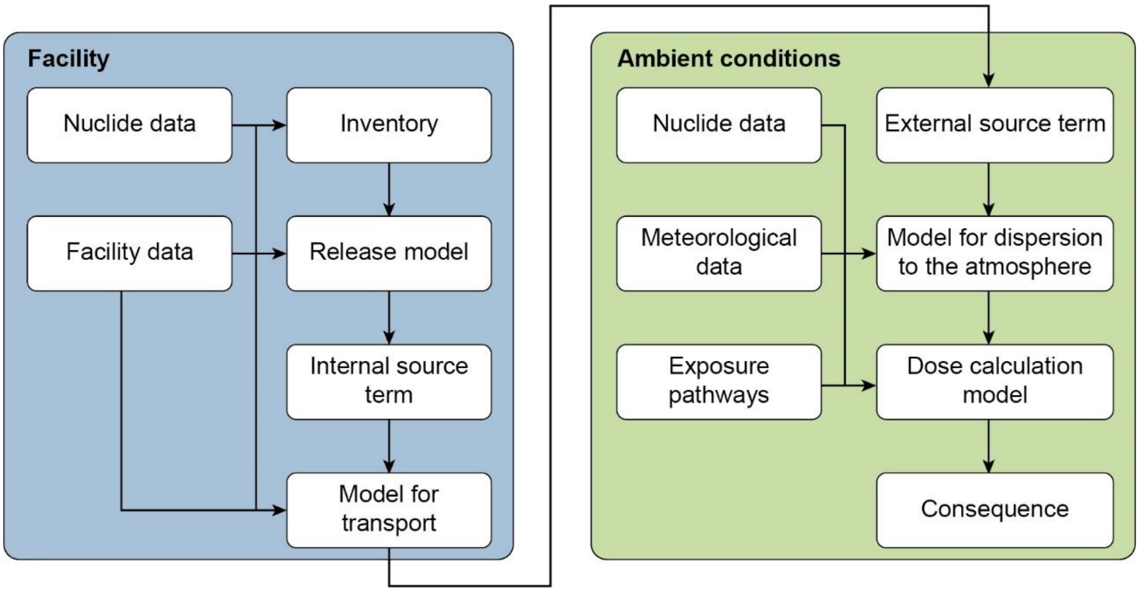


Figure 6-1. Overview of methodology for calculating release, discharge, activity dispersion and radiation dose (SKBdoc 1483954).

The dimensioning quantity of fuel in each section of the facility shall serve as the basis for the source term calculation and is specified in (SKBdoc 1865624). The basis for the environmental impact assessment is the activity inventory in the spent fuel and its structural materials and core components or in any of the facility's systems (e.g. a given pool's water phase), which is affected by the initiating event so that parts of the inventory are discharged from the fuel or system. This released amount is referred to as the *internal source term*. After release, the radioactive substances are transported further through the facility, whereupon they are affected by separation processes and decay. The amount of activity leaving the facility from a given discharge point for further transport to the surrounding environment is referred to as an *external source term*.

A calculation model for dispersion in the atmosphere, including precipitation on ground, is used for discharges to the environment. The results of this calculation, in the form of nuclide-specific activity concentration in air and the amount that has fallen to the ground, are used to calculate the consequence, the radiation dose, to a human being. The dose is specified for an adult who is outside the facility area. The methodology from the dispersion calculations for all events is taken from (SKBdoc 1483954).

The Gaussian dispersion model is used for both realistic and conservative calculations of the radiation dose during events in Clab, see Figure 6-2. The extent of the activity cloud and the radionuclide concentration in the air are modelled with a normal distribution horizontally (perpendicular to the wind), vertically and with the speed of the wind in the direction of spread.

The model does not take into account changes in wind direction or wind speed during the discharge period. The dispersion parameters in the horizontal and vertical planes have been determined experimentally and parameterisations, including Pasquill-Gifford (Clarke 1979), are available for different distances and weather types (Pasquill classes A-F). Consideration is given to the fact that the activity concentration increases when the plume is reflected from the ground and at the so-called inversion ceiling height, above which there is stable stratification and the vertical displacement of the air package is slowed.

