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Swedish Radiation Safety Authority

Report

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

Oskarshamn Very Low-level Radioactive Waste Disposal Facility, MLA3, Sweden

2023:10

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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, OKG AB. 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 recommendation of the European Commission of 11 October 2010 on the application of Article 37 of the Euratom Treaty (2010/635/Euratom) requires each member state to provide the Commission with general data related to nuclear activities, as for instance construction and operation of nuclear waste repositories. The purpose is to make it possible to determine whether the implementation of the activities is likely to result in radioactive contamination of the water, soil or air of another member state.

This report describes the consequences of construction and operation of a near surface disposal facility (landfill) for very low-level radioactive waste (MLA3) at the Oskarshamn Nuclear Power Plant. The total amount of waste will amount to a maximum of 18,000 m3. The repository is planned to receive waste from decommissioning of the two nuclear reactors Oskarshamn 1 and 2 as well as waste from the operation of the reactor Oskarshamn 3. In addition to waste from OKG, waste generated during the operation of the interim storage facility for spent nuclear fuel (Clab) and waste generated from the decommissioning of two nuclear reactors in Barsebäck in the south of Sweden is planned to be disposed of at MLA3.

The presented information regarding radioactive discharges to air or water at normal operation of the landfill, at unplanned events and accidents as well as during the post-closure period indicate that there will be no releases that will give measurable dose levels in other member states.

Discharges to water via leachate are assessed to be the dominant pathway for spreading of nuclides and gives the highest dose contribution. Radiological discharges to air are not expected to occur due to the dense construction of the repository cap and the characteristics of the deposited waste.

The dose to the individual of the public most likely receiving the highest dose, due to expected releases from the facility is estimated to be less than 1.3 nanosievert per year (nSv/y). The dose to the individual of the public most likely receiving the highest dose due to unexpected events, such as degraded technical barriers and fire, is calculated to be less than 1 microsievert per year (μSv/y). In the event that a drinking water well is established in the vicinity of the facility, or in the case that contaminated soil is used for agricultural purposes the doses are estimated to be up to 2 μSv/y.

If the assessed maximum exposure levels from discharges during normal conditions to adults, children and infants in the vicinity of the facility are below 0.01 mSv per year and there are no exceptional pathways of exposure, e.g. involving the export of foodstuff, no data on effective dose in other affected member states are required. The doses to a person of the public most likely to receive the highest dose are well below the specified limits. Any data on effective dose in other affected member states are therefore not required.

Data and models used for the calculations have been chosen to ensure that the results are not underestimating the discharges and doses.

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1. Introduction

The purpose of this report is to provide the Commission with general data regarding the construction and operation of a near surface disposal facility (landfill) for very low-level radioactive waste at the Oskarshamn's Nuclear Power Plant (NPP). The document aims to determine whether the implementation of the plans is liable to result in radioactive contamination of the water, soil or air of another European Union Member state. The report follows the guideline in Annex 4 of the Article 37 of the Euratom Treaty (2010/635/Euratom) [1].

Construction and operation of a nuclear facility such as a landfill for very low-level active waste in Sweden requires license by the Swedish regulatory body SSM (Swedish Radiation Safety Authority) and the Land and Environmental Court. An application in accordance with required legislation and procedures is currently under audit by the responsible authorities.

The most common definitions and abbreviations used in this report are given in appendix 1.

1.1. Oskarshamn Nuclear Power Plant and current Landfills

The Oskarshamn nuclear power plant is owned and operated by OKG AB which is also the holder of the nuclear licence to operate a current landfills for very low-level radioactive waste on the Oskarshamn industrial site. OKG AB is jointly owned by Uniper which owns 54.5 % and Fortum which owns 45.5 % of the company.

Oskarshamn NPP is located in southern Sweden, on the east coast approximately 350 km south of Stockholm and about 20 km north of the town of Oskarshamn with approximately 20,000 inhabitants. The NPP has three boiling water reactors, BWR, which are designed and constructed by ASEA-ATOM. Oskarshamn 1 (492 MWe) operated during 1972-2017 and Oskarshamn 2 (661 MWe) operated during 1974-2015. The third and largest reactor Oskarshamn 3 (1450 MWe) commenced operation in 1985 and is planned to continue its operation until 2045.

The nuclear reactors Oskarshamn 1 (O1) and Oskarshamn 2 (O2) have been taken out of service and are currently subject to decommissioning[1]. During the ongoing dismantling and demolition period, which plans to proceed until 2028, radioactive waste with different characteristics will be produced. An overview of the Swedish system for handling of spent fuel and different kinds of nuclear waste is given in this section of the report. Some of the very low-level radioactive waste appearing during decommissioning is planned to be disposed in the new landfill.

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[1] General data in accordance with Article 37 of the Euratom Treaty regarding decommissioning of the reactors O1 and O2 have been submitted to the European Union in June 2017. For the Commission Opinion of the plan, see Eur-lex (2017/C 413/01) (Dec 4th, 2017).

At the Oskarshamn NPP site, there are at present two landfills for very low-level waste. The first stage (MLA1) was operating between 1986-1999 and contains about 5,200 m^3 waste. The second stage (MLA2) was put into operation in 2004 and a final disposal campaign was carried out in 2020. The total volume of waste deposited in MLA2 is approximately 7,500 m^3. The waste deposited in MLA1 and MLA2 originates from the operation of the three reactors O1, O2 and O3 and from the central intermediate storage for spent nuclear fuel (Clab), which is also located at the Oskarshamn industrial site. Both MLA1 and MLA2 are closed.

1.2. New Landfill (MLA3)

This report concerns a third, independent landfill called MLA3. The total amount of waste that is planned to be added to the landfill within the framework of the new permit will amount to a maximum of 18,000 m^3. Unlike previous land repositories MLA1 and MLA2, MLA3 is mainly expected to contain waste generated from the demolition of decommissioned NPP´s.

In addition to receive waste generated at the site, MLA3 it is also planned to receive and dispose waste from two decommissioned reactors on the NPP site at Barsebäck[2]. Barsebäck is located in the far south of Sweden and the reactors there have been shut down since 1999 and 2005 respectively. The Barsebäck nuclear company is fully owned by Uniper, hence it has the same owner as the OKG. The waste generated at Barsebäck is expected to be of similar type as the waste from OKG.

In MLA3, about 12,000 m^3 of the waste will originate from demolition of decommissioned NPP´s (about 7,000 m^3 from O1 and O2 in Oskarshamn and about 5,000 m^3 from demolition of the two nuclear reactors B1 and B2 in Barsebäck). The remaining quantities originate from the operation of Oskarshamn 3 and Clab.

1.3. Legal conditions for the management of nuclear waste

According to Swedish legislation, the license holders of the nuclear power plants have the technical and financial responsibility for the management and disposal of the low and intermediate level nuclear waste generated during operation as well as the spent nuclear fuel. The license holders are also responsible for the decommissioning of the nuclear facilities. Since the mid-1970s the nuclear power companies have been allocating funds to cover the costs associated to the management of spent nuclear fuel, nuclear waste from decommissioning and the decommissioning of the nuclear facilities. These funds are administered by the Nuclear Waste Fund.

Sweden has developed a system for the disposal of spent nuclear fuel and other nuclear waste. To facilitate this work, the nuclear power companies have formed

[2] General data in accordance with Article 37 of the Euratom Treaty regarding decommissioning of the Barsebäck nuclear power plant have been submitted to the European Union in May 2019. For the Commission Opinion of the plan, see Eur-lex (2019/C 351/02) (Oct 14th, 2019).

the company SKB (Swedish Nuclear Fuel and Waste Management Company), which is responsible for the development and operations for the final management for the spent nuclear fuel, including the interim storage and encapsulation plant, as well as the geological repositories for low and intermediate level waste. SKB is also responsible for the transportation of the waste and fuel to its facilities. The waste handling chain is shown schematically in Figure 1 below.

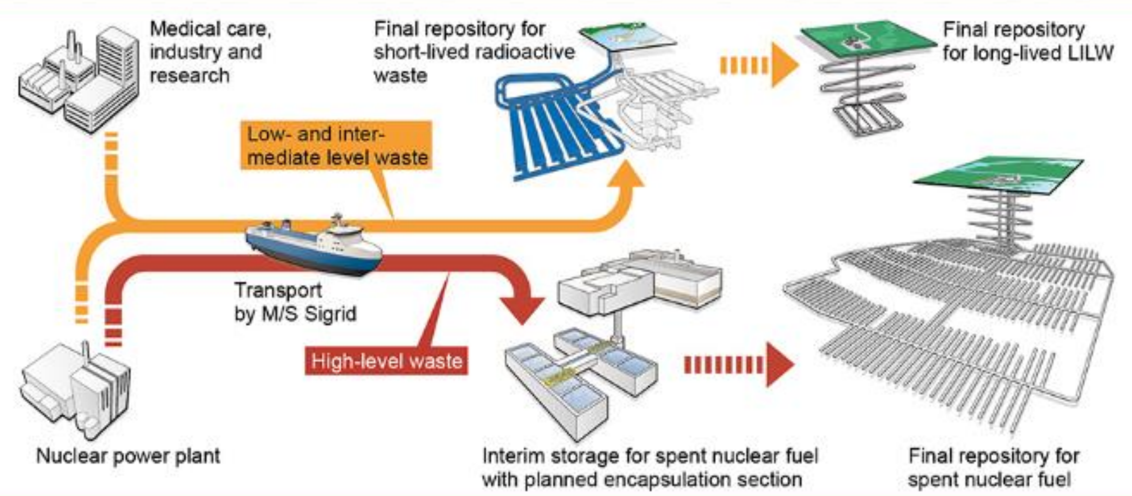


Figure 1. SKB's system for dealing with Swedish high-, intermediate- and low-level radio-active waste. The facilities indicated by dotted arrows have not yet been licensed or built. LILW = Low and Intermediate Level Waste.

The figure above does not include disposal of very low-level radioactive waste (VLLW). Such waste, generated from operation of nuclear power plants, is cur-rently being disposed of in landfills belonging to, and operated by, the three NPP's currently in operation. Barsebäck NPP has no landfill.

Other permitted options for handling of very low-level waste includes:

- Disposal in a geological repository for short-lived low and intermediate level waste (SFR), see Figure 1. License to expand the SFR has been granted to be able to receive decommissioning waste from the Swedish NPP's. The extended repository not expected to be in operation until 2029.
- Off-site treatment for volume reduction or clearance.
- Clearance. Clearance of materials, either directly or after treatment.

1.4. Licensing procedure for nuclear facilities

In order to receive the required licenses for construction and operation of a land-fill for very low level active waste, two licensing processes are run in parallel; one application has been submitted to the Swedish Radiation Safety Authority (SSM) and one to the Land and Environmental Court.

1.5. Swedish Radiation Safety Authority - SSM

The Swedish Radiation Safety Authority (SSM) reports to the Ministry of the Environment and has a mandate from the Swedish Government within the areas of nuclear safety, radiation protection and nuclear non-proliferation.

The authority works proactively and preventively in order to protect people and the environment from the undesirable effects of ionizing and non-ionizing radiation. SSM has developed regulations (SSMFS) to give a more detailed framework for e.g. nuclear facilities.

SSM is the responsible supervisory authority regarding the permit procedure and daily operation of facilities for the disposal of radioactive waste. The authority establishes, among other things, radiation protection conditions that the license holder must comply.

No radiation protection conditions have yet been established for MLA3, as the facility does not yet have a license. The application in accordance with The Act on Nuclear Activities (which SSM handles) has been submitted in autumn 2021. However, MLA3 is expected to receive similar radiation protection conditions as the previous repository MLA2.

In general, in order to receive a permit for the construction of a nuclear facility, a safety analysis report (SAR) must be approved by SSM. The requirement to have an approved SAR is found in SSMFS 2008:1 [2], which is part of the Swedish Radiation Safety Authority regulations. The regulations in SSMFS 2008:1 apply to measures required to maintain safety in connection with the construction, possession and operation of nuclear facilities with the aim of, as far as reasonably achievable, taking into account the best available technology, preventing radiological accidents and preventing the unlawful handling of nuclear material and nuclear waste. The regulations comprise provisions on technical, organisational and administrative measures.

However, the regulatory requirement according to SSMFS 2008:1 exclude landfills, hence there is no requirement to produce a SAR for the construction and operation of the MLA3. However, as a license condition, a technical description of the construction is expected to be required prior to the construction

1.6. Environmental impact assessment

According to the requirements in the Environmental Code, an Environmental Impact Statement (EIS) should be produced and submitted with the license application. These requirements are also applicable when applying for a license for a nuclear waste facility according to the Act on Nuclear Activities.

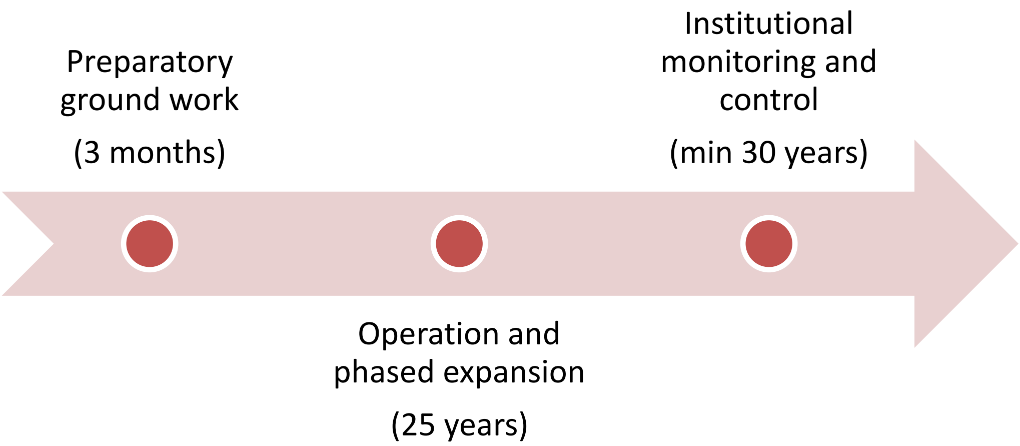
Early in the Environmental assessment process a hearing is held involving the authorities, neighbours and other stakeholders. The EIS describes the direct and indirect impact of the planned activity. The EIS includes a site description of the plant or activity as well as descriptions of the technology that will be used, considering the best available technique (BAT). Different alternatives for both these aspects are compulsory. The EIS also describes the impact on people, animals, plants, land, water, air, climate, landscape and the cultural environment. Furthermore, it describes the impact on the management of land, water and the physical environment in general, as well as on the management of materials, natural resources and energy.

The Swedish Environmental Protection Agency, Swedish EPA, the County Administrative Board (CAB), the local Environmental and Public Health Committee and the SSM are also consulted later in the licensing procedure and are given the opportunity to propose conditions.

1.7. Time plan

Preparatory work for the construction of MLA3 may begin as soon as all permits are in place and is expected to take a few months. A hearing was held at the Land and environment Court in May 2023. On June the 21st the Court issued a license and license conditions according to the Environmental Code. The Court notices that a license according to the Nuclear Activities Act is needed before any disposal of waste in the repository can be conducted.

The repository will be expanded in stages during the operating period. The number of sub-stages/campaigns is difficult to anticipate as it depends on the time periods in which what type of waste is generated and in what amount. The operating time is planned to be approximately 25 years. Control of the facility from a radiological and conventional perspective is proposed to last for at least 30 years after the last disposal campaign. At that time, it is expected that the control and monitoring due to the content of radioactive substances in the waste can be ended.



2. The site and its surroundings

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

The Oskarshamn NPP is located on the east coast in the southern part of Sweden, see Figures 2 and 3.

Figure 2. Location of Oskarshamn NPP (Bing Maps).

Oskarshamn NPP is not located at a close distance to any other member state; the nearest one is Denmark with a distance of 300 km. The distance to the closest neighbouring member states, see Table 1.

Table 1. Oskarshamn NPP neighbouring states.

