Disposal of LLW/ILW: The Extension of the SFR-Repository for Handling and Disposal of Decommissioning Waste - 14489

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ABSTRACT

The Swedish Nuclear Fuel and Waste Management Co (SKB) operates a repository for disposal of short-lived low and intermediate level radioactive waste (LILW), the SFR, located close to the Forsmark NPP ca 150 km north of Stockholm. The repository with a storage capacity of 63,000 cubic meters is built in crystalline rock with some 60 m rock cover under the Baltic Sea, and was commissioned in 1988. The waste deposited in SFR is short-lived and originates mainly from operation and maintenance of nuclear reactors and operational waste from interim storage of spent nuclear fuel. The waste consists primarily of spent organic ion exchange resins from reactor water and condensate water clean-up, and waste in the form of trash, scrap and mechanical components from maintenance work, etc. A smaller quantity consists of similar waste from other industrial and medical activities and research.

SFR is planned to host also the LILW from longer operational life-times and future decommissioning of the existing nuclear power plants. At present there is a project at SKB for the expansion of the existing SFR facility to host also decommissioning waste. The aim is to expand the facility with *ca* 120,000 cubic meters of waste volume, and to have the extended facility in operation around year 2023.

THE EXISTING FACILITY, SFR 1

The repository for radioactive operational waste, SFR 1, is located in Forsmark in northern Uppland in the immediate vicinity of the Forsmark nuclear power plant. SFR 1 is built to receive, and after closure serve as a passive repository for low- and intermediate-level radioactive operational waste. The disposal chambers are situated in bedrock beneath the sea floor, covered by about 60 metres of rock. [1] The repository has been designed so that it can be abandoned after closure without further measures to be taken to maintain its function.
The waste deposited in SFR 1 is short-lived and origins mainly from operation and maintenance of nuclear reactors and from interim storage of spent nuclear fuel. The waste consists primarily of spent organic ion exchange resins from cleaning of reactor water and waste in the form of trash, scrap and mechanical components from maintenance work, etc. A smaller quantity consists of similar waste from other industrial and medical activities and research.

The various parts of the repository (Figure 1) are designed to accommodate the different types of containers and materials and to provide adequate protection depending on the activity levels present in the different types of waste. Waste types in the different parts of the repository are shown below.

- Silo – for intermediate-level, solidified waste.
- BMA – for intermediate-level, mostly solidified waste.
- 1BTF – for ash drums.
- 2BTF – for dewatered ion exchange resins from condensate clean-up (CCU).
- BLA – for low-level solid waste such as trash and scrap.

All repository parts are located at the same depth beneath the sea. The bottom of the silo reaches down another 60 metres. The disposal capacity of the facility is about 63,000 m³ and the total volume of excavated rock is about 400,000 m³. The following sections provide a brief description of each repository part.

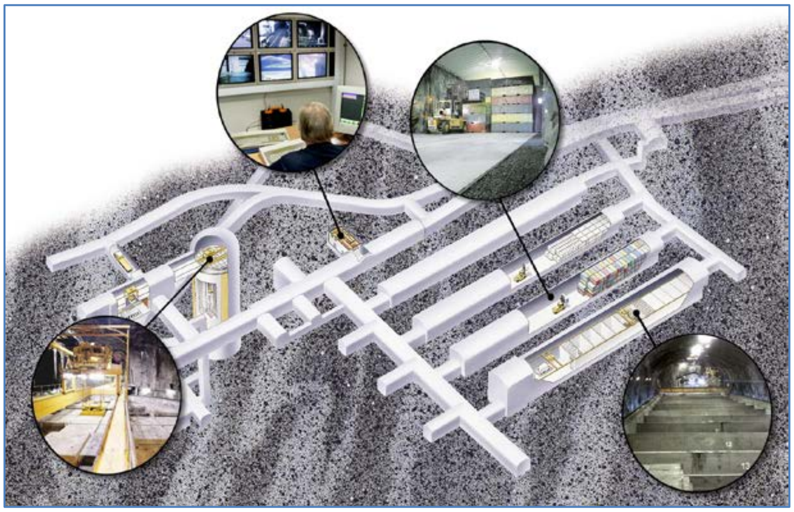

Fig. 1. General plan of SFR 1, repository for low and intermediate level radioactive waste.