The plume rise, which is dependent on e.g. the flow rate and heat content of the discharge, can be modelled. This can be done by correcting the discharge height, i.e. by applying an effective discharge height. However, in the analysis of accident scenarios involving discharge to air, no consideration is given to plume rise since the temperature difference between the discharge cloud and the surroundings is small.

Fallout of activity takes place by dry and/or wet deposition. This is modelled with the calculated concentration in air and parameters dependent on the chemical form of the radionuclides.

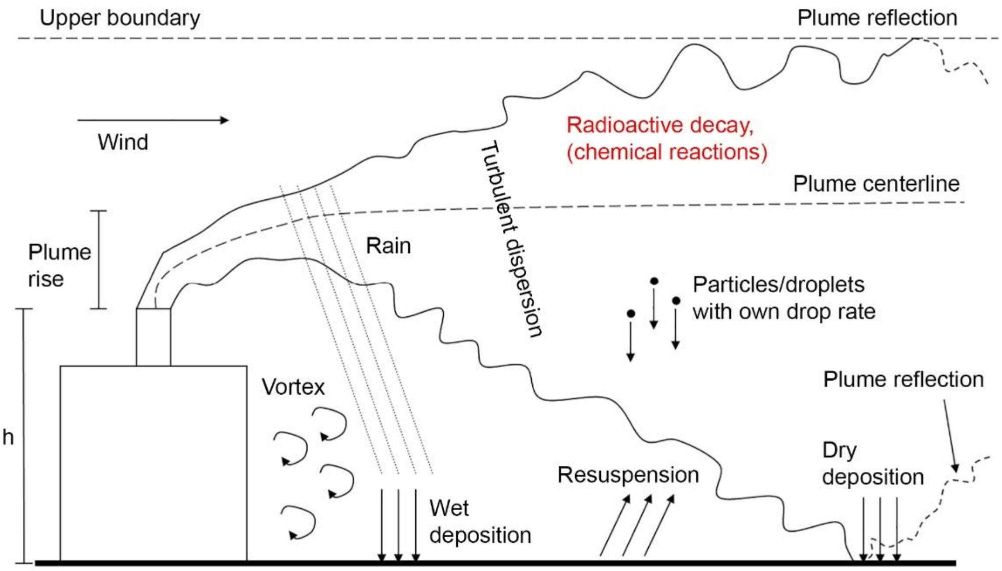


Figure 6-2. Processes that affect atmospheric dispersion (SKBdoc 1483954).

The Gaussian plume model described in (SKBdoc 1483954) is considered to apply to distances from 100 metres out to a maximum of 100 kilometres from the point of discharge. The parameter values are reliable up to a few tens of kilometres (Clarke 1979) and the uncertainty increases substantially in the model outside 30 kilometres.

Clab's main chimney is at a height of 36 metres above ground level. At discharge heights greater than 25 metres, the modelling assumes weather in class D, see Table 6-1. For events where the integrity of the surrounding building is assumed to be lost, the discharge to the surroundings is assumed to occur as a discharge to the ground and the discharge height is assumed to be 20 metres, which entails F-class weather.

Table 6-1. Specified weather conditions according to (SSM 2009a, 2009b, 2009c) to be used in both conservative and realistic environmental impact calculations.

	Discharge height	
	Lower than 25 m	**25 m or higher**
Wind speed (m/s)	2	3
Stability according to Pasquill classification (-)	F	D
Inversion ceiling height (m)	100	150

The discharge time is assumed to be one hour for both conservative and realistic analyses regarding handling mishaps in Clab. When calculating discharges from a boiling event, either a discharge time corresponding to the event's postulated duration (30 days in Clab) or a discharge time corresponding to the time it takes to boil off the water until one metre of water remains above the spent nuclear fuel. In the event of a total loss of cooling in storage pools, boiling only occurs after about one week. In the event of a total loss of cooling of the receiving pools, it takes just over three weeks. This means that the actual boiling time is shorter than the conservative 30 days the course of events is assumed to take from the initiating event.