Nation	Distance to border (km)	Metropolitan area	Population (millions)	Distance to metropolitan area (km)
Denmark	300	Copenhagen	2.0	320
Latvia	320	Riga	1.0	500
Estonia	380	Tallinn	0.6	520
Germany	350	Berlin-Bran-denburg	5.9	540
Finland	360	Helsinki	1.1	560
Lithuania	370	Vilnius	0.6	580
Poland	350	Warsaw	2.7	600

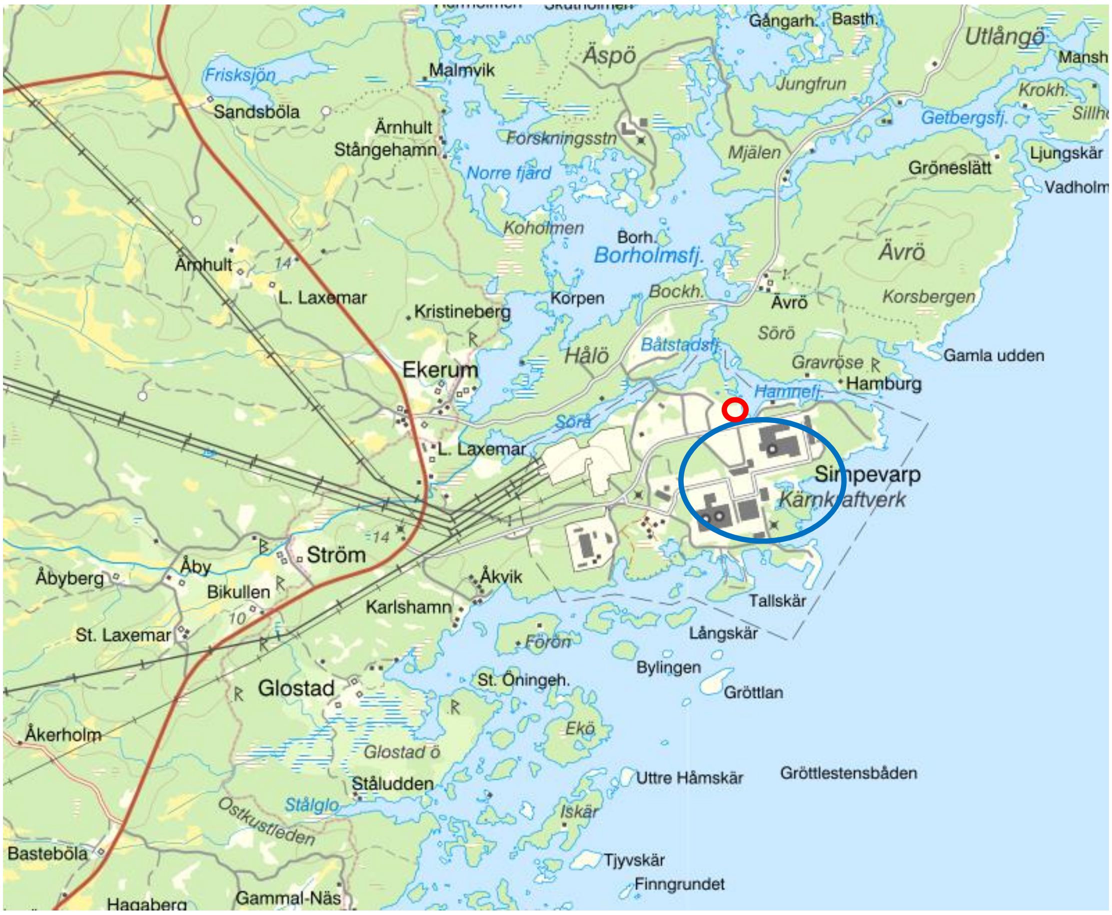


Figure 3. The Oskarshamn Nuclear Power Plant site. The reactors O1, O2 and O3 are circled in blue. Location of current and planned land repositories are marked in red.

The Nuclear Power Plant (NPP) is located by the Baltic Sea in the municipality of Oskarshamn on a peninsula called Simpevarp, 8 km northeast of the village of Figeholm and 20 km north-east of the town of Oskarshamn, the coordinates of which are 57°25'N 16°40'E according to WGS84 (the World Geodetic System 1984).

The landfill is situated within the northern part of the NPP industrial site, see the red circle in Figure 3. On site are the two filled and finally covered land repositories MLA1 and MLA2. The landfill, MLA3, is planned to be located about 50 metres west of MLA2 (see Figure 4), and at a distance of about 150 metres from the nearest water recipient, Hamnefjärden.

The foundation level of the repository is planned at about +4,5–6 m (height system RH2000).

Figure 4. Location of current and planned land repositories.

Other nearby installations are:

Oskarshamn 3, a boiling water type reactor which is currently in operation. The reactor has an electric power of 1,450 MWe. Oskarshamn 3 is situated on the Simpevarp peninsula approximately 400 metres south-east of MLA.

Oskarshamn 1 and 2, two boiling water type reactors currently taken out of operation and subject to ongoing decommissioning. O1 was in operation between the years 1972 and 2017 and had an electric power of 492 MWe. O2 was in operation between the years 1974 and 2015 and had an electric power of 661 MWe. O1 and O2 are situated on the Simpevarp peninsula approximately 600 metres south of the landfill site.

The Central Interim Storage Facility for Spent Nuclear Fuel (Clab) is situated about 1 km southwest of Oskarshamn 1 and 2. Clab is owned and operated by SKB.

2.2. Geology and seismology

The soils in the area are thin and therefore exposed rock is very widespread on the surface. The surface of the rock has eroded and been reshaped by the glacial ice. Moraine is the most common type of soil. The height differences within the NPP industrial area are small. Large areas around the site have been greatly changed by blasting, excavation, filling or other forms of foundation work, as is also the case in the MLA area of the site. The Simpevarp peninsula is dominated by two different categories of bedrock. One type of bedrock is a granite type called “Smålandsgranit”. The other type is Dioritoid, a metamorphic volcanic type that consists of different small rock granule that varies in colour from grey to grey black. The rock Dioritoid has often been recrystallized to a more granite like rock. This is especially valid for the bedrock at Simpevarp, see Figure 5. The bedrock at Simpevarp differs from the surrounding areas which are mostly granite. The bedrock in the area was created approximately 1,800 million years ago from volcanic activity.

Figure 5. The types of bedrock and deformation zones. Green areas consist of Dioritoid and red consist of Smålandsgranit. The deformation zones are given in red lines or black dashed lines (figure from OKG report 2010-07329 [4]).

Seismic activity is very low in Sweden, relative to other parts of the world. Sweden is located deep within the Eurasian lithosphere plate, earthquakes with a higher magnitude are thus extremely rare. Micro-earthquakes occur every day, but they are so weak that they are not noticeable. In about every ten years, an earthquake that reaches magnitude 4.0 occurs. Most earthquakes in Sweden are caused by isostasy after the last ice age. The strongest earthquake in modern times in the

Nordic countries and in Sweden occurred in 1904 off the Koster Islands. It reached 6.0 on the Richter scale and was felt over large parts of southern and central Sweden. [3]

Surface processes such as landslides and erosion are not very common on the Swedish east coast. According to [5], about five percent of Sweden's land area consists of clay and silt soils. A quarter of these soils, mainly clay soil, are estimated to be prone to landslides.

As shown in Figure 6 below, landslides or ravines have not occurred in Oskarshamn area, according to the responsible authority (the Swedish Geological Survey, SGU).

Figure 6. Traces of occurred landslides and ravines in loose soil layers. Analysis based on detailed height data and information from SGU soil databases. SGU, 2021. [6]

The local soil type in the MLA area has also been studied in a geotechnical survey, carried out as a basis for the environmental permit application for MLA3. The top soil layer consists of filling, underlain by moraine on rock. Samples of the fill have been taken to a depth of 1.5 m in test pits and the fill consists predominantly of sandy gravel of partially crushed material with frost hazard class 1 (indicating soil with no frost-lifting properties). In connection with the test pit excavation, large amounts of rock and blocks have been found, especially within 0.5-1 m depth from the ground surface. Naturally stored soil has not been found during the pit excavation. Probing within the area indicate that the relative soil solidity is high to very high. [7]

Changes in geology are not anticipated over the time period considered for the assessment of post-closure impact (less than 100 years).

2.3. Hydrology and hydrogeology

The Simpevarp area consists of solid bedrock with some deformation zones and with very low ground water flow [8]. Extensive research of the bedrock has been carried out in cooperation with SKB. The researched area includes the area below the Simpvarp peninsula. The level of groundwater follows mainly the topography and is close to ground level.

Data from SGU's well register [9] show that the groundwater level in the immediate area is approximately 1.5–6 m below the ground. Within the area of MLA site, filling masses with a thickness of between 1–3 m have been applied on top of the rock. The geotechnical investigation at the site of the landfill [7] shows that groundwater does not occur in the soil layer. This indicates that the groundwater in the area consists of reservoirs in the bedrock.

The fresh water supply for Oskarshamn NPP comes from the lake Götemaren that is situated 8 km north-west of the location of Simpevarp. The intake of cooling water for the nuclear reactors is situated on the south side of the peninsula. The outlet for reactor O3 (formerly also O1 and O2) is on the north side, see Figure 7. Since Hamnefjärden is a narrow coastal inlet, the flow rate of the discharged cooling water is locally strong. The flow rate of the outlet water then decreases rapidly as the flow enters the Baltic Sea after 800 metres. During normal operating conditions at Oskarshamn 3, the cooling water is heated about 10 ºC.

Figure 7. Oskarshamn NPP with the cooling water outlet for Oskarshamn 3 in blue. Former cooling water outlet for Oskarshamn 1 and 2 in yellow. The outlet into Hamnefjärden is on the north side of the Simpevarp peninsula.

Just outside the location at the Simpevarp peninsula, there is open water. The littoral area to the north and south consists of a lot of small islands and a coastline that is full of small fjords, coves and bays.

The Baltic Sea is a brackish sea with limited water exchange with the Atlantic Ocean. There are no river tributaries within 10 km from Simpevarp. In the Baltic Sea there is hardly any tide water. In the southern part of the Baltic Sea, the tide can be a few centimetres.

The area around the power plant is not sensitive to flooding. The land is relatively high in relation to the sea level. Furthermore, the area can withstand heavy rain without flooding occurring. Hydrological changes over the time period considered for the assessment of post-closure impact are mostly related to climate changes.

2.4. Meteorology and climate

2.4.1. Meteorological measurements

A local meteorology mast (MET), located about 1 km south west of the MLA site, collecting weather data. It has the ability to measure temperature, atmospheric pressure, wind speed and direction at three different levels, 2, 10 and 100 metres (before year 2014 these levels were at 25, 70, and 100 metres) from the reference level +110.0 (10 meters above sea level). One purpose with the local meteorology mast is to be able to obtain data for calculations of radioactive releases following an initiating event.

Meteorological data for the site is supplemented and evaluated based on data from nearby meteorological stations. These nearby stations have relevant data for the weather conditions on the site and have longer measurement series.

Temperatures vary over the year and in Oskarshamn during the period 1961-2006 the lowest measured temperature was at -34.6 ºC and the highest at +33.2 ºC. The highest average temperature is during month of July at 16.5 ºC and lowest in February at -2.5 ºC.

2.4.2. Wind

The most common wind direction is from the southwest. Average wind speed is between 3 and 4 m/s. See Figures 8 and 9.

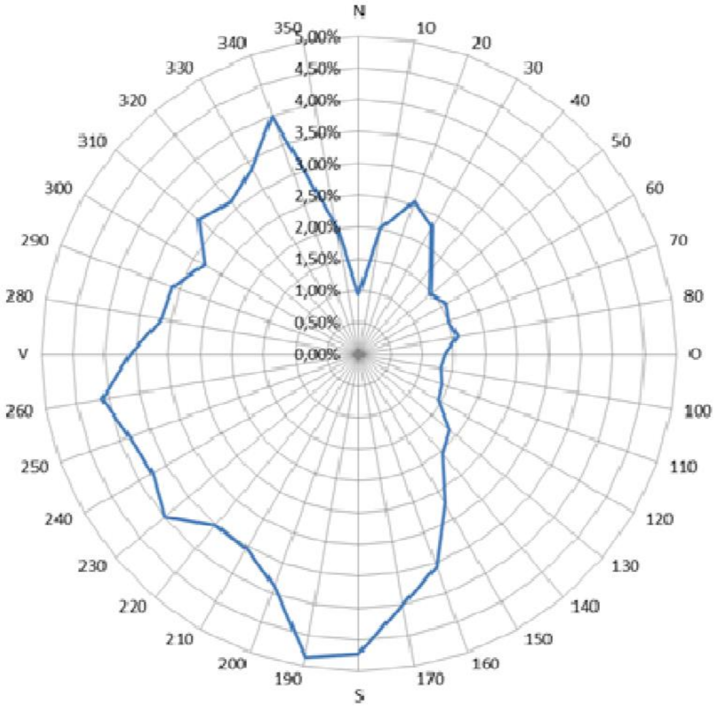


Figure 8. Wind direction and duration at the Simpevarp peninsula in 2010-2013. [10]

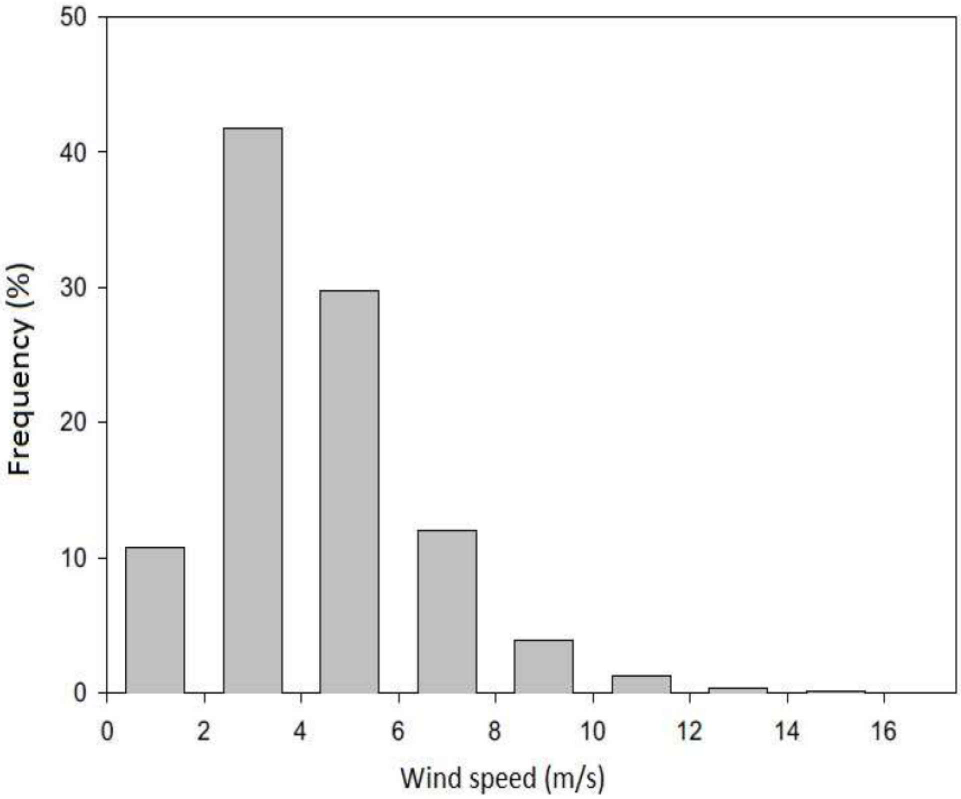


Figure 9. Wind speed distribution at the Simpevarp peninsula, at 25 metres in 1996-2000. [10]

Pasquill atmospheric stability class is a measurement of turbulence in air. Values range from A (very unstable) to F (stable) and how turbulent the air is affects the spread of activity, se Figure 10. Most frequent for the location is class D. Pasquill class is a parameter used in calculations of spread of activity via the air.