Silo

The silo is built as a free-standing concrete cylinder, Figure 2. The silo is constructed of in-situ cast concrete and is founded on a bed of sand and bentonite. The silo contains most of the radioactivity in SFR 1 (about 80%) and therefore has the most extensive barriers. The innermost barrier is the waste package and consists of the waste matrix and the waste container (the packaging). The waste container is grouted with porous concrete which together with the reinforced concrete compartment walls and silo walls constitute additional barriers. Around the silo walls is gravity compacted bentonite as a diffusion barrier between the silo and the rock.

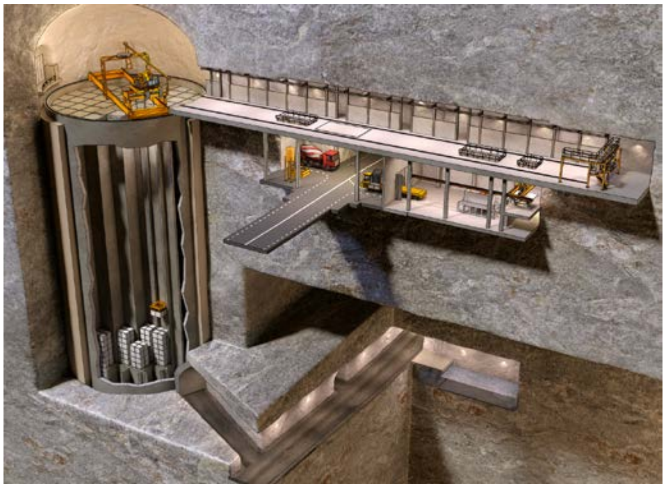

Fig. 2. Silo in SFR 1, for intermediate level waste with a surface dose rate of less than 500 mSv/h.

Rock Vault for Intermediate-Level Waste, BMA

The rock vault (silo) for intermediate-level waste contains approximately 20% of the total activity in SFR 1. The packages consist mainly of moulds or drums, see Figure 6, and the repository consists of a number of in-situ cast reinforced concrete storage compartments, Figure 3. During the operational phase a prefabricated concrete lid covers the filled compartments. On top of the prefabricated lids, a concrete layer is cast to give the structure added stability and tightness.

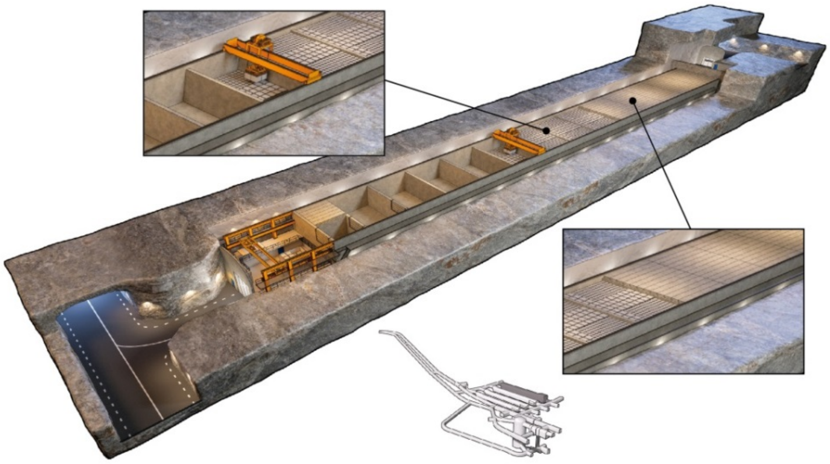

Fig. 3. 1BMA in SFR 1, rock vault for waste with a surface dose rate of less than 100 mSv/h.

Rock Vaults 1BTF and 2BTF

The vaults 1 and 2BTF are designed primarily for storing concrete tanks and drums with low activity, see Figure 4. The vaults have a concrete floor, and rock walls and roofs are lined with shotcrete. The ash drums in 1BTF are grouted with concrete.