According to U.S. NRC Regulatory Guide 1.183, the iodine discharged from the fuel is assumed to be 0.15% organoiodine. The remaining iodine is assumed to immediately dissolve into iodine ions (I^-) and then oxidise into elemental iodine (I_2). The final distribution of iodine discharged into the environment is thus 0.15% organoiodine and 99.85% elemental iodine.

In the conservative analysis, it is assumed that all crud on the fuel is discharged to the water phase when the pools boil. The activity that is dissolved in the pool water, consisting for the most part of radioactive nuclides from discharged fuel crud, is discharged to the air through binding with aerosols and steam containing tritium. Together with gaseous fission products, this activity follows the air out through the chimney, i.e. no deposition on system surfaces is assumed. Table 6-2 presents activity discharges for the two analysed boiling events, one in the storage section pools and one in the receiving section pools.

Table 6-2. Activity discharge for boiling events (SKBdoc 1888747).

Nuclide	**Storage section pools (720 h)**	**Receiving pools (720 h)**
	[Bq]	**[Bq]**
Mn-54	$1.1 \cdot 10^{12}$	$5.9 \cdot 10^{10}$
Fe-55	$4.9 \cdot 10^{13}$	$8.6 \cdot 10^{11}$
Co-58	$9.6 \cdot 10^{10}$	$2.3 \cdot 10^{10}$
Co-60	$9.7 \cdot 10^{13}$	$8.9 \cdot 10^{11}$
Ni-59	$1.5 \cdot 10^{11}$	$2.9 \cdot 10^{8}$
Ni-63	$2.0 \cdot 10^{13}$	$4.3 \cdot 10^{10}$
Pu-238	$2.6 \cdot 10^{9}$	$7.1 \cdot 10^{6}$
Pu-239	$3.8 \cdot 10^{8}$	$9.5 \cdot 10^{5}$
Pu-240	$6.5 \cdot 10^{8}$	$1.6 \cdot 10^{6}$
Pu-241	$2.9 \cdot 10^{10}$	$1.4 \cdot 10^{8}$
Am-241	$1.2 \cdot 10^{9}$	$9.8 \cdot 10^{5}$

Am-243	$3.0 \cdot 10^{7}$	$7.5 \cdot 10^{4}$
Cm-244	$1.3 \cdot 10^{9}$	$5.4 \cdot 10^{6}$
I-129	$5.3 \cdot 10^{7}$	$5.2 \cdot 10^{6}$
Cs-134	$2.3 \cdot 10^{10}$	$1.2 \cdot 10^{9}$
Cs-137	$1.5 \cdot 10^{11}$	$2.2 \cdot 10^{9}$
Sr-90	$9.8 \cdot 10^{8}$	$1.5 \cdot 10^{7}$
Kr-85	$5.8 \cdot 10^{12}$	$2.8 \cdot 10^{11}$
Ag-108m	$3.3 \cdot 10^{9}$	$2.0 \cdot 10^{7}$
Ag-110m	$5.7 \cdot 10^{8}$	$7.9 \cdot 10^{7}$
Sb-125	$2.2 \cdot 10^{9}$	$9.1 \cdot 10^{6}$
H-3	$4.8 \cdot 10^{10}$	$1.1 \cdot 10^{9}$