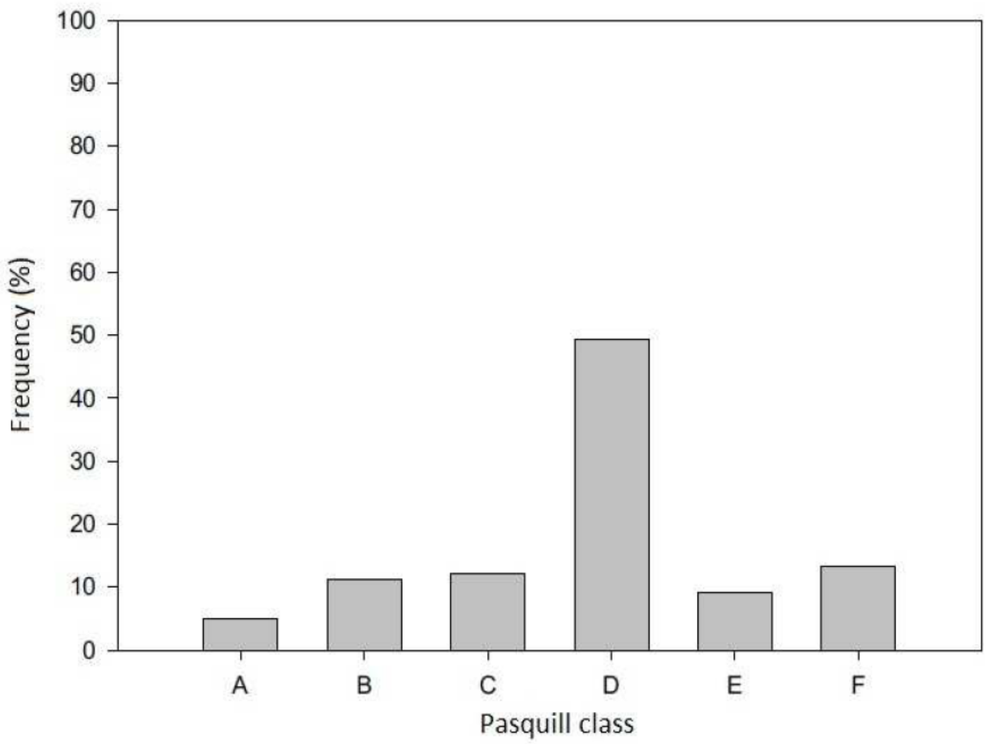


Figure 10. Relative distribution of calculated Pasquill class at Simpevarp, data 1996 to 2000. [10]

2.4.3. Precipitation

The heaviest rainfall occurs during the summer and usually over a short period of time when thunder clouds appear. During the winter months, warm sea temperatures combined with a cold north-easterly wind can create heavy snowfalls which give a large amount of precipitation, see Table 2. Annual precipitation is about 600 mm.

Table 2. Rainfall duration and intensity.

Frequency	Duration 10 minutes	Duration 60 minutes	Duration 24 hours
1/year	5 mm	10 mm	23 mm
1/100 years	17 mm	30 mm	75 mm

2.4.4. Extreme weather

Extreme weather (storm, tornadoes, ice storm, heavy rainfall) is rare in Sweden and especially on the Swedish east coast in relation to other parts of the world.

2.4.5. Climate change

Climate aspects have been one of the important factors studied as a basis for the environmental permit application and has been evaluated in a climate report [11].

In the climate survey, climate aspects such as sea level rise and increased precipitation has been considered to be most relevant aspects to study in relation to the planned repository. Increasing temperatures due to global warming was considered as well.

Increasing temperatures

The mean temperature in Sweden is expected to continue to rise. In 2100, the annual average temperature is estimated to be 11 degrees compared with 6.4 degrees during the reference period 1961–1990. The average summer temperature is estimated to exceed 20 degrees and the number of days with heat waves will increase from 2.4 days/year to over 20 days/year. This will probably mean an increase in longer periods of drought. Drought can lead to cracking in soil layers which could negatively affect the sealing of the landfill and therefore entail an increased risk of a greater leakage of water into the repository. Prolonged periods of heat wave and drought can also lead to an increased risk of fire.

Increased precipitation and flood risk

Precipitation is expected to increase, albeit slightly less, on the coast of south-eastern Sweden. Climate research also shows that intensive short-term precipitation in terms of both frequency and volumes will increase in the future. There is therefore a generally increased risk of flooding in future climates. A general surface mapping of the MLA area has been produced where elevation data and low points have been studied (see Figure 11). The analysis shows that the area in the vicinity of the planned landfill does not currently show any pronounced low points. Adjacent to existing landfills, there are smaller areas where bodies of water can form.

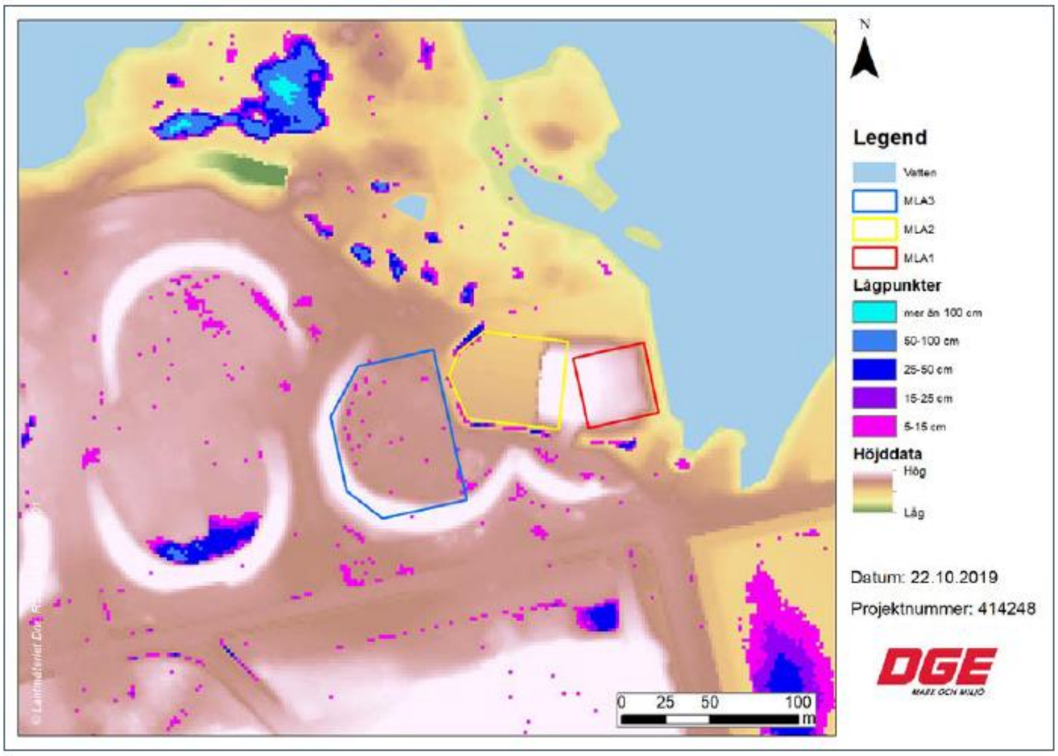


Figure 11. Height elevation data and low points in the area around MLA3 (blue shape).

In the area of the landfill, there is no stormwater network with a risk of flooding in connection with heavy rain or torrential rain.

Effects of sea level rise

Due to climate change, sea level is expected to rise in many coastal areas around Sweden. How the average water level changes over a longer period of time is mainly determined by the water levels of the world oceans and the ongoing land uplift. Rising seas affect the Swedish coasts to a very different degree, mainly because the speed of land uplift varies in different places.

In the climate survey, effects on the water level in regard to the latest IPCC climate scenario (AR6) has been analysed for the year 2100 to determine whether the landfill is prone to flooding from the sea in the long term. A water safety level has been calculated at +2.99 m, considering factors of expected sea level rise in the year 2100, local land uplift (isostasy) as well as an added safety margin of 0.5 m, see Table 3.

Table 3. Calculated safety level in year 2100 according to AR6.

	IPCC – AR6
Future mean water level in cm (95 percentile)	110
Highest calculated sea water level in cm according to observations	153
Safety margin in cm	50
Land uplift in Oskarshamn (0.264*105) in cm	-27.72
Mean water level in RH200 for the reference period 1986-2005 [cm]	13.9
Safety level in cm	**299**

The report shows that the foundation level for MLA3 is situated about 1.5-3 metres above the calculated safety level (+2.99 m) in the year 2100. This gives a good margin for the repository to withstand any high sea water and rising sea levels due to climate change.

A model of the climate scenario for the MLA site in the year 2100 is shown in Figure 12.

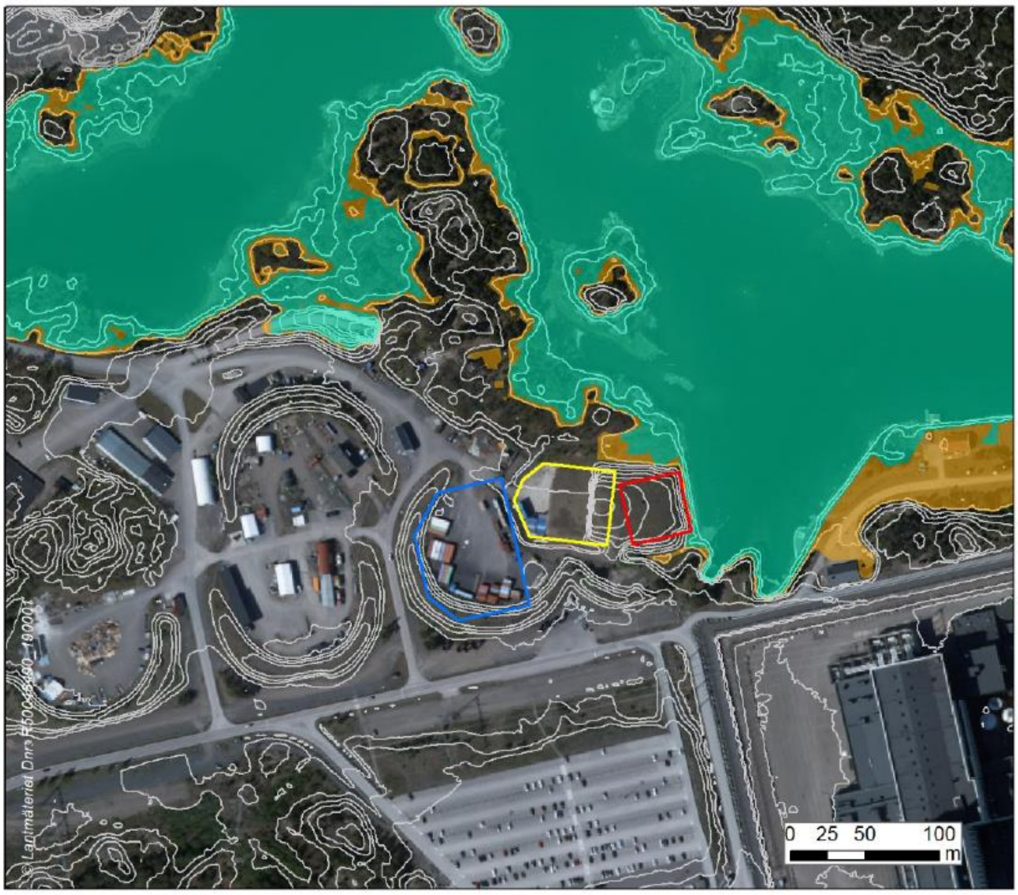


Figure 12. Global sea level in the year 2100 (green), added safety level 0.5 m (orange), location of MLA3 (blue). Height system RH2000.

2.5. Natural resources and foodstuffs

The nearest protected area for drinking water resources is located in Fårbo, 11 kilometres from the site. Since 1983, drinking and process water for Oskarshamn nuclear power plant is taken from the Lake Götemaren through a pipeline to a water supply plant operated by Oskarshamn NPP. Lake Sörå is used as a reserve water supply for drinking and process water for the plant. Surface water in the close vicinity is used only on a small scale as drinking water for humans or to some extent for livestock in nearby residents.

Groundwater or surface water has no impact on water used in any neighbouring member states.

Fishing is prohibited in the entire recipient Hamnefjärden and in an area, out to sea, with a radius of 300 meters calculated with the centre from the mouth of the bay. The ban is adopted to prevent fishermen from potentially damage measuring equipment that is placed in the waters. There are a small number of active fishermen in the Baltic Sea area outside of Simpevarp.

In the vicinity around Oskarshamn NPP, the density of the population is very low and there are few farms located nearby, the main use of the land areas is forestry. As the land across Hamnefjärden is owned by the OKG company, no agricultural activity is taken place in the direct vicinity of the NPP site.

The types of crops produced in the county of Kalmar in 2015 and the numbers of different livestock in 2013, are shown in Tables 4 and 5. The numbers of livestock included are those from Kalmar County (representing a wider area) and Oskarshamn. The use of arable land is dominated by production of fodder and grass for domestic animals.

Agricultural activities are low in the area around Oskarshamn NPP, no specific information exists of export of crops or livestock from this region to other member states. Since the region around Oskarshamn NPP does not produce any large quantity of foodstuffs, it is fair to assume that the significance of exports is negligible.

No major changes in future population patterns, habits and food sources in the area is expected in the time period considered for the evaluation of radiological impact from the landfill (i.e. the end of the active institutional monitoring and control period, approx. year 2080).

Table 4. Crops produced in Sweden as a total and in the county of Kalmar. No data exist for the smaller area, the municipal of Oskarshamn, around Oskarshamn NPP. The data is taken from the database DAWAS belonging to the Swedish Board of Agriculture for the years 2013 and 2015.

Crop	Year	Sweden ton/year	Kalmar ton/year
Sugar beet	2015	1,200,000	4,500
Potatoes	2015	764,000	30,000
Rapeseed	2015	346,000	18,000
Cereal	2015	6,068,000	195,000
Leguminous plants	2015	170,000	2,000
Total		**8,548,000**	**249,500**
Percentage		100%	2.9%

Table 5. The amount of 4 different types of livestock in Sweden, in the county of Kalmar, and in the municipal of Oskarshamn. The data is taken from the database DAWAS belonging to the Swedish Board of Agriculture for the years 2013 and 2015.

Livestock	Year	Sweden no.	Kalmar no.	Oskarshamn no.
Cattle	2013	1,496,526	150,790	4,136
Pigs	2013	1,398,875	74,092	1,821
Poultry	2013	16,540,365	1,914,829	455
Sheep	2013	576,769	38,050	1,802
Total		**20,012,635**	**2,177,761**	**8,214**
Percentage		100%	10.8%	0.04%

2.6. Other activities in the vicinity of the site

The planned landfill, MLA3, will be located within the Oskarshamn NPP site. On site are the three nuclear reactors O1, O2 (subject to decommissioning) and O3 with steam turbines and electricity generators. Apart from that are several facilities and activities that are necessary for running the power plant, including:

- cooling water intake (on the south side of the Simpevarp peninsula),
- cooling water outlet (see Figure 7)
- buildings and facilities for the management and storage of radioactive waste
- oil-fired reserve power units
- hydrogen plant
- sewage treatment plant
- waterworks
- oil storage
- workshops, and
- recycling station.

Within the industrial area there are also the current land repositories MLA1 and MLA2, and a rock vault for intermediate storage of low- and intermediate-level waste (BFA). The OKG industrial area is about 100 ha.

On the Simpevarp peninsula there is also SKB's central intermediate storage for spent nuclear fuel (Clab) and the access tunnel to SKB's rock laboratory on Äspö.

Industrial activity on the site is expected to remain in some form during the active institutional monitoring and control period of MLA3 (approx. until 2080).

3. The Repository

3.1. Conceptual approach and design

3.1.1. Disposal concept

The landfill is designed in accordance with the requirements for a conventional landfill for hazardous waste. An impermeable cap or cover is designed to minimize the amount of leachate. The bottom construction consists of a geological barrier and a liner to collect and lead the leachate that is formed via a collection tank for leachate and then via a filter barrier before the leachate is released to the recipient Hamnefjärden. Two control wells and a valve or other shut-off device on the outlet of the leachate tank enable sampling of leachate and measurement of volumes.

The design of conventional landfills is governed by Ordinance (2001:512) on landfilling of waste, which is the Swedish implementation of the EU Directive (1999/31/EC) on the landfill of waste. Facilities for disposal of radioactive waste are excluded from these regulations, but the rules on conventional waste can still be expected to be indicative. OKG has chosen to design MLA3 so that the requirements imposed on a conventional landfill for hazardous waste are met. This has been assessed by the fact that a small amount of the waste that is landfilled has properties that correspond to conventional hazardous waste and also because it is a proven and modern solution.