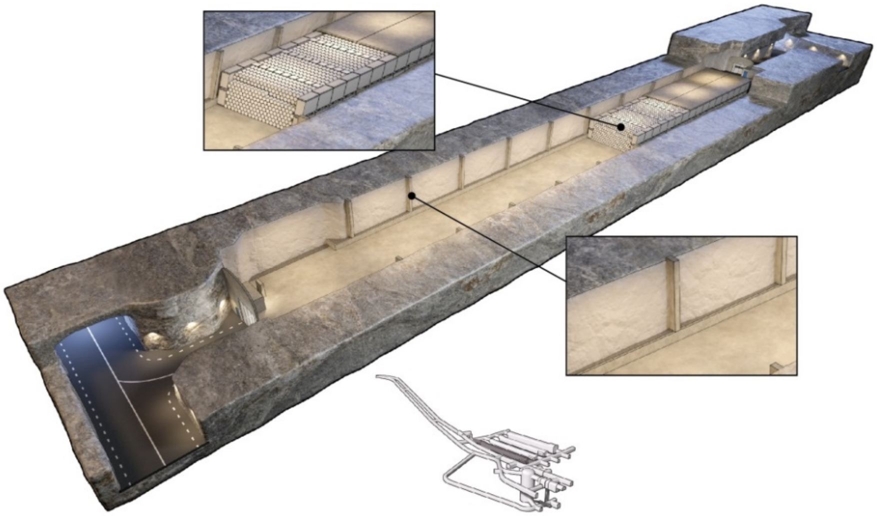

Fig. 4a. 1BTF in SFR 1, for waste (mainly ash drums) with a surface dose rate of less than 10 mSv/h.

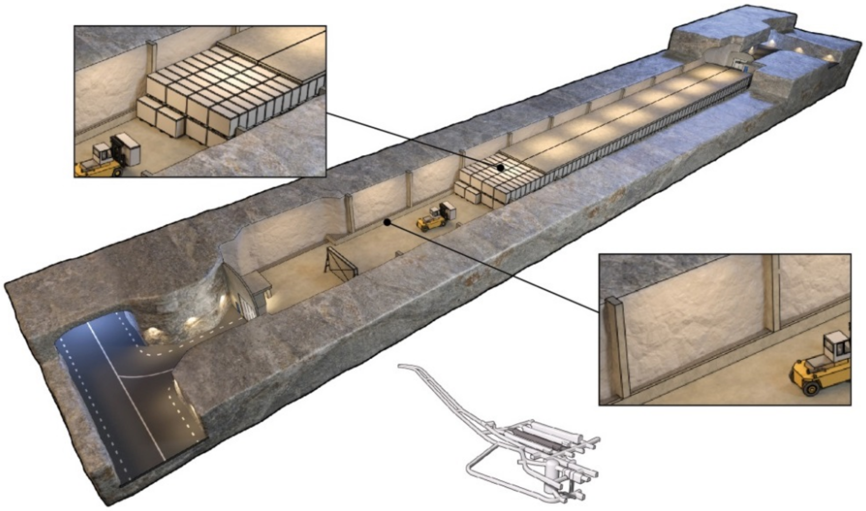

Fig. 4b. 2BTF in SFR 1, rock vault for concrete tanks (containing dewatered CCU-resins) with a surface dose rate less than 10 mSv/h.

Rock Vault for Low-Level Waste, BLA

The rock vault has a concrete floor, and the rock walls and roof are lined with shotcrete, Figure 5. The waste packages are standard shipping containers (cf. Figure 6).