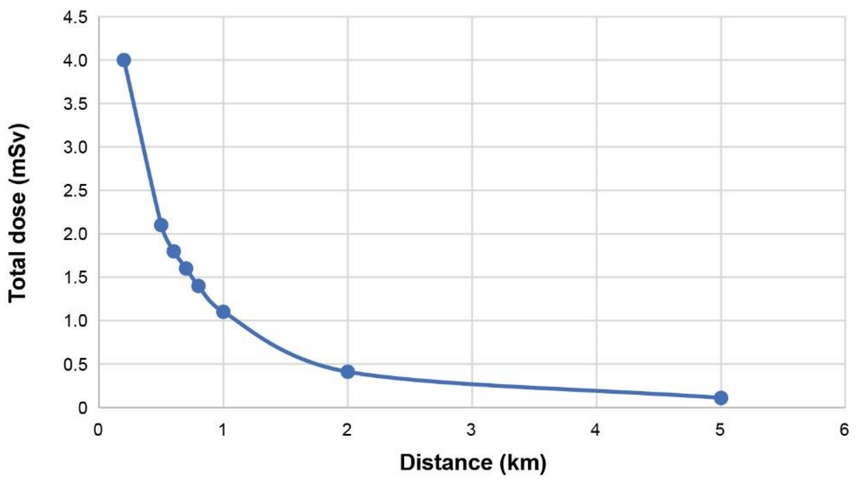
For calculating environmental consequences in the form of dose to a third party from events at Clab, three exposure pathways are included: external irradiation from the plume (cloud dose), from radioactive substances deposited on the ground (ground irradiation) and via the ingestion of radioactive substances via inhalation (inhalation). Radiation doses are calculated and reported for the range of 200 metres to 30 kilometres. Any decrease in the activity concentration in the air due to deposition is disregarded. This is a conservative assumption.

The ground dose is calculated up to 30 days after the start of the discharge. This time period has been chosen for historical reasons (previously completed environmental impact assessments at the nuclear power plants) and because different countermeasures cause difficulties in estimating the dose contribution from the ground for longer than 30 days. Examples of countermeasures include remaining indoors and evacuating.

The total effective dose to an adult assumed to be outdoors at different distances in the centre of the plume during plume passage where the concentration and fallout of activity can be expected to be highest is presented in Table 6-3.

Table 6-3. Dose during boiling in storage section pools, conservative case. (SKBdoc 1888747)

Distance	Dose Storage section pools (720 h)
[km]	[mSv]
0.2	4.0
0.5	2.1
0.6	1.8
0.7	1.6
0.8	1.4
1	1.1
2	0.41
5	0.11



The peak dose is obtained at a distance of 200 metres and it is the contribution from ground dose that dominates the total dose. For the storage section pools, the ground dose is 71%, the inhalation dose is 28% and the cloud dose is 1% of the total dose at all distances. The dose contribution from the different nuclides at a distance of 200 metres is illustrated in Figure 6-3, where it is evident that

Co-60 dominates the contribution to dose in the case of boiling in the storage section's pools, followed by Pu-238.

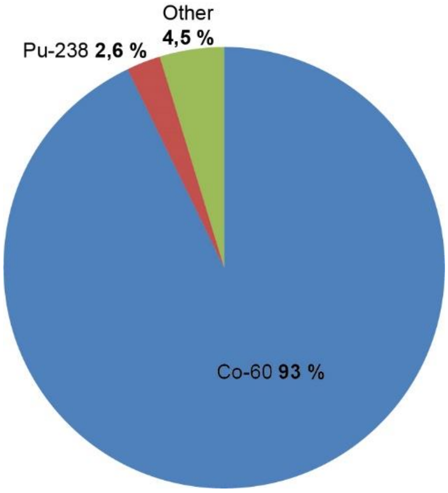


Figure 6-3. Percentage of dose to an adult resulting from the discharge of Co-60, Pu-238 and other nuclides from the storage section pools. Of the other nuclides, Pu-240, Am-241 and Cm-244 contribute approximately 1% each.

Results from analysing boiling in the receiving section's pools show consistently lower doses at all distances, with the highest dose (3.6 mSv) at a distance of 200 metres.

Boiling events have been classified as unlikely events with an acceptance criterion of 50 mSv (SKBdoc 1865660). The acceptance criterion is met for the events of boiling in the storage section's pools and boiling in the receiving section's pools. The calculations were done using conservative methods. Furthermore, boiling would be the event in Clab that gives rise to the highest dose, which is why it is reported.

6.3.2 Accidents entailing releases into an aquatic environment

No accidents have been identified that could lead to discharges into water that affect surrounding Member States.

7 Emergency plans, agreements with other Member States

Overall requirements for emergency preparedness are set out in Chapter 4, Section 2 of SSMFS 2018:1. The adapted defence-in-depth system must be able to control and/or limit discharge in radiological emergencies. In order to do this, there is a well-prepared crisis organisation in place, in accordance with detailed requirements in SSMFS 2014:2.