The chosen repository cover is designed so that the infiltration through the hydraulic barrier should be less than 5 liters of water per square meter and year.

The design is also chosen to take natural phenomena into consideration. Slopes are designed to not be steeper than 1:3 and not flatter than 1:20. When calculating the risk of landslides or avalanches, a safety factor of approx. 1.3 is used. The repository is also designed with an overflow drain in order to prevent water pressure from building up within the repository.

3.1.2. Location of the landfill

MLA3 is placed as a free-standing landfill in close proximity to the former landfill MLA2, see Figure 13. The bottom surface of the repository is estimated at approximately 7,400 m^2, including the sloping foot of the cap.

Figure 13. Location and proposed design of MLA3.

3.1.3. Bottom construction and geological barrier

The bottom structure of the repository corresponds to a conventional landfill for hazardous waste. At the bottom of the base structure, an artificial geological barrier is planned that must meet conditions in accordance with paragraphs 19 and 20 of Ordinance (2001:512) on landfilling of waste with a transport time for water through the barrier of more than 200 years.

In Sweden, with moraine soils and a relatively shallow groundwater level, there is normally no natural geological barrier that meets the requirements, which is why an artificial geological barrier is built. Artificial geological barriers usually consist of different types of natural or processed clay.

The construction of the landfill's bottom structure is planned to take place in the following steps (see also Figure 14):

- Initially, the ground surface is levelled with gravel and packed so that a stable terrace is obtained. The terrace is designed with an even slope of about

1% towards the north side so that leachate on the bottom liner structure is led there naturally.

- A geological barrier with a thickness of 0.5 m and a permeability of $1.0*10^{-10}$ m/s or lower is installed above the terrace. Embankments/edges are constructed on the outer edges of the bottom structure in order to prevent any leachate from flowing out of the bottom structure, except through the installed system for disposal of leachate.

- Above the geological barrier, a synthetic geomembrane is placed, and above that is a protective layer (to protect the geomembrane).

- A leachate collection layer is installed above the waterproofing layer for collection of leachate. In the eastern part of the leachate collection layer, leachate pipes are laid which, in the same way as the leachate collection layer, slope down towards the north short side where the leachate pipes connect to a tight pipe that is led out through the bottom structure. Leachate collection layer consist of crushed rock or crushed concrete, with a permeability greater than $5*10^{-10}$ m/s.

- Around the bottom structure, a stormwater ditch with drainage is constructed to divert surface-/stormwater from the landfill. The stormwater ditch is also constructed with a slight slope towards the northern short side so that clean stormwater/surface water naturally flows towards the northern short side.

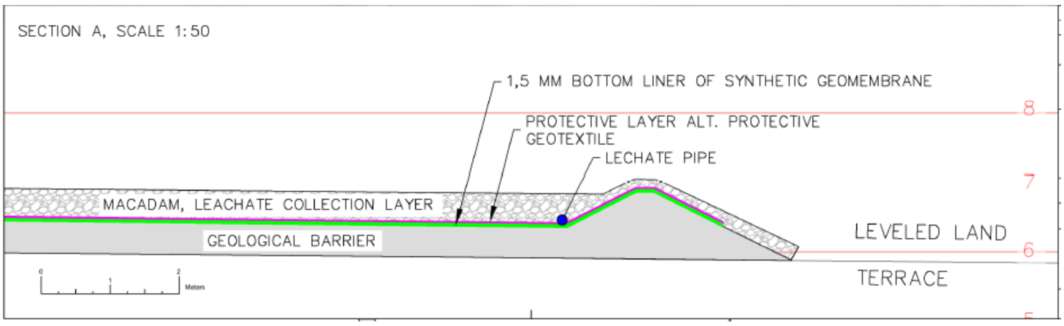


Figure 14. Design of the bottom structure.

Construction of the bottom structure will be adapted to the demand for landfill space in such a way that it is built in sub-stages depending on when there is a greater need for disposal of waste. Preliminarily, the bottom structure will be constructed in three sub-stages.

In order to handle leachate and surface water rationally, the sub-stages will start in the north and be expanded in stages to the south. Each stage will include the construction of a geological barrier, a bottom liner, protective layers and leachate collection layers with leachate pipes.

3.1.4. Disposal process and waste disposal

The waste is intended to be placed in the repository in a stepped structure. Either the waste is packed in containers (hard waste, larger components) or in "soft" garbage bales (paper, plastic, textiles etc.). Concrete blocks may be placed directly in the repository, without the need of a container. The containers and the other waste packages are expected to be set up and stacked with a forklift at a height of up to 4 containers, similar to what was done for MLA2 (see Figures 15 and 16). The total waste volume is 18,000 m^3.

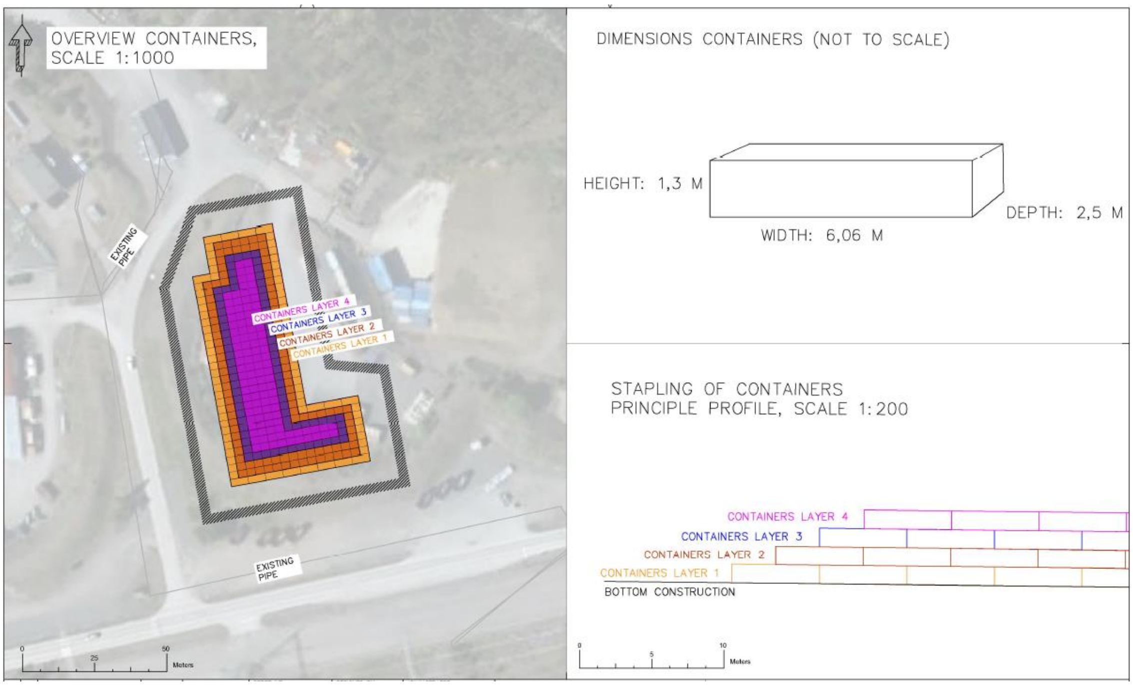


Figure 15. Proposal sketch. Waste disposal structure of MLA3.

Disposal will take place in accordance with OKG's established routines. Disposal of waste has historically, i.e., for MLA1 and MLA2, been executed through several campaigns. In conjunction with the disposal campaigns, the landfill will be expanded in stages.

One campaign consists of approximately 1,500 m^3 of waste and is expected to last for a few weeks. The following steps are performed:

- During the campaign, the waste is collected from an existing building for intermediate storage of very low-level radioactive waste and transported by truck to the repository area.

- The waste may be temporarily stored on the repository site during the disposal campaign. In that case, the waste is placed on a hardened surface and protected from precipitation.
- The waste is then lifted into the repository in accordance with the decided disposal key.
- Cavities and air pockets in and between containers are filled with stone flour and lighter packing is performed continuously. The waste is also levelled with stone flour to obtain a dome-shaped surface on which the final cover should rest. The final cover is then laid over the extended part of the repository.
- A temporary cover is installed at the disposal front, which is then dismantled before the next deposit campaign.

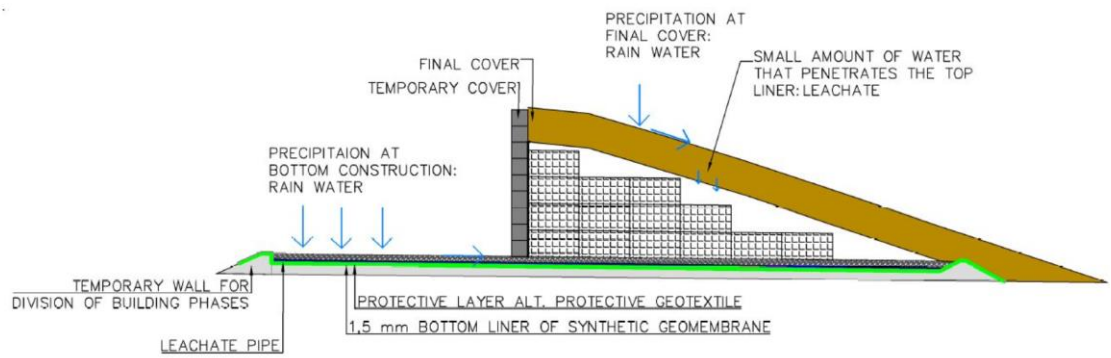


Figure 16. Principle sketch of phased expansion and temporary closure.

Figure 17. To the left: Each container is filled with stone flour in order to minimize air pockets and to create stability over time. To the right: Structure of landfill with a core of containers and garbage bales on top. Images from former disposal campaigns for MLA2 (2004).

The radioactive waste is emplaced in the landfill without intention of retrieval. However, if desired, it is possible to recover the waste both in the operational phase and during the post-closure period.

3.1.5. Design of the cover

The final cover of the repository is designed so that it meets the requirement in accordance with section 31 of Ordinance (2001:512) on landfilling of waste. The requirement indicates that the amount of leachate passing through the cap may not exceed 5 liters per square meter and year. The cap, which has a total thickness of 1.5 m or more, includes the following layers, described from the outside of the repository and inwards (see also Figure 18):

- Protective soil cover
- A material separating layer (if necessary, depending on selected filling materials)
- Drainage layer
- Protective layer
- Double sealing layers consisting of a synthetic geomembrane and a bentonite liner
- Protective layer
- Levelling layer

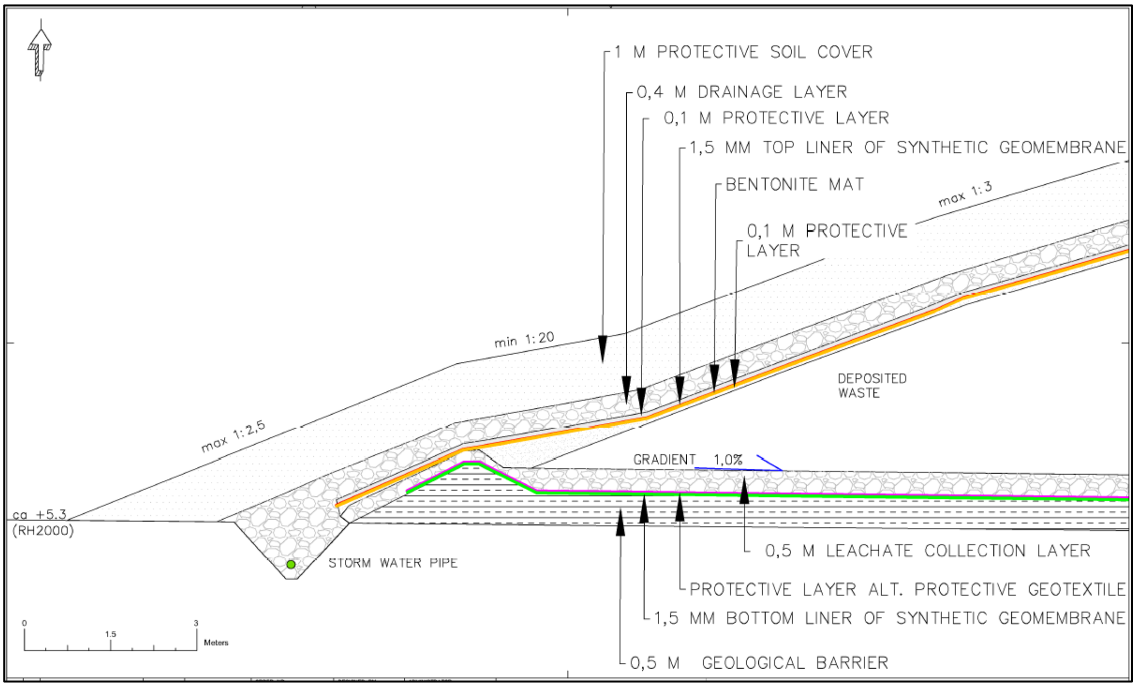


Figure 18. Cross-section of the ground repository's construction, including design of the toe of slope. Note that this sketch might be subject to minor changes regarding the stated measurements.

The bentonite liner and geomembrane are installed with special work descriptions, documentation and material descriptions. Double layers of waterproofing materials with geomembrane and bentonite liner are a proven construction method where both materials work together.

About 0.1 meter of stone flour is placed over the geomembranes and on top of this is a 0.4 m thick drainage layer consisting of crushed stone. The sealing layers of bentonite liner and geomembrane must not be trafficked or loaded before more than 0.5 m of material has been applied above the sealing layers.

Figure 19. Construction of the final cover. Images from former disposal campaigns for MLA2 (2004). Image from former disposal campaign for MLA2 (2004).

The protective layer aims to protect the underlying liners from damage and, together with the drainage layer, to establish a pressure on the bentonite liner before it becomes re-saturated and swells. Drainage layers on top of the cloth prevent water from accumulating.

Finally, a 1 m thick protective layer is applied, and the final shape is adjusted with moraine, soil and gravel. Immediately after completion, the upper surface is sown with a suitable seed mixture. To ensure that the completed repository blends into the environment, plants growing in the surrounding area may spread on the landfill. However, to avoid the risk of root penetration through the waterproofing layer, regular removal of trees and plants with deeper roots is executed.

In order to monitor possible changes in the landfill, levels for checking settlements are inserted, designed as a steel plate with a pipe that protrudes slightly above the surface of the repository. After the campaign has ended, a reference measurement is made at these points in order to enable monitoring of settlement risks.

3.2. Wastes to be disposed of in the repository

The waste that may be considered for placement in the soil repository is within the average nuclide specific activity concentration 0.1–100 Bq/g and has a surface dose of <0.5 mSv/h. It is of the lowest activity class, so-called short-lived very low-level waste. This waste is in principle comparable to a conventional industrial and demolition waste, but due to its origin it has to some extent been contaminated with radioactive particles. The amount of induced activity in the waste is limited.

The short-lived very low-level waste contains a small amount of radionuclides with half-lives below 31 years and only a limited amount of radionuclides with longer half-lives. The waste can be handled without special radiation shielding.

The permit application for MLA3 includes disposal of 18,000 m^3 of waste. 12,000 m^3 of this waste derives from demolition and 6,000 m^3 comes from operation.

The waste expected to be placed in MLA3 consists mainly of replaced components, scrap metal, concrete and rubbish such as used protective clothing, plastic and paper and cabling, etc.

The radioactive waste consists of organic and inorganic material. At OKG, the radioactive waste is categorized into the main fractions of combustible, inert and metallic material. In Table 6 below, waste categorisation from former land repositories MLA1 and MLA2 is shown.

Table 6. Categorization of waste that is object to deposit in MLA3.