SKB has established instructions for the measures to be taken in the event of operational disturbances in accordance with SSMFS 2008:1. Clab is always staffed with operations personnel to deal with operational disturbances. For operational disturbances, or breakdowns, which develop into radiological emergencies, there are prepared contingency measures which are reported in the facility's contingency plan. The plan has been safety reviewed and reported to the Swedish Radiation Safety Authority.

Clab is classified as a contingency category 2 facility according to SSMFS 2018:1. This category refers to activities where there may be a radiological emergency in the area where the activities are carried out that may result in people outside the area being exposed to doses that warrant urgent measures to avoid deterministic health effects and limit the risk of stochastic health effects. However, current events are not deemed to have the potential to cause serious deterministic health effects outside the area where activities are conducted. In order to support or take over operational responsibility in the event of a radiological emergency, an organisation is constantly on standby. Contingency measures are described in the instructions included in the facility's contingency plan (SKBdoc 1064644). The plan and the organisation are regularly tested in realistic exercises. In a prolonged radiological emergency, other societal organisations will also contribute resources to manage the situation and mitigate the consequences of it.

7.1 Intervention levels

There are two intervention levels for information and alarming (SKBdoc 1064644):

- Information regarding near-accidents (low level of intervention).
- Area alarm (high level of intervention).

Information regarding near-accidents is a lower intervention level for an event or disturbance occurring at Clab resulting in serious injuries to personnel or the facility or imposing threats of serious injuries to personnel or the facility. No discharge of radioactive substances that require protective measures for the surroundings is expected. At this level, all or part of the crisis organisation's contingency management is called in to handle the incident. The authorities are informed to give them the opportunity to convene a small administrative staff. This lower intervention level provides the opportunity to act at an early stage of an abnormal event. The purpose of the lower intervention level is to facilitate decisions on convening additional parts of the crisis organisation and to provide authorities with information regarding the uncertainty or whether there is a risk that a minor event may progress into a worse situation. Depending on which event has occurred, it is handled in accordance with the action list that is relevant for the situation in question and in accordance with the applicable instruction.

Area alarms are a higher intervention level for an event or disturbance occurring at Clab that threatens the safety of the surrounding area. The threat entails that the facility's disrupted operations have deviated from the expected function, entailing a risk to the surrounding area. The facility may also have been impacted by factors whose consequences have not been analysed or for some other reason are not clearly visible and for which the safety of the surroundings cannot be guaranteed. Discharges of radioactive substances that require protective measures for the surrounding area cannot be excluded. In the event of an area alarm, the Clab crisis organisation is summoned and the County Administrative Board in Kalmar County and SSM are notified within one hour. Sirens warning of immediate danger are sounded indoors and outdoors, and the general public is notified outside the power plant area via sirens, RDS and Radio Sweden.

7.2 Events at OKG

For events at OKG, the nuclear power plant is responsible for sounding the alarm and providing information on the Simpevarp Peninsula, as well as providing information to authorities and media. In the event of a serious incident at OKG resulting in an evacuation order, the on-duty shift supervisor or area manager at Clab decides whether all or only certain personnel should evacuate. This is based on a risk assessment. OKG is responsible for executing evacuation of the peninsula.

Both Clab's and OKG's contingency plans contain information on contact routes between the two organisations' contingency management teams.

7.3 International arrangements

Sweden has signed international and bilateral agreements at a national and official level regarding early notification and subsequent information in the event of a nuclear accident. SMHI, which is staffed around the clock, receives notifications of accidents in other countries. SSM is also staffed around the clock and is responsible for passing on the information nationally and also for sending information to other countries in the event of an accident in Sweden. The most important agreements are:

- The binding European Community Urgent Radiological Information Exchange (ECURIE) requires that notification be given if measures are being taken to protect the national population.
- Bilateral national agreements with Norway, Denmark, Finland, Germany, Russia and Ukraine on accident warnings.
- IAEA Convention EMERCON emergency warning system for cases in which another country may be affected by discharge.

7.4 Contingency and planning zones

The government has decided on new contingency and planning zones to be implemented by 1 July 2022 at the latest. A planning zone with a radius of about two kilometres will be introduced around Clab. The basis for this is a selection of design-basis events and the consequences calculated for these (SSM 2017). This work has been carried out by the Swedish Radiation Safety Authority in consultation with the Kalmar County Administrative Board and the Swedish Civil Contingencies Agency. Within the planning zone, there must be preparations for evacuation based on data from radiation measurements of the ground surface. Radiation doses cannot arise around Clab in conjunction with accidents that warrant a contingency zone. Work is under way between SKB and the Administrative Board of Kalmar County to implement the planning zone.

8 Environmental monitoring

The environmental monitoring at Simpevarp peninsula and its surroundings is operated by OKG. The purpose of the radiological environmental monitoring programme is to examine the impact on the environment on account of the operation of Clab. At Simpevarp, the activities at reactor O3 and activities related to dismantling and demolition of O1 and O2 are also included in the programme since OKG and Clab are both located at the Simpevarp peninsula. The levels of radionuclides in the vicinity of Clab are monitored, as a complement to measurements of the discharges to air and water. The monitoring programme also detects larger unregistered discharges. Long term monitoring of radionuclides in the environment produces basic data enabling estimation of potential effects on biological life in the recipient. The results can be used for informing the public and as a basis for international reporting and other collaboration in the environmental area.

The Swedish Radiation Safety Authority (SSM) requires nuclear facilities to monitor the environment in accordance with a programme specified by the authority in the regulation on Protection of Human Health and the Environment in connection with Discharges of Radioactive Substances from certain Nuclear Facilities, SSMFS 2008:23 Section 20. At present the SSI (the former Swedish Radiation Protection Authority) report 2004:15 describes the content of the environmental monitoring programme for the four nuclear power plants in Sweden, as well as nuclear activities in Studsvik and the fuel fabrication facility in Västerås. The main focus is on biota, but also water, atmospheric precipitation, digested sludge and sediments are included. The report was revised in 2005.

SSI 2004:15 defines selection of samples and their locations, preparation, analyses, evaluation and reporting. The samples include e.g. moss, apples, seabed sediment, close-by manufactured milk, fish and meat, and the samples are analysed by nuclide specific gamma spectroscopy using High Purity Germanium detectors (HPGe). The main radionuclides are Cs-137 and Co-60 as well as naturally occurring radionuclides, mainly K-40. The activity levels and the detection limits of specified radionuclides are reported to SSM. Sampling is performed by the Swedish University of Agricultural Sciences (SLU). Sample preparation and analyses are performed at the OKG environmental laboratory, in accordance with the guidelines developed by SSM for environmental monitoring. Meteorological data are continuously recorded.

The monitoring programme consists of two different parts: one annual and one extended investigation every fourth year. The annual programme makes it possible to detect changes in the environment in the short-time interval and to detect trends on a longer time-scale. The extended investigations give more correct long-term results and also cover a wider geographic area. The sampling locations are shown in Figure 8-1.

To ensure the quality of the measurements, inter-calibrations are performed on an annual basis for radiochemical analyses at OKG, together with other nuclear power plants in Sweden and Finland as well as other organisations involved in radiochemistry. Audits and follow-up of sampling and results are also performed by SSM.

There are 25 area dosimeters that are evaluated on a quarterly basis. On the Simpevarp peninsula there are 25 area thermoluminescent dosimeters (TLD) that are used to measure beta and gamma radiation. The dosimeters are placed on various distances from Clab and the nuclear power plant. Some of the dosimeters fulfil the SSMFS 2008:23 section 22 requirement to continuously monitor gamma radiation in the vicinity of the facility.

On site there are also nine dose rate meters in the so called Skylink system that continuously measure the dose rate at various location close on the Simpevarp peninsula. Two units are mobile and can be placed where needed. The instruments consist of two Geiger-Müller (GM) tubes and are designed to be able to measure low dose rates (>20 nSv/h) at normal operation as well as elevated dose rates (<10 mSv/h) at accident conditions. The measurements are checked twice a week as part of the normal routines in the emergency preparedness organisation.