	Waste	**Description**	
Combustible	Paper	Paper towels, protective clothing, corrugated cardboard, cardboard	Compactable = “Soft waste”
	Textile fibre	Gloves, shoe protection, overalls, cloths	
	Plastic	Protective clothing, plastic gloves, garbage bags, packaging, cellulose-free cloths	
	Rubber	Gloves, hoses, cable glands	
	Cabling	Cables and wire	
Not flammable	Insulation	Mineral wool, glass wool	
	Small metal	Wire, foil	
	Inert material	Concrete, sand, soil, sludge	Not compactable
	Metal	Screws, bolts, component parts, whole components, tools	

Forecasts from completed radiological surveys and data from already produced waste show that the waste volumes per constituent fraction will change in the future from a significant part combustible to a larger proportion of inert material (eg. concrete) and metal and insulation.

A small amount of the waste that will be deposited in the landfill has properties that correspond to conventional hazardous waste (eg. spray bottles, chemicals, fluorescent lamps, etc.).

Non-compactable waste that is to be placed in the landfill (see Table 6 above) is placed in 20 feet containers. If necessary, concrete blocks can be sawn to a suitable size and placed directly in the landfill, without the need for a container. The reason for this is that placing concrete blocks in containers would entail an increased risk of voids and cavities in the soil repository, which could create settlement risks in the long term. Compactable, “soft waste” is collected in plastic garbage bags (so-called garbage bales) which are the compacted, wrapped in steel strips and measured nuclide-specifically to ensure that they meet the acceptance criteria.

The waste is temporarily stored in containers in a waste storage building on the OKG site between landfill campaigns.

Due to the very low activity levels, the waste will not generate any measurable heat, neither during the deposit period nor when the repository is completed. Neither is the waste subject to any risk of criticality.
The organic fraction of the waste (which is the only part with potential to develop gas during degradation) is packaged in compacted waste bales which prevents impact on the waste and potential of subsequent gas formation.

3.2.1. Waste acceptance criteria and waste package verification procedure

The waste to be placed in MLA3 will need to meet set requirements, radiation protection conditions, set by the supervisory authority in connection with the permit being issued. At present, there are no radiation protection conditions for MLA3, but the current terms for MLA2 can be expected to be indicative. The radiation protection conditions for MLA2 [12] describe a number of criteria which the waste must meet:

Waste acceptance criteria:

1. In the part of the repository built in accordance with the permit on 29 March 1985, there may at no time be more than 100 GBq of radioactive substances. In the part of the repository built in accordance with the permit

on 18 September 2000, there may at no time be more than 200 GBq of radioactive substances, of which a maximum of 0.2 GBq may consist of alpha-radiating substances.

2. For each waste package, the inventory of radioactive substances of radiation protection significance shall be determined by direct or indirect nuclide-specific measurements.

3. The estimated average nuclide-specific content of radioactive substances in the waste during a deposit campaign, must in year 2075 not exceed the restrictions set out in Annex 2 of the Radiation Protection Conditions. Restrictions do not apply to the content of naturally occurring radioactive substances up to the levels contained in corresponding materials outside a nuclear facility.

The estimated nuclide-specific content of radioactive substances in individual waste packages may in 2075 be a maximum of a factor 10 higher than the restrictions set out in Annex 2. Waste may not be diluted or mixed in order to meet the restrictions for an individual package.

Any occurrence of radionuclides of radiation protection significance other than those listed in Annex 2 shall be reported and evaluated.

4. The surface dose rate of waste packages that are landfilled must be less than 0.5 mSv / h.

5. The waste must be packed to avoid the spread of activity at landfill. Waste packages must be marked based on identity.

Requirements for registration and reporting:

6. Landfilled waste must be registered. The register shall for each waste package contain information, alternatively references to relevant documents, about:

a. Identity of the waste package
b. Origin of the waste package
c. Waste treatment, as well as physical and chemical form
d. Treatment date
e. Amount of waste
f. Nuclide-specific content of radioactive substances, with reference date
g. Calculated nuclide-specific content of radioactive substances in year 2075
h. Surface dose rate with reference date, and
i. Deposition position

7. No later than three months before a planned deposit, a report of the deposit must be submitted to SSM. The report must contain:

   a. a schedule for the deposit campaign
   b. a compilation of current waste packages with information in accordance with condition 6 a-h
   c. a compilation and evaluation of previous experience of the operation of the landfill based on the results of the control programme
   d. information on the controller and the controller's plan for independent control

   Any changes must be notified to SSM immediately.

8. No later than three months after a completed deposit, a final report from the independent inspector, as well as an update of the amount of waste and the inventory of radioactive substances in the repository, must be submitted to SSM.

In addition, the requirements at deposit campaigns are stated in the following conditions:

Requirements at deposit:

9. The design of the waste packages, their disposal and the installation of the sealing layer must take place in such a way that the risk of uneven settlements or landslides that can damage the sealing layer or other protective functions is minimized.

10. If this can be achieved without the landfill's function deteriorating, waste packages with a lower content of radioactive substances must be placed as low in the repository as possible.

11. Stage terminations must be carried out in such a way that the spread of activity in connection with the next deposit is avoided.

12. Each deposition event shall end with the application of a waterproofing layer and a protective layer. The protective layer must be sown. Temporary final coverage is accepted in the expansion direction.

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

N/A. The waste intended to be disposed in the landfill is not expected to release any gaseous or airborne radioactive substances. The design of the landfill does not include any ventilation system, but it is designed with a dense and impermeable cap, and the waste is not prone to release airborne effluents.

3.4. Drainage system and the treatment of liquid effluents

MLA3 is designed with a leachate collection system which consists of drainage pipes in the drainage layer of the bottom structure, which transports leachate to the north short side. On the north side, leachate is led in tight pipes through the embankment/edge of the bottom structure to a collection tank. In the collection tank, monitoring of volumes, flows and content of leachate can take place. The collection tank is planned to contain a volume of about 30 m^3, and must be designed to enable inspection, sampling of water and measuring of flows. The tank is provided with an overflow drain and an outlet with a valve or another shut-off device. The outlet leads the water to a filter barrier through which the leachate passes before it flows out into the recipient Hamnefjärden.

The filter barrier is planned to be constructed as a wide ditch filled with filter material similar to what was used for the existing filter barrier at MLA2 (gravel, peat and sand). The filter material works by separating and adsorbing contaminants from the leachate. If necessary, the filter material can be replaced and adapted to work better for purification of the contaminants found in the leachate.

To avoid leakage to the surroundings, the barrier is provided with a waterproofing layer at the bottom. The filter barrier is of the same type as for MLA2 and is constructed as a separate system just north of the existing barrier, see Figure 20. In addition to the collection tank, two control wells are planned to be built which further enables sampling of leachate. One well is constructed directly outside the ground repository and the other is constructed at the end of the filter barrier.

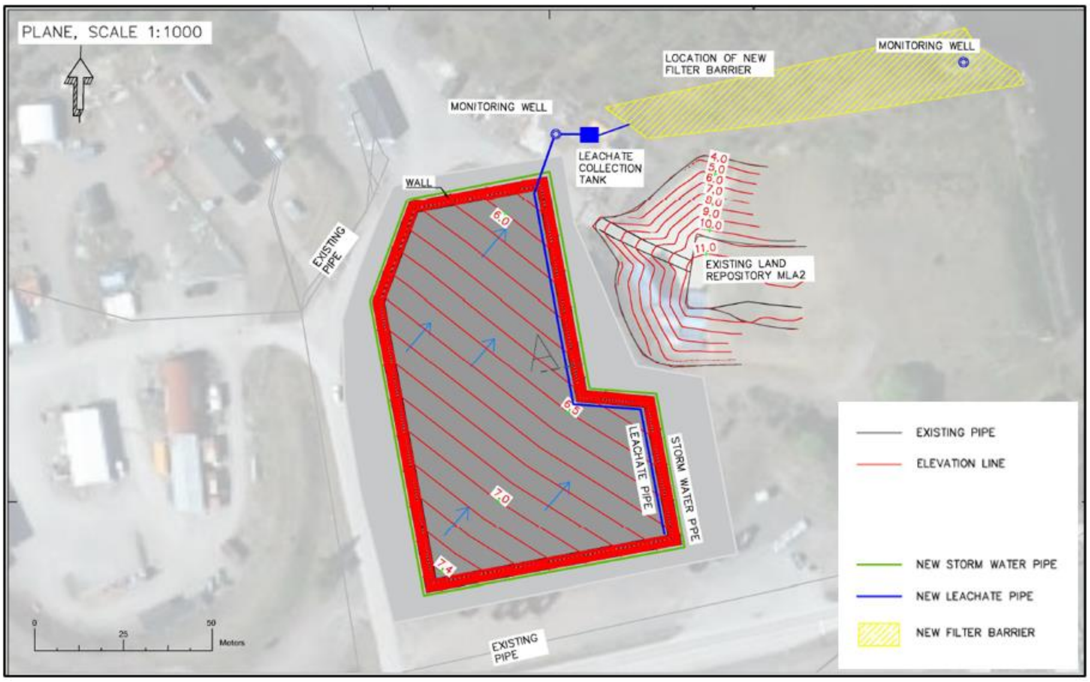


Figure 20. Bottom structure and system for management of leachate.

3.5. Management of secondary solid and liquid waste in normal conditions and in the case of an accident

N/A. No secondary radioactive waste will be generated in the landfill.

4. Release from the Installation of Airborne Radioactive Effluents in normal conditions

The landfill MLA3, in similarity to current land repositories on the Oskarshamn site, is constructed in such a way as to not release radioactive effluents to the air. This is partly due to the characteristics of the waste, the minor radioactivity levels and the design of the repository with a dense and impermeable final cover.

Airborne radioactive effluents have not been subject to monitoring in permits for landfills in Sweden and will not be included in the application for MLA3 either.

Consequently, this section is not applicable.

5. Release from the Installation of Liquid Radioactive Effluents in normal conditions

Releases of liquid radioactive effluents from the landfill during normal conditions are expected to be very low, and due to the system with filter barrier, releases of radioactive effluents to the sea are expected to be virtually non-existent. Leachate from the landfill will be monitored regularly in accordance with a monitoring program approved by the authority SSM.

In order to enable assessment of radiological discharges and dose contribution to representative individuals, a radiological impact assessment has been produced [13]. With regard to the fact that the waste inventory for MLA3 is not yet fully known, as well as some other uncertainties with regards to the modelling of chemical and physical development in a landfill, the analysis is based on several assumptions. To compensate for the uncertainties, a highly conservative approach has been used, basing the analysis on a simple model that would give the expected conservative results (i.e. a higher resulting dose) compared to a more realistic model.

The calculation result should therefore not be interpreted as strictly expected consequences, but as doses caused by a hypothetically overestimated release.

5.1. Authorisation Procedure in Force

The Act on Nuclear Activities 1984:3, the Radiation Protection Act 2018:396, together with the Ordinance on nuclear activities 1984:14 and the Radiation Protection Ordinance 2018:506, stipulate the requirements for all nuclear activities in Sweden. SSM has developed regulations (SSMFS) to give a more detailed framework for different nuclear facilities. Some of the regulations are available in English.

SSM supervises that nuclear operations are conducted safely by issuing regulations as well as carrying out follow-ups and checks of activities related to nuclear safety and radiation protection. One aim is to ensure that personnel and environment are exposed to as little ionizing radiation as possible.

The most important regulation with respect to this report is called SSMFS 2018:1 - The Swedish Radiation Safety Authority’s Regulations on Basic Provisions for Licensed Activities with Ionizing Radiation.

Regulations for the protection of the general public and the environment are described in chapter 5 section 1 of SSMFS 2018:1:

- The consequences of a nuclear facility from a radiation protection point of view for the public and the environment must be assessed and documented on the basis of the nature and scope of the activity. The valuation shall be carried out within the commencement of the operation, include the time during which the operation is ongoing, discontinued and the time thereafter, as well as refer to emissions of radioactive substances to the environment and other exposure to ionizing radiation from the operation. The valuation must be kept up to date. Radiation doses to the public shall be calculated in accordance with paragraphs 2 and 3. (paragraph 1)

- Radiation dose to the general public must be calculated using a method that is adapted to the nature and scope of the operation. The method must be transparent, verified and validated and conservative as far as possible and reasonable. Assumptions, parameters and data used in the calculation must be described and justified in terms of relevance. The method must be documented and kept up to date. (paragraph 2§)

- Radiation dose to the public should be calculated for a hypothetical person who represents the group or groups of people in the public that are expected get the highest radiation doses from the activity (representative person). The calculation of radiation dose must be made for the age categories 0–5 years, 6–15 years, respectively 16–70 years. When calculating radiation dose from inhalation and intake of radioactive substances current dose coefficients specified by the International Radiation Protection Commission (ICRP) shall be applied. (paragraph 3)

- *Dose restrictions for the general public*
  The dose restriction regarding effective dose to persons in the general public during which radiation protection is to be optimized, shall be 0.1 millisievert per year and nuclear facility site. (paragraph 4)

Discharge limits for radioactive releases from nuclear waste facilities for low-level radioactive waste such as land repositories are not specified in the Swedish legislation. The licensee holder is however subject to follow the specific radiation protection conditions set by SSM. These include, among other, waste acceptance criteria, provisions in the disposal process, provisions on monitoring and control, as well as on documentation and reporting.

5.2. Technical aspects

The activity is mainly in the form of surface contamination (surface dose of <0.5 mSv/h) and the waste will need to comply with the requirement regarding the average nuclide specific activity concentration ranging between 0.1–100 Bq/g.

The waste inventory for MLA3 is not yet determined, but analyses have been made on corresponding data for MLA2.

The releases of liquid radioactive effluents from MLA3 are expected to be near negligible. This is both due to the dense construction of the final cover with the technical demand of an infiltration of less than 5 litres/m^2 and year and also due to the filter barrier which the leachate is transported through, aiming to delay and adsorb liquid or dissolved solid particles. The filter barrier is not included in the model calculations.

5.3. Monitoring of discharges

Monitoring and sampling of liquid discharges are made on a quarterly scale for the current land repositories MLA1 and MLA2 and are regulated by the existing self-monitoring programme for OKG and Clab. In similarity, sampling and monitoring of leachate is proposed in the permit application for MLA3. For further description of the monitoring programme.

5.4. Evaluation of transfer to man

Evaluation of radiological consequences from the repository has been made using model calculations in the radiological impact assessment. Most of this section is a translation from the assessment, see [13].

5.4.1. Assumptions on waste data and calculation of radioactive effluents

General waste data applied in the calculations in the radiological impact assessment are given in Table 7.

Table 7. General data for deposited waste.

Parameter	Value	Comment
Volume of waste	18,000 m^3	Note that this number indicates bulk volume of packages, and thus that it does not include the other parts of the ground repository structure.
Density of waste	500 kg/m^3	OKG's experience is that the waste density varies between 500 - 800 kg/m^3. As lower density gives conservative calculation results, 500 kg/m^3 is used.

As there is at present no permit issued for MLA3, the activity inventory in the impact assessment is estimated to be based on the corresponding state and data for MLA2.

According to the current radiation protection conditions for MLA2, a maximum limit of 200 GBq activity (of which 0.2 GBq are alpha-radiating nuclides) in the repository is permitted at any given time. In the analysis for MLA3, the inventory is assumed to be twice the size of the MLA2 inventory (since the waste volume in the repository is expected to be about twice the size of MLA2). This entails a waste inventory of 400 GBq, of which 0.4 GBq are alpha-radiating nuclides.

In order to be able to calculate radiological consequences, the activity is required to be distributed nuclide-specifically. To estimate which nuclides are suitable for analyze, as well as how the total activity is distributed over these, the nuclide-specific activity inventory in newly produced waste (MLA2 campaign 7 according to [14]) has been multiplied by a dose factor and inverse Kd value (see below for theory, data and references) to provide an expected relative dose contribution to a representative person. The highest contributing alpha-nuclide and the other nuclides which makes the highest relative contribution in both the short-term perspective (at closure) and in one longer perspective (after 30 years of decay) has subsequently been chosen to constitute representative nuclides for MLA3.

This analysis shows that if H-3, Co-60, Ni-63 and Sr-90 are included along with Pu-238, these nuclides together constitute about 99% of the relative dose contribution in both time perspectives.

Pu-238, which becomes the highest contributing alpha-nuclide, is assumed to constitute the total alpha inventory of 0.4 GBq.