SSM also has a regional measuring system that consists of permanent measuring stations around nuclear power plants that is in operation since 2017. The system consists of 20 measuring stations (GM-tubes). The purpose of this system is to detect and follow-up large emissions during accident or a large failure condition.

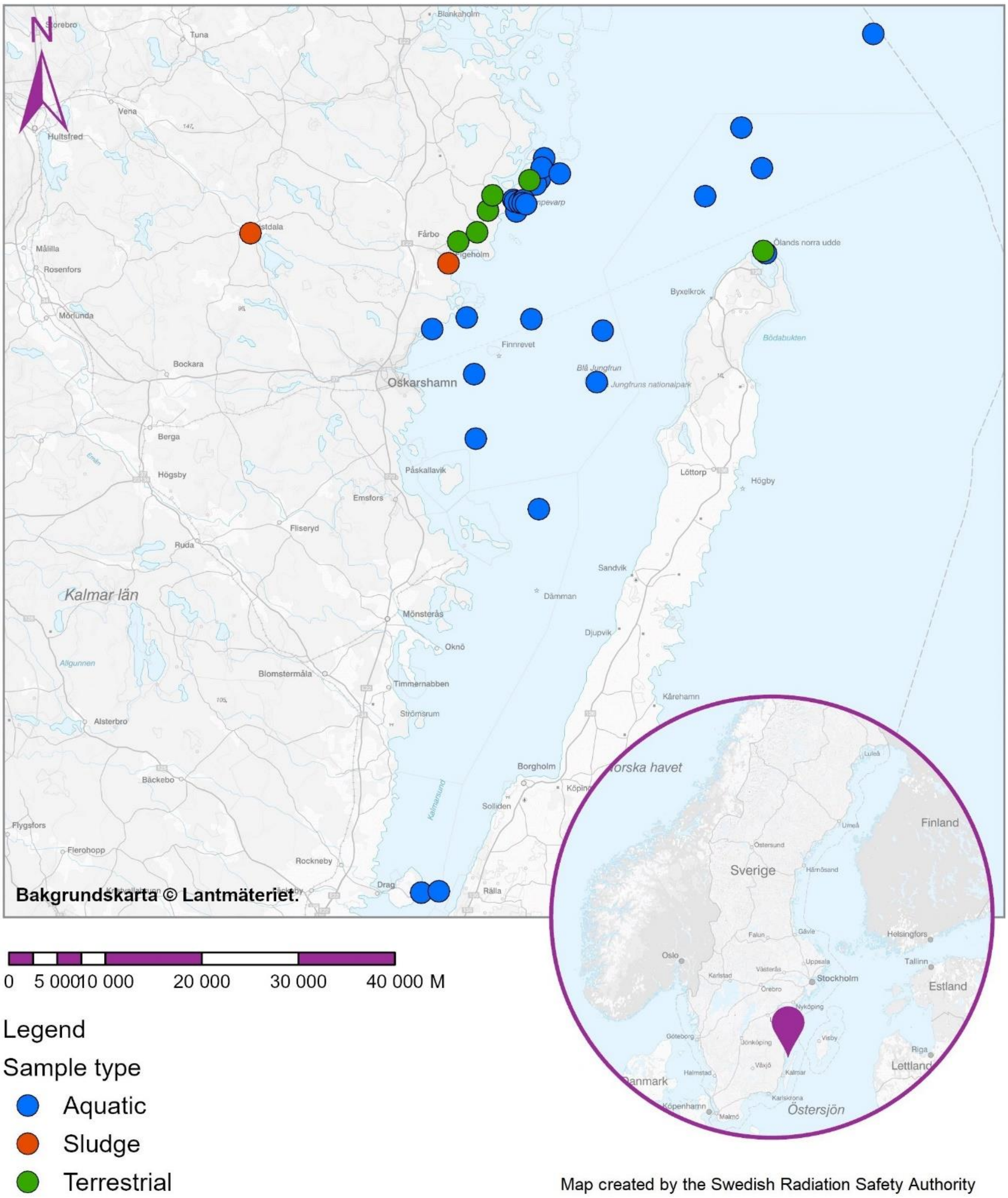


Figure 8-1. Sampling stations in the vicinity of Simpevarp in the environmental monitoring programme, both on land and in water.