The rest of the activity has been divided into the four other nuclides, H-3, Co-60, Ni-63 and Sr-90, in accordance with the distribution of these four nuclides in the waste that constitutes MLA2 campaign 7 according to [14].

In the radiological impact assessment, the landfill is assumed to be filled with the maximum permitted activity levels at closure, distributed of the representative nuclides above. In Table 8 below, the nuclide-specific distribution in the repository is presented, both at closure and 30 years after closure, when the active institutional monitoring and control phase is at an end and the public is allowed to access the site[3].

Table 8. Activity at closure and after 30 years of decay (Bq).

Nuclide	Activity at closure	Activity after 30 years of decay
Co-60	2.4E+11	4.6E+09
Pu-238	4.0E+08	3.2E+08
Sr-90	1.3E+08	6.1E+07
Ni-63	9.7E+10	7.9E+10
H-3	6.7E+10	1.2E+10

5.4.2. Conceptual description and assumptions

The normal operating model is based on IAEA [15] and has been supplemented with the following assumptions regarding the function of the landfill:

[3] Assumed for calculation purposes.

- The permitted activity in the landfill is assumed to be homogeneously distributed over the permitted volume of waste.

- Waste and matrix materials (eg stone flour or sand) are assumed to be mixed to a total volume corresponding to the volume of waste even if the waste, in reality, is surrounded by the matrix material[4]. Volume between waste packages is ignored.

- The sealing layer on the repository is assumed to let in water corresponding to the maximum permitted amount each year (5 liters/m^2, year).

- Infiltrating water is assumed to flow through the waste and out again without any form of delay or retention. These are conservative assumptions as the repository has been constructed with a small space between the waste packages where any infiltrating water can flow without affecting/leaching out of the waste.

- Activity is leached by the infiltrating water at a rate that is determined by the K_d value of each substance.

- The estimated discharge is further assumed to flow directly to the sea, i.e. without any retention or delay of nuclides outside the repository (e.g. in soil or filter barrier).

5.4.3. Calculated annual discharge of liquid radioactive effluents

The landfill is modelled with a precipitation-exposed area of 6,300 m^2. Following the assumptions and data stated in section 3.1, an infiltrating water volume ($V_{infiltation}$) is calculated.

$$V_{infiltration} = 6300\ m^2 * 5\frac{l}{m^2 year} = 31500\frac{l}{year} = 31{,}5\frac{m^3}{year}$$

To calculate how much of the nuclides is released by the infiltrating water, it is assumed that all activity is available for leaching via the infiltrating water, and that the distribution is described according to subject-specific distribution coefficients, Kd, according to

$$Kd = \frac{Bq\ in\ solid\ phase\ (\frac{Bq}{kg}\ dry\ weight)}{Bq\ in\ liquid\ phase\ (\frac{Bq}{m^3})}$$

Kd values are received from tabulated data in [15] for a sand filled landfill.

[4] Containers also contain a certain amount of matrix material.

Assuming that all infiltrating water flows through waste with a homogeneous activity concentration and leach out activity according to the respective nuclide's Kd value, [15] gives the following equation for the proportion of activity of nuclide *i* which is leached from the repository each year:

$$Activity\ fraction\ leached\ for\ nuclide\ i\ (year^{-1}) = \frac{V_{infiltration}}{V_{repository}(\omega + \rho * Kd_i)}$$

In the equation,

- $V_{repository}$ is the volume of the repository (conservatively assumed to be equivalent to the waste volume, 18,000 m^3)
- ω is the moisture content in the waste (conservatively assumed to be zero)
- ρ is the dry density of the waste (500 kg/m^3)

By multiplying the calculated amount of leached activity with the activity inventory for the specific nuclide, the released activity is given in the unit Bq/year, see Table 9.

Table 9. Conservatively calculated annual discharged activity from the landfill at normal operation.

Nuclide	Released fraction ($year^{-1}$)	Released activity (Bq, $year^{-1}$)
Co-60	5.4E-05	1.4E+07
Pu-238	6.5E-06	2.6E+03
Sr-90	2.7E-04	3.4E+04
Ni-63	8.8E-06	8.5E+05
H-3	3.5E-02	2.3E+09

The model assumes that the first year's emissions are repeated every coming year. Thus, no account it taken of the fact that the activity in the landfill decreases year by year through leaching as well as radioactive decay.

5.4.4. Models and parameter values

The radioactive discharges (Bq/year) are converted into dose (Sv/year) by multiplying the discharged radioactivity with specific dose factors.

The dose factors that are used in the radiological impact assessment are existing values earlier determined by adding OKG-site specific parameters to a calculation model called PREDO (*PREdiction of DOses from normal releases of radionuclides to the environment*). PREDO is the modelling tool used in Sweden for calculation and analysis of radiological discharges from all Swedish nuclear facilities and is reviewed and approved by the Swedish authority SSM. For calculations on dose from liquid radioactive discharges from the MLA3, the aquatic part of OKG's PREDO model is used.

Assumptions, calculations, and data used for the model can be found in the following reports:

- PREDO – PREdiction of DOses from normal releases of radionuclides to the environment. Methodology for the assessment of radioactive releases to the aquatic environment. QP.50000- 63747891 [15]

- PREDO – PREdiction of DOses from normal releases of radionuclides to the environment. Results OKG. QP.50000-88004884 [16]

- PREDO – PREdiction of DOses from normal releases of radionuclides to the environment. Site Report Oskarshamn. QP.50000-63744912 [17]

- PREDO – PREdiction of DOses from normal releases of radionuclides to the environment. Representative person. QP.50000-63744910 [18]

The radiological impact assessment applies the PREDO model with a modified water exchange, set at 1.8 km^3/year according to [20], in order to compensate for the lower cooling water flow from O1 and O2 (due to decommissioning). The model and other parameters are reported in detail in reports [16-19] above.

PREDO primarily aims to produce dose factors (Sv/year per Bq/year) that should be used to estimate the effective dose to people from the general public from emissions of radioactive substances during normal operation at nuclear installations. In addition to this, the tool can calculate concentrations of radioactive substances in the environment caused by emissions, in order to be able to assess possible consequences for the environment.

To calculate the radiation dose to the public from emissions of radioactive substances PREDO applies the method recommended by the ICRP [21]. According to this method, radiation dose is calculated to a so-called representative person. This can be one hypothetical or real individual, who is representative of the most exposed individuals in the current population. It is further stated that the representative person must cover every relevant potential route of exposure. Different living conditions are described by considering different types of families, e.g. vegetarian family, farmer family, average family etc. Within each family, dose factors are then calculated for the individual groups:

- adults (16-70 years)
- children (6-15 years), and
- infants (0-5 years).

In [19] is described how representative individuals of the public are being identified and which assumptions are made.

In the radiological impact assessment, dose has been calculated to the respective age group in an assumed average family.

The PREDO model entails radiological consequences, in Sv per year, per annual Bq released according to Table 10.

Table 10. Dose factors to representative individual from unit emission (Sv/year /Bq/year)

	Co-60	**Pu-238**	**Sr-90**	**Ni-63**	**H-3**
Adults	8.5E-17	8.0E-16	1.0E-17	4.9E-19	1.0E-21
Children	8.6E-17	4.9E-16	2.4E-17	8.2E-19	1.5E-21
Infants	8.9E-17	5.0E-15	8.4E-17	4.7E-18	3.9E-21

Exposure pathways for discharges to water
The exposure pathways that have been taken into account in the aquatic PREDO-model [16] includes

- External exposure due to swimming, boating and time spent at the beach
- Internal dose due to inhalation of sea spray,
- Internal dose due to ingestion of seafood and fish, as well as crops, cattle and drinking water

See Figure 21 below for the exposure pathways.

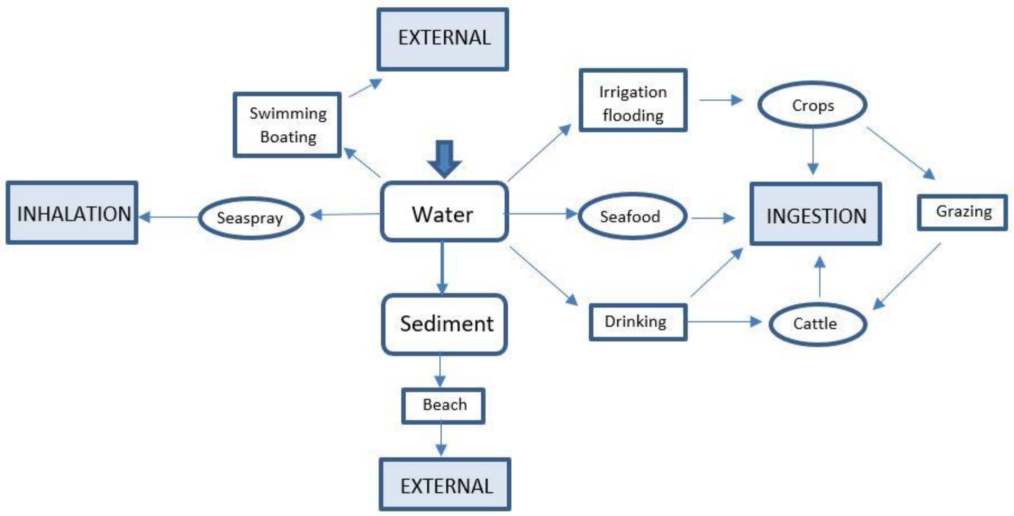


Figure 21. Exposure pathways in the PREDO aquatic model. [16]

Discharges to water
Discharges to water are modelled in a process where the radioactive leachate water that has been in contact with the waste is dispersed into the greater water volume from precipitation and surface water runoff that flows through the filter barrier and into Hamnefjärden. In Hamnefjärden, which has an increased water exchange due to the cooling water discharge from reactor O3, the discharges will be diluted and distributed to the Baltic Sea.

PREDO is a box model. In the model, the discharges are evenly distributed over the year. The areas are described by boxes with certain volumes and water renewal times (see Figure 22). PREDO have “nested boxes” where the boxes increases in area, and water exchange is used to describe transport of water and nuclides from the local box to the surrounding box. The sediments are described using three boxes: one for upper bottom layer, one for the intermediate bottom layer and one for the deep bottom layer (which is less exposed to resuspension and biological processes). The water renewal is high, so the discharges are efficiently mixed with the surrounding waters.

The volume of the boxes is determined with respect to the fish territories together with information about the water spreadout plume. The model in [16] describes how radionuclides are released, how they are adsorbed on particles and transferred to surrounding sediments, how they are re-suspended back into the water, what factors dominate the uncertainties of the model, and the like. There are parameter values for e.g. annual sediment growth, sinking velocity for particles and amounts of suspended material.

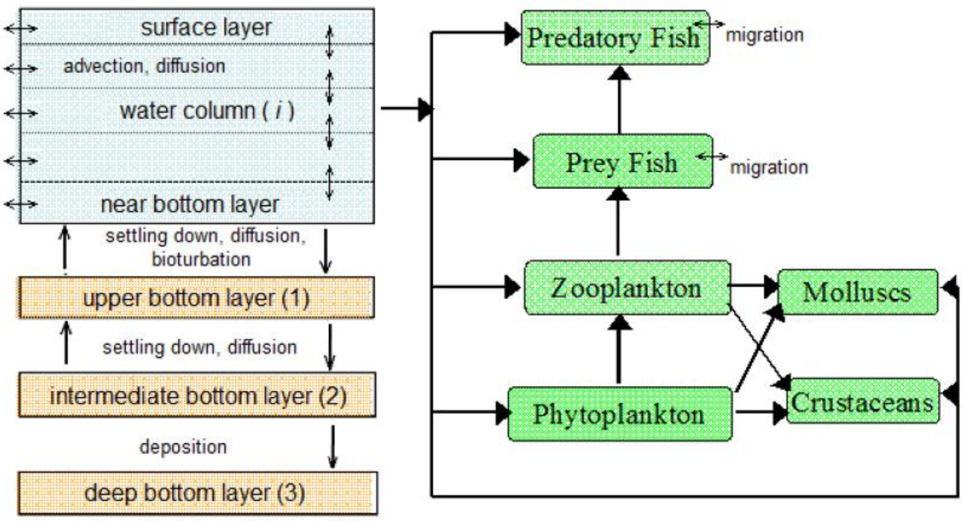


Figure 22. PREDO aquatic model - modelling of radionuclide transport processes. [16]

5.4.5. Evaluation of the concentration and exposure levels

When the annual liquid radiological release is combined with the dose factors above, the result is obtained dose to representative individuals in the average family according to Table 11.

Table 11. Calculated dose to representative individual at normal operation (Sv/year).

	Co-60	Pu-238	Sr-90	Ni-63	H-3	Total
Adults	1.2E-09	2.1E-12	3.4E-13	4.2E-13	2.4E-12	1.2E-09
Children	1.2E-09	1.3E-12	8.1E-13	6.9E-13	3.4E-12	1.2E-09
Infants	1.2E-09	1.3E-11	2.9E-12	3.9E-12	9.2E-12	1.3E-09

The highest dose is thus obtained for infants and corresponds to approximately 1.3 nSv/year.

Compared to the dose restriction, of 0.1 mSv/year, regarding effective dose to persons in the general public from normal operation of nuclear installations at the entire OKG site, the result of 1.3 nSv/year is negligible. Furthermore, it is well below the limit for requiring data on effective dose in other member states.

6. Disposal of Solid Radioactive Waste from the installation

N/A. This section is not applicable.

7. Unplanned Releases of Radioactive Effluents

7.1. Review of accidents of internal and external origin

The licensee of a nuclear facility must verify that the probability of serious disturbances or mishaps is low and that, should such an event nevertheless occur, the consequences to the environment and personnel are acceptable.

The landfill in question for this report is excluded from the requirement of SSMFS 2008:1 regarding the need to produce a safety assessment report (SAR). Radiological consequences derived from unplanned events and accidents have, however, been assessed in the radiological impact assessment [13] which has been part of the basis for the Environmental Impact Statement (EIS) in the license applications.

Accidents studied in the radiological impact assessment have consisted of a number of events which has been estimated to be able to cause radiological emissions to air or water. The radiological impact assessment has identified the events from a conservative approach and has focused on identifying umbrella cases or worst-case scenarios.

Regarding events that can lead to air emissions, few such events have been able to be identified. The analysis has therefore conservatively focused on an umbrella case that is expected to be able to cover any other events that may have been missed, but which would thus give less air emissions than the umbrella case. The incident that has been identified and assessed concerns a fire in the entire repository. The incident is considered very unlikely given that the waste that is planned to be disposed of is mostly inert. In addition, OKG has a local fire brigade who can take care of possible fire, should it occur on site. However, the incident is judged to have the highest predictable consequences regarding radiological emissions to air and is therefore assessed.

Incidents that can lead to radiological discharges to water could occur in several ways, but it is considered that they all have in common that they include damage to the final cover and thus increased water discharges from the repository. Such damage could theoretically occur, for example, through long-term settlements that damage the waterproofing layer, or climate-related events such as floods. However, flood risks from the sea have been assessed as highly unlikely even with regard to climate change.

In order to be able to cover several scenarios that could lead to damage to the final cover and thus increased water discharges, a very conservative calculation case has been set up here as well. In the event, the final cover is assumed to be defective to the extent that all precipitation infiltrates the repository already at closure. This is a very conservative assumption because the bentonite liners and geomembrane in the sealing layer are expected to be intact for several centuries. Furthermore, leachate samples are taken regularly, which would show any defects long before the cover is completely defective.

7.2. Evaluation of the radiological consequences of releases to atmosphere

Radiological releases to atmosphere have been calculated for a single worst-case scenario regarding fire within or in the vicinity of the landfill. The assessed scenario involves a fire in the entire landfill. This section is mainly a translation from [13], see the report for more information on the calculations.

The fire is assumed to occur in connection with closure of the repository, in order to conservatively assume the highest deposited activity. It is further assumed that the activity is homogeneously distributed in the waste volume. To consider that different substances have different mobility and thus the tendency to be released and spread to the environment at a fire, so-called FRF values (Fire Release Fraction) are used. The nuclide-specific activity affected by the fire is thus multiplied by the substance-specific FRF value to give an estimate of the released activity.