The surveillance programme is in general divided in two sampling periods; spring (1 April to 1 June) and autumn (1 September to 31 October), see Table 8-1 and Table 8-2. The samples for the extended investigation performed every fourth year are collected in the spring period see Table 8-3.

Table 8–1. Sampling on land.

	Sampling period	
Sample	**Spring**	**Autumn**
Natural vegetation		
Haircap moss	X	X
Reindeer lichen		X
Spruce sprout		X
Cultured vegetation		
Lettuce (in July)		X
Pasture		X
Threshed grain		X
Fruit (apple)		X
Berries (redcurrant)		X
Animal samples		
Cattle (beef)		X
Milk (every second week)	X	X
Sludge, sewage plant		
Ankarsrum		X
Figeholm		X
Kristdala		X

In recent years there have been problems with access to cattle and threshed grain since there are no farms with these kinds of production nearby anymore. The sludge from Kristdala has been sent to

Oskarshamn because the station is normally unmanned. Milk is analysed every other week when the cows are outside.

Table 8–2. Sampling in water.

	Sampling period	
Sample	**Spring**	**Autumn**
Sediment		X
Algae		
Biofouling samples (once a month)	X	X
Bladder wrack		X
Molluscs		
Theodoxus		X
Common sea mussel		X
Baltic sea clam		X
Fish		
Yellow eel	X	X
Baltic flounder	X	X
Baltic herring		X
Pike	X	X
Perch	X	X

There are alternative species for some of the sample types in case it is difficult to catch specimens with the correct size in the specific position.

Table 8-3. Sampling in extended investigation.

Sample	Sampling period spring
Algae	
Green algae (Cladophora glomerata)	X
Bladderwrack	X
Molluscs	
Theodoxus	X
Common sea mussel	X
Baltic sea clam	X
Sediment	X

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Appendix 1 – Abbreviations

ALARA	As low as reasonably achievable, optimization of radiation protection.
Bq	Becquerel. Unit for radioactive decay.
BAT	Best available technology.
BWR	Boiling water reactor.
Clab	Central interim storage facility for spent nuclear fuel.
ECURIE	European Community Urgent Radiological Information Exchange.
EMEC	Earthquake catalogue.
EMERCON	IAEA Emergency Convention.
FENCAT	Earthquake catalogue.
E1, E2, E3, E4	Event class 1-4.
HEPA	High efficiency particulate arresting (filter).
HPGe	High Purity Germanium.
IAEA	International Atomic Energy Agency.
ICRP	International Commission on Radiological Protection.
INES	International Nuclear Event Scale.
EIA	Environmental impact assessment.
OKG	OKG Aktiebolag, owner of Oskarshamn nuclear power plant.
O1, O2, O3	Oskarshamn nuclear reactors 1, 2 and 3.
PGA	Peak Ground Acceleration.
PSAR	Preliminary safety analysis report.
PWR	Pressurised water reactor.
SAR	Safety analysis report.
RDS	Radio Data System.
SFR	Final repository for short-lived radioactive waste.
SFS	Swedish code of statutes.
SLU	Swedish University of Agricultural Sciences.
SKB	Svensk Kärnbränslehantering AB. Swedish nuclear fuel and waste management co.
SMHI	Swedish Meteorological and Hydrological Institute.
SNSN	Swedish national seismic network.
SSM	The Swedish Radiation Safety Authority.
SSMFS	The Swedish Radiation Safety Authority's code of statutes.
STF	Safety-related technical specifications.

TMB Transscandinavian magmatic belt.

Sv Sievert, unit for radiation dose. mSv millisievert 10^{-3} Sv. μSv microsievert 10^{-6} Sv.

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

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