The FRF values are taken from [22] and are shown in Table 12 together with the released activity.

Table 12. FRF and released activity at fire within the entire landfill.

Radionuclide	Activity within the entire repository at closure (Bq)	Fire Release Fraction (FRF)	Released activity at fire within the entire repository (Bq)
Co-60	2.4E+11	0.001	2.4E+08
Pu-238	4.0E+08	0.001	4.0E+05
Sr-90	1.3E+08	0.01	1.3E+06
Ni-63	9.7E+10	0.01	9.7E+08
H-3	6.7E+10	0.5	3.3E+10

The effective dose has been calculated using the Matlab code DoseCalc [23] [24]. The program describes the proliferation of nuclides in the atmosphere and deposition on the ground using a Gaussian plume model [23]. The activity cloud distribution in the air is modelled with a normal distribution in the horizontal (perpendicular to wind direction) and vertical direction with the wind speed in the direction of propagation. DoseCalc uses dose coefficients from ORNL's Dose Coefficient File Package, DCFPAK 3.0 [25] which is based on radiological decay data from ICRP Publ. 119 [26].

The choice of methodology and input data for DoseCalc follows [27] as well as analysis requirements from SSM [28] regarding the radiological environmental consequences of nuclear power reactors.

During the entire course of the fire, an individual is assumed to be outdoors, downstream in the wind direction. External dose from cloud radiation and internal dose from inhalation (with an integration time of 50 years) is calculated during the time it takes for the plume to pass. External irradiation from nuclides deposited on the ground is integrated for a period of 30 days after the fire. No consideration is given to protective measures.

In accordance with [27], the emission height of 20 meters is used to represent all discharges at a height of 0-25 meters. The distance from the point of discharge to where the dose is calculated is set at 200 m in accordance with [28].

DoseCalc input parameters have been retrieved from [28], and some of them presented in Table 13.

Table 13. Input data used in the calculations according to [27]).

Parameter	Value
Emission level	20 m (represents all discharges at 0-25 m height including diffuse leakage)
Initial spread	20 m
Duration of discharge	1 h
Wind speed	2 m/s
Inversion height	100 m
Stability class (Pasquill)	F

The resulting dose is given in Table 14 below. The highest dose to an individual 200 meters from the fire has been calculated to 1.6 μSv.

Table 14. Dose in case of fire in the repository.

Fire scenario	Adult, 200 m distance from the incident (Sv)
The entire landfill	1.6E-6

Consequences from the worst case scenario studied regarding fire are therefore negligible and well below the value (1 mSv) where studies of dose to another member state needs to be made. Additionally, OKG does not expect any food exports from the vicinity of Simpevarp.

7.3. Evaluation of the radiological consequences of releases into an aquatic environment

The calculation case for discharges to water relates to increased water discharges in the event of damage to the waterproofing layer and has been analysed in a model manner similar to the normal operating case, i.e. the discharges are expected to occur over a long time horizon (annual scale). For information on how the normal operating case has been calculated. This section is mainly a translation from [13], see the report for more information on the calculations.

The only parameter that distinguishes this event from the normal operating model is that the parameter of infiltrating water is set to a higher value. This is due to the assumption of a completely defective waterproofing layer, and consequently that all precipitation would infiltrate the repository.

According to [29], the highest measured annual rainfall in all of Sweden is 1,866 mm. Use of this value for the landfill thus corresponds to a rounded permeability of 2 m^3/m^2 and year on the entire surface of the ground repository of 6,300 m^2, and thus an infiltrating water volume of 12,600 m^3/year.

Assuming that the calculation case for normal operation is applicable in all the other calculation parameters, emissions are obtained according to Table 15.

Table 15. Annual liquid release from landfill at completely defective waterproofing layer.

Radionuclide	**Discharge fraction ($year^{-1}$)**	**Discharge (Bq/year)**
Co-60	2.3E-02	5.5E+09
Pu-238	2.6E-03	1.0E+06
Sr-90	1.1E-01	1.4E+07
Ni-63	3.5E-03	3.4E+08
H-3	1.0E+00	6.7E+10

If the same dose factors as for normal operation are assumed, this discharge results in a dose according to Table 16.

Table 16. Resulting dose to representative individuals at completely defective waterproofing layer (Sv/year).

	Co-60	**Pu-238**	**Sr-90**	**Ni-63**	**H-3**	**Total**
Dose adults	4.7E-07	8.3E-10	1.4E-10	1.7E-10	6.8E-11	4.7E-07
Dose children	4.7E-07	5.1E-10	3.2E-10	2.8E-10	9.7E-11	4.7E-07
Dose infants	4.9E-07	5.2E-09	1.1E-09	1.6E-09	2.6E-10	5.0E-07

The highest dose in this worst case scenario is obtained by infants and corresponds to approximately 0.5 µSv/year.

The consequences from this scenario are well below the value (1 mSv) where studies of dose to another member state need to be made.

8. Emergency Plans; Agreements with other Member States

The operator of the Oskarshamn NPP has a plan for emergency preparedness [30] in the event of an emergency or a threat of an emergency at the facility. The plan describes the whole scope of the emergency preparedness at OKG including reference to relevant documentation regarding radiation protection measures. Relevant documentation including checklists for all functions in the emergency preparedness organisation is collected in a handbook that is available for the Emergency Preparedness Management. The handbook is well-known, and training is performed regularly.

The current plan describes the organisation, including available personnel with competence in relevant areas, such as Emergency Preparedness Management (Crisis Management Team, CMT), Engineer on Duty (EOD), Area Supervisor (Crisis Manager, CM), Plant Supervisor O1, Plant Supervisor O2, Plant Supervisor O3, Radiation Protection Supervisor, Service Supervisor and Information Supervisor.

Alarm levels, instructions and routines to activate the alarm, instructions for informing relevant authorities and evacuation plans are described. Equipment and technical facilities for radiation measurements and contamination control are available and their use is regularly exercised. Meteorological data is measured and registered continuously.

According to the Swedish Regulation on Civil Protection [31] the County Administrative Board of the County of Kalmar has established an emergency plan [32] where the Oskarshamn NPP is included. The plan covers organisation, liaison with other authorities and the operator, where and how to measure radioactivity, how to handle public information, personnel and material resources available in the county, and methods of decontamination.

Sweden has signed international and bilateral agreements on a national and official level concerning the early notification and subsequent information in the event of a nuclear energy accident. The Swedish Meteorological and Hydrological Institute (SMHI), which is manned around the clock, receives notifications of accidents abroad. The Swedish Radiation Safety Authority SSM, which is manned around the clock, is responsible for forwarding the information nationally, and also for sending information from Sweden in the event of an accident in the country. The most important agreements are:

- Bilateral national agreements with Norway, Denmark, Finland, Germany, Russia, and Ukraine on warnings of accidents.
- The IAEA convention EMERCON on warnings of accidents if another country might be affected by release.
- The binding EU directive on early notification (ECURIE, European Community Urgent Radiological Information Exchange) requires that a

warning must be given if measures are adopted for protection of the domestic population.

9. Post-Closure Period

9.1. Regulatory and administrative provisions

The repository is planned to be in operation during a period of approximately 25 years. Thereafter, a period of active institutional control and monitoring commences. In the permit application for the repository, the active institutional control phase is suggested to last for at least 30 years.

After the end of the active institutional control phase (approx. year 2080), the radioactive substances in the landfill will have decayed to the nuclide specific activity concentration levels given in the license conditions that SSM is expected to establish.

Before each disposal campaign the waste is characterized and reported in a plan for the up-coming disposal campaign is submitted to SSM. After disposal, a final report is also submitted to SSM, with an update of the amount of waste and the inventory of radioactive substances in the repository. In addition, information about radioactive nuclides deposited in the repository is registered in a waste database (GADD) that is administered by SKB. In summary, there is a systematic way in which the waste is documented and recorded, and the information is stored for future needs.

Measures undertaken during the active institutional control period are suggested to be corresponding to measures for monitoring and control during the operational period. The proposed measures are described in section 10.

No active measures are proposed after the active institutional control phase (i.e., 30 years after closure). When the active institutional control phase is ending, the repository is left with barriers and leachate collection systems intact. However, passive institutional control can be expected, similar to the control of other landfill facilities. The barriers are expected to degrade in the long term, the time aspect for when this happens is hard to estimate. However, discharges of radiological nuclides during the passive phase are expected to be well below limits for radiological effects on human health and the environment.

No dismantling programme for auxiliary installations is planned.

Periodical safety reviews before closure are performed in accordance with the environmental monitoring programme, closer described in section 10.

9.2. Radiological impact during post-closure period

Radiological impact during the post-closure period is expected to be similar to that described in the normal operation case, in the sense that no significant discharges of radionuclides are expected. It should further be noted that consequences of an eventual release would decrease in time due to radioactive decay.

The barriers of the repository are expected to deteriorate in the long term, which would lead to higher discharges of leachate from the repository. During the active institutional control and monitoring phase, however, settlements are regularly monitored, and leachate is regularly measured which would give indication of the barrier performance. During the active institutional control and monitoring phase, the landfill is also expected to remain within the physical protection of the OKG site (protected with fences), which would prevent intrusion by humans.

Apart from this normal evolution scenario described above, some specific (and considerably more unlikely) scenarios have been studied in the radiological impact assessment [13]. The following sections are mainly translations from that report.

The post-closure scenarios that have been studied are:

- Exposure by spending time at the landfill
- Cultivation of crops at the landfill
- Construction of a well in the vicinity of the landfill

The scenarios are evaluated in the end of the active institutional monitoring and control period (i.e. 30 years after the final deposit). The calculated consequences for each scenario are presented below. A summarizing table of all studied events is presented in section 9.3.

9.2.1. Exposure by spending time at the landfill

In this event, a person without knowledge of the previous use (and tentative risk of elevated radiation levels) is assumed to stay at the landfill area. Two separate calculations are made:

- A calculation where the repository is assumed to be intact and a person is staying on top of the shallow land burial permanently (8,760 hours per year),
- A calculation where a person is assumed to dig down through the protective cover to the geomembrane and bentonite liner levels (where it can be assumed that the person discovers that the repository is not a natural formation) and is there during a working day (8 hours).

In these calculations, it is assumed that the public has access to the landfill area no earlier than 30 years after closure.

The landfill is modelled as a homogeneous volume with a waste layer that is 3 m deep (average depth when the waste volume corresponds to 18,000 m^3 and the landfill area 6,300 m^2). The waste here is assumed to consist of carbon (density 500 kg/m^3).

Above the waste volume, a 0.1 m thick levelling layer is modelled below the bentonite mat (which due to its relative thinness is not modelled). Above the liner, there is an additional 0.1 m thick protective layer, a 0.5 m thick drainage layer and a 1 m thick protective cover.

All these shielding layers are assumed to consist of sandy or gravelly materials with the density 1500 kg/m^3.

All calculations are done with Microshield version 12.00X with buildup in the outermost shielding layer. Surface dose rate is calculated 1 cm outside the outermost shielding layer. Only the nuclide Co-60 is considered, and the inventory is considered 30 years after closure and assumed to be homogeneously distributed in the waste volume.

At ground level, where a total of 1.7 m of material shields the waste, the surface dose rate is calculated to 7.3E-12 mSv/h. In the case of a permanent stay on top of the repository, this corresponds to a dose to an adult of approximately 0.06 nSv/year.

At liner level, when the waste is shielded from only 0.1 m of material, the surface dose rate is calculated to about 3.3E-05 mSv/h. For a working day of 8 hours, this corresponds to a dose to an adult of about 0.3 μSv.

9.2.2. Construction of a well in the vicinity of the landfill

In this event, it is assumed that a well is built in the vicinity of the ground repository after it institutional control, i.e. after 30 years. A person is assumed to receive his annual drinking water consumption from the well.

Model and data

To calculate releases to water, the normal operating model is used, but the activity inventory has been corrected for 30 years of decay. In this scenario, it is assumed that the water is available in a well before it flows out to sea. However, it is not reasonable to assume that only water that has flowed through the landfill is available in the well. This is because other precipitation in the area flows in the same direction as leachate from the repository and thus is also available in the well.

For this report no studies on actual runoff in the area have been made. Instead, it is assumed that the mixture is limited to the water that comes as precipitation on the repository. This means that the water that flows through the repository is assumed to be mixed with the amount of water that rains on the landfill but that flows of as surface water through the surface layers without penetrating to the waste.

In Oskarshamn municipality, the average rainfall is 521 mm/year according to [33]. Of these 521 mm, the normal operating model assumes that 5 mm infiltrates through the sealing layer and thus is leaching out activity. The other 516 mm is assumed to flow as surface water on the final cover and directly towards the well without leaching out activity. Calculated on the surface of the repository of 6300 m^2 corresponds to the 31.5 m^3 (6300 $m^2 \cdot 0.005\ m^3 / m^2$year) flowing through the landfill is mixed with approx. 3250 m^3 (6300 $m^2 \cdot 0.52\ m^3 / m^2$year) other water.

The annual emissions obtained from the normal operating model (with the waste inventory at 30 years after closure) is thus assumed to be evenly distributed in the annual precipitation of about 3280 m^3.

This water is then assumed to be drunk from a well. Water consumption has been retrieved from [34] and set to:

- Adults: 0.376 m^3/year
- Children: 0.076 m^3/year
- Infants: 0.05 m^3/year

Consumption of water from the well 30 years after closure is calculated to result in a dose according to Table 17.

Table 17. Resulting dose from the scenario with consumption of well water 30 years after closure (Sv/year).

Nuclide	**Co-60**	**Pu-238**	**Sr-90**	**Ni-63**	**H-3**	**Total**
Adults	1.0E-07	5.4E-08	5.3E-08	1.2E-08	8.9E-07	1.1E-06
Children	6.8E-08	1.1E-08	2.3E-08	4.5E-09	2.3E-07	3.4E-07
Infants	1.1E-07	1.2E-08	1.8E-08	8.8E-09	3.2E-07	4.6E-07

The highest dose is obtained by adults and corresponds to about 1 µSv/year.

9.2.3. Cultivation of crops at the landfill

In the event of cultivation at the landfill, a person without knowledge of the previous use of the site (and the consequent risk of contamination) is assumed to cultivate the soil in the landfill area. The cultivation is assumed to take place 30 years after closure, when the active institutional monitoring and control of the landfill ceases.

Two different emission pathways have been analyzed: via leachate and via material mixing.

Discharge via leachate
Discharges via leachate and mixing with precipitation water have been calculated in the same way as in the scenario described in the previous section.

This water is assumed to irrigate arable land. It has been conservatively assumed that the soil is saturated with water and contains 12 kg of water for every kg of dry matter.

Discharge via material mixing
In this scenario it is assumed that a subset of waste is mixed with the topsoil. This should be seen as a hypothetical scenario as it may not be likely that waste material, which is separated from ground level by at least 1.7 m material and a geomembrane and bentonite liner, could be physically mixed with soil intended for cultivation.

In this hypothetical scenario, calculations are made for two different cases where the soil is mixed with materials so that 1 % and 10 % of the mass, respectively, consists of waste materials. This corresponds to the soil having 1 % and 10 %, respectively, of the waste activity concentration. These assumptions have been taken from [35].

Furthermore, an assumption has been made regarding the water content in the soil, in order to be able to calculate tritium uptake. In the material mixture calculation, it has been assumed that the water content is 1 kg water per kg dry weight soil.

Calculations of resulting doses has been made according to the methods described in the sources [18] and [34]. From the reports, parameter values are also obtained.

By using crop-specific root uptake factors, *CR*, which describes the relationship between the activity concentration in the plant as well as in soil, the activity concentration in crops can be calculated. Thereafter, the activity concentration can be converted to wet weight by taking into account the water content of the crop.

Note that this methodology does not apply to H-3 (tritium), as it is taken up as tritiated water rather than substance-specific root uptake. For H-3 it is instead assumed that the crop water content has the same tritium concentration as the water in the soil.

When including data on consumption habits and dose coefficients relating intake to dose, the annual dose to representative persons can be calculated. It is here conservatively assumed that all annual consumption of cereals, root vegetables and vegetables originate from the cultivated soil.

In Table 18 the water content is given, in Table 19 root uptake factors, in Table 20 consumption habits and lastly in Table 21 dose conversion factors for intake are presented.

Table 18. Fraction of water content in cereals, root vegetables and vegetables [34].

	Cereals	Root vegeta-bles	Vegetables
Fraction of water	0.12	0.87	0.92

Table 19. Concentration ratio (CR) (Radionuclide concentration in crop per radionuclide concentration in soil) for cereals, root vegetables and vegetables ((Bq/kg dry substance)/(Bq/kg dry substance)). [34]

Substance/element	Cereals	Root vegetables	Vegetables
Co	5.0E-03	5.4E-02	1.7E-01
Pu	1.8E-03	1.1E-04	8.3E-05
Sr	1.3E-01	1.6E-01	7.6E-01
Ni	7.6E-03	6.1E-02	6.1E-02

Table 20. Annual consumption of cereals, root vegetables and vegetables (kg). [34]

Product	Adults	Children	Infants
Cereals	52	53.7	64.9
Root vegetables	39.8	40.1	28.6
Vegetables	21.3	6.44	5.98

Table 21. Dose conversion factors for intake (Sv/Bq). [36]

Radionuclide	Adults	Children	Infants
Co-60	3.4E-09	1.1E-08	2.7E-08
Pu-238	2.3E-07	2.4E-07	4.0E-07
Sr-90	2.8E-08	6.0E-08	7.3E-08
Ni-63	1.5E-10	2.8E-10	8.4E-10
H-3	1.8E-11	2.3E-11	4.8E-11

The resulting dose from the scenarios with cultivation on the landfill (both the discharge via leachate and the material mixing scenario) are presented in Table 22 below. Note that only the most conservative scenario with mixing of 10 % waste in the cultivated soil is shown. The 1 %-case would result in a tenth less dose compared to the 10 %-scenario.

Table 1. Dose to representative person in the scenario with cultivation of crops on the landfill 30 years after closure (Sv/year).

	Dose when spreading to soil via leachate			Dose when spreading to soil via material mixing		
	Adults	**Children**	**Infants**	**Adults**	**Children**	**Infants**
Co-60	2.6E-09	6.5E-09	1.5E-08	1.4E-07	3.4E-07	7.8E-07
Pu-238	1.4E-10	1.5E-10	3.1E-10	6.7E-08	7.2E-08	1.4E-07
Sr-90	1.3E-08	2.6E-08	3-6E-08	1.5E-07	3.0E-07	4.1E-07
Ni-63	2.9E-10	5.0E-10	1.5E-09	1.0E-07	1.7E-07	5.0E-07
H-3	1.4E-07	1.4E-07	2.4E-07	1.5E-07	1.5E-07	2.5E-07
Total	1.6E-07	1.8E-07	2.9E-07	6.0E-07	1.0E-06	2.1E-06

As presented in Table 22, infants are receiving the highest dose in both scenarios. The dose is about 0.3 µSv/year in the case with spreading via leachate and 2 µSv/year in the case with 10 % waste mixed into the cultivated soil.

9.3. Evaluation of effective doses in all studied scenarios

It should be noted that all the events and scenarios that have been studied in the radiological impact assessment are set up in a highly conservative manner in order to account for any uncertainties. Even with this, in some cases unrealistic, approach, the estimated emissions from the landfill are low. In Table 23, a summary of estimated total dose is given for the different analyzed scenarios, both in chapter 6 and 8.

Table 23. Resulting calculated dose from all studied events.

Scenario	Adults	Children	Infants
Completely defective waterproofing layer (Sv/year))	4.7E-07	4.7E-07	5.0E-07
Permanent stay at landfill (Sv/year)	6.0E-11	-	-
Stay during a working day (8 h, intrusion to the waterproofing layer) (Sv)	3.0E-07	-	-
Cultivation of soil, spreading via leachate (Sv/year)	1.6E-07	1.8E-07	2.9E-07
Cultivation of soil, spreading via material mixing (10 % waste) (Sv/year)	6.0E-07	1.0E-06	$\boxed{2.1E-06}$
Water consumption from nearby well (Sv/year)	1.1E-06	3.4E-07	4.6E-07
Fire in the entire landfill, adult 200 m distance	1.6E-06	-	-
Fire in one m^3 of waste	9.1E-11	-	-

The highest total dose is obtained in the event of cultivation in the soil repository, with the very conservative assumption that 10 % waste is mixed into the cultivated soil and that the individual receives his entire annual consumption of cereals, root vegetables and vegetables from the cultivated soil. The event gives a resulting dose of 0.002 mSv to the most sensitive individual group (infants).

The landfill is thus assessed to not pose any risk to adults, children or infants, neither living in the vicinity of the plant nor in relevant areas of other affected Member states.

10. Environmental monitoring

10.1. General description of environmental monitoring on the Simpevarp peninsula

MLA3 is planned to be located on the Oskarshamn site. As an existing NPP site with several nuclear facilities, the whole Simpevarp peninsula is covered by an extensive environmental monitoring and surveillance programme. The purpose of the radiological environmental monitoring programme is to examine the impact on the environment as a result of the operation of the nuclear power plants, activities related to dismantling and demolition of O1/O2 as well as operation of other nuclear facilities on site, such as the land repositories. The activities at the interim storage for spent fuel (Clab) 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 the nuclear power plants 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 SSM 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. The SSI report 2004:15 [37] (SSI - the former Swedish Radiation Protection Authority) 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 report 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 unit O3, in accordance with the guidelines developed by SSM for environmental monitoring. Meteorological data are also 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 23.

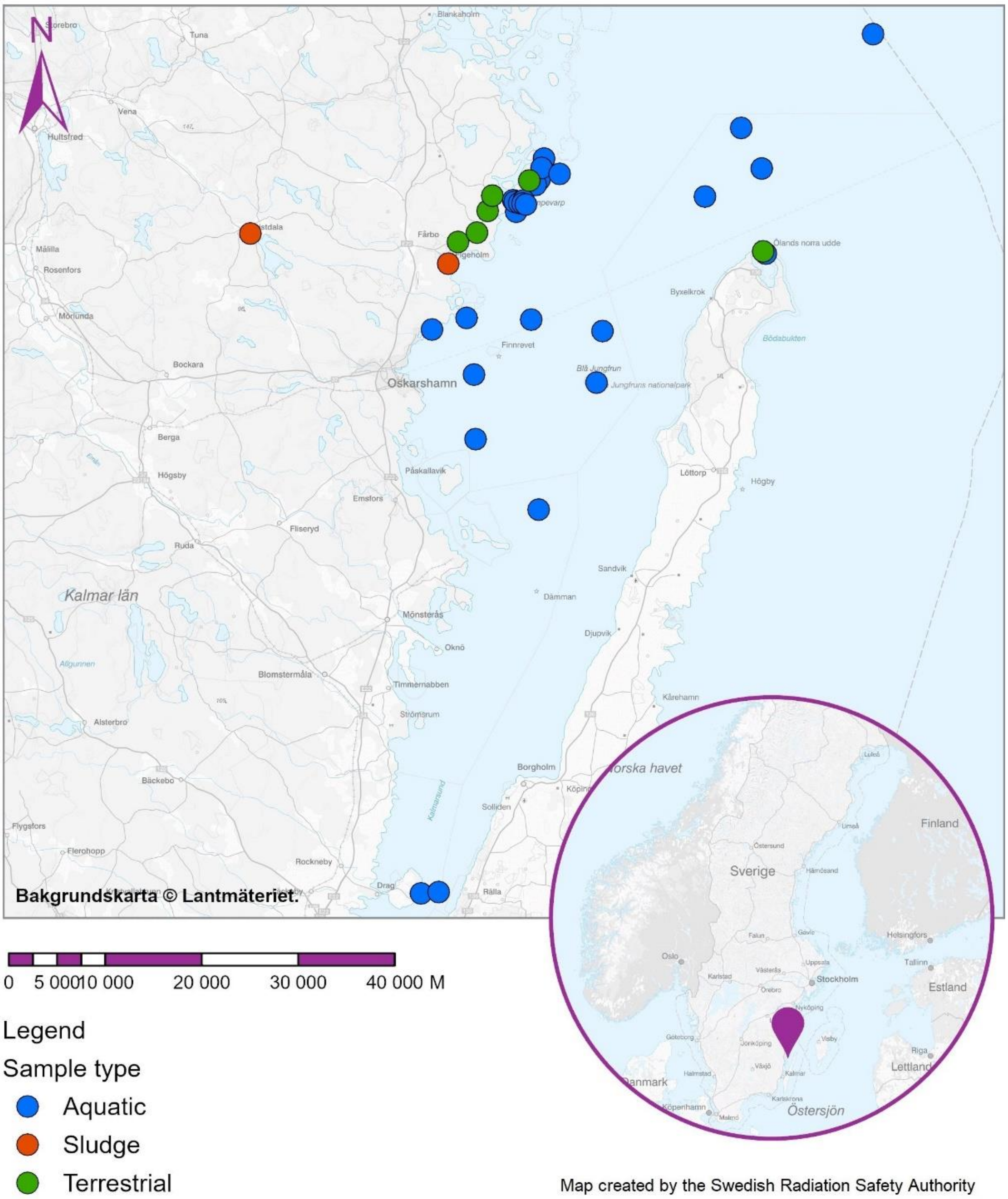


Figure 23. Sampling stations in the vicinity of Simpevarp in the environmental monitoring programme, both on land and in water [37].

There are 25 area dosimeters that are evaluated on a quarterly basis. As a supplement, there are nine dose rate meters that are checked twice a week for trend analyses. The dose rate meters can also be used during accident conditions for estimation of source term and for calculation of dose to the surroundings.
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.

The monitoring programme will continue as long as OKG and SKB/Clab handle radioactive material at Simpevarp. This includes the post-closure period (the active institutional monitoring and control period) in the case of MLA3.

10.2. Monitoring of MLA

Monitoring specifically linked to MLA3 will be designed in accordance with the radiation protection conditions that SSM imposes on the facility in connection with the permit. Since MLA3 does not have a valid permit, monitoring measures in this section will be described on basis of the current environmental monitoring programme for MLA2, which will likely be guiding for the conditions imposed to MLA3.

Radiation protection conditions 13-15 [12] respectively state that:

13 An environmental monitoring programme must be in place for the landfill.

14 The programme shall include an annual sampling and analysis of the content of gamma-radiating nuclides in water samples from sampling points downstream the repository. The results must be reported annually to SSM. Need for other measures to control the function of the landfill, such as control of erosion and settlements, must be evaluated and the measures shall be taken if necessary.

15 The landfill will be under radiation protection control until year 2075. During this time, the measures for maintenance and monitoring which are needed in respect to protection of human health and the environment must be taken.

Monitoring of the current land repositories is described in section 5 in the self-monitoring programme for the entire Oskarshamn site [38].

Two main types of monitoring are required:

- Ocular control of settlement risks and clearing of deep-rooted vegetation, in order to prevent damage to the waterproofing layer.

- Sampling and analysis of leachate, in accordance with the permits for MLA 1 (1985-03-20, 11.1821.12 84-84) and MLA2 (2000-12-01, M 700/99).

In addition, the waste that is to be deposited is required to undergo nuclide-specific activity determination, dose rate measurement and approval by SSM.

10.2.1. Sampling of leachate

Monitoring by sampling of leachate is performed 4 times a year, in accordance with the monitoring programme [38].

Sampling of leachate from both MLA1 and MLA2 is included in the monitoring programme. The two stages have different types of leachate monitoring systems.

- MLA1 has a low point with a pump pit and a collection system and sampling of leachate. The water is pumped from the pump pit to Hamnefjärden via a line.
- In MLA2, the leachate flows through a filter barrier (similar to what is planned for MLA3) that has two sampling points (GW2 and GW3). Groundwater sampling (GW1, reference value) also occurs upstream of the geological barrier. The geological barrier is drained through gravity drainage towards Hamnefjärden.

In similarity to MLA2, the leachate collection system for MLA3 is also planned to be constructed with three sampling points (before, in the middle of, and after the filter barrier).

Sampling is performed in accordance with Table 24 below.

Table 24. Sampling of leachate from MLA1 and MLA2, respectively. [38]

Sampling point	Frequency and method	Parameter	Remark
MLA1, sampling tank 767 T1	Four times annually (April, July, October, December) 2 litres of water is retrieved from tank 767 T1. Afterwards the tank is drained.	Gamma spectrometry	In accordance with operational instruction
		TOC	
		Conductivity	
		pH	
		Metals (Cr, Cu, Co, Ni, Zn, Cd, Hg and Pb)	
MLA1, system 767, pumped out leachate from pump well	Summarizing flow meters, hour counter for the running time of the pumps and number of pump starts registered in one counter.	Flow	In accordance with operational instruction
MLA2, 767 GW1 (ground water upstream), 767 GW2, (leachate in the middle of filter barrier) and 767 GW3 (leachate downstream barrier).	Four times annually (April, July, October, December) water is taken from ground water pipes.	Same as MLA1	In accordance with operational instruction. If no water is retrieved in the geological barrier, content is documented as 0 value. The pipes 767 GW 2-3 enables that groundwater level in the barrier can be determined.

Personnel at OKG are set to perform the sampling according to schedule. The OKG laboratory are handling the samples and send them to an accredited laboratory.

10.2.2. Documentation and registration

In accordance with the monitoring programme [38], the following activities are required:

- The analysis results from leachate samples are recorded in the chemistry database.

- Information on packaging code, waste category, quantity, number of packages, surface dose rate and activity content for waste that is deposited is registered in a waste register.

- Counters for the pumps' running times and flow meters (m^3) are read at each sampling opportunity and registration takes place in a logbook.

- Precipitation (mm) is read every month in Simpevarp's village. The information delivered to OKG's laboratory which enters the amount of precipitation in OKG's database for environmental tests.

- The annual inspection of the entire facility regarding settlement and landslide trends are documented in a message noting the following:
  - General status of the facility
  - Any damage to layers
  - Tendencies to landslides and landslides, at and around the slope foot and at and behind the slope crown
  - Overgrowth of the landfill with risk of root penetration
  - Clogging of the drainage ditch
  - Growth of the geological barrier with risk of root penetration
  - Other injury.

- If landslide trends are observed, stabilizing measures must be considered and at implementation of measures, SSM must be informed.

10.2.3. Reporting

Regarding reporting, an annual report is prepared to report the amount of waste deposited and activity content and results from chemical and radiochemical analyses made on the leachate from the shallow land burial.

The report is compiled by a waste engineer regarding low- and intermediate-level waste from external databases available for the purpose. OKG's laboratory performs chemical and radiochemical analyses.

The annual report on MLA also forms the basis for OKG's annual environmental report to the County Administrative Board where, among other things, information on emissions is reported in the emission declaration.

An application for a permit for disposal of waste packages is made to SSM prior to each deposit campaign and a final report is reported to The County Administrative Board and SSM after the campaign has been completed.

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Appendix 1 – Definitions and terms used in this document

Acceptance criteria	Conditions to verify that a requirement is met
BAT	Best Available Technique
B1	Barsebäck 1
B2	Barsebäck 2
Clab	Central interim storage for spent fuel
Disposal key	A document presenting the placement of every waste package within the repository. The disposal key is sent to SSM and requires approvement before a disposal campaign may begin.
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
LILW	Low and Intermediate Level Waste.
MLA	Landfill for very low-level waste at Oskarshamn
MLA1 and MLA2	Earlier and finished stages of land repositories at Oskarshamn
MLA3	New landfill for very low-level waste at Oskarshamn
NPP	Nuclear Power Plant
O1	Oskarshamn 1
O2	Oskarshamn 2
O3	Oskarshamn 3
OKG	Oskarshamns KraftGrupp (the utility)
PREDO	PREdiction of DOses from normal releases of radionu-clides to the environment.
SFR	Final repository for short-lived radioactive waste
SFS	Swedish Code of Statutes

SGU	The Geological Survey of Sweden – expert agency
SKB	Swedish Nuclear Fuel and Waste Management Company
SMHI	Swedish Meteorological and Hydrological Institute
SSM	Swedish Radiation Safety Authority
SSMFS	Swedish Radiation Safety Authority regulations
VLLW	Very Low Level Waste

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