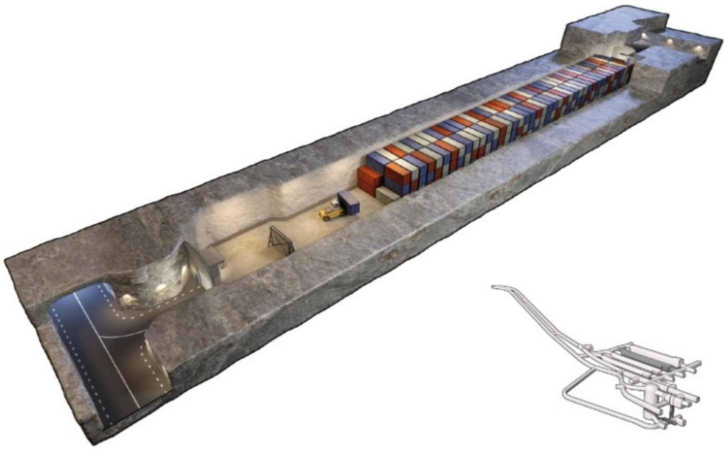

Fig. 5. 1BLA in SFR 1, for containers with low level waste having a surface dose rate of less than 2 mSv/h.

The Waste in SFR 1

Much of the radioactive waste in SFR 1 is present as bead resin, powder resin, mechanical filter aids and precipitation sludge. Another large part of the waste volume in SFR 1 consists of metals, above all carbon steel and stainless steel. Further materials in the waste include cellulose (paper, cotton and wood) and plastics (e.g. polystyrene, PVC, polyethylene, polypropylene, etc.), mineral wool (used for insulation), concrete and brick. Various additional materials are also included in smaller quantities.

Waste to SFR 1 is mainly packaged in the following containers:

- Concrete moulds (with cement-solidified ion exchange resins, filter aids and evaporator concentrate as well as concrete-stabilized trash and scrap metal).
- Steel moulds (with cement- or bitumen- or concrete-stabilized trash and scrap metal).
- Steel drums (with cement- or bitumen-solidified ion exchange resins).
- Steel drums (with cement-stabilized ash drums).
- Standard containers (mainly with trash and scrap metal).
- Concrete tanks (with dewatered ion exchange resins).

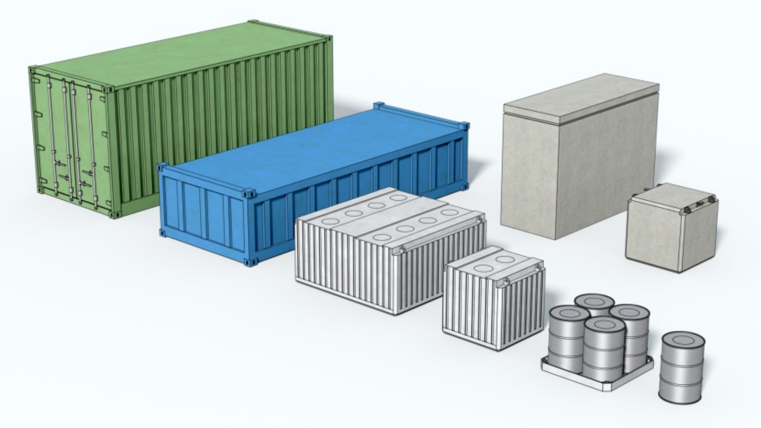

Fig. 6. Types of waste containers in SFR 1.

THE EXTENSION OF SFR

The extension of the repository will host one rock vault for ILW, four vaults for LLW, and one vault for disposal of BWR reactor pressure vessels (RPVs). Figure 7 shows an illustration of a possible layout for the extension of SFR.

Fig. 7. An illustration of a possible layout for the extension of SFR (left sections).

According to present plans, the extension must facilitate about 120,000 m^3 waste. Most of the decommissioning waste can be placed in repository parts similar to the existing 1BLA. For the additional operational waste and a small part of the decommissioning waste a repository part with more technical barriers is needed, planned as a repository part similar to 1BMA.

As the existing SFR 1 has been in operation for more than 20 years, valuable experience from the operation and long-term safety assessments of the repository has been used when designing the extension. E.g. the ILW rock vault is designed as separate caissons and planned to be erected with non-reinforced concrete (cf. Figure 8), compared to the construction of the existing ILW vault which is one long reinforced concrete structure. The method to produce the caissons will be tested and evaluated in full-scale in the next coming years. As the concrete walls will be non-reinforced care must be taken to ensure that no waste having a significant risk of swelling will be allowed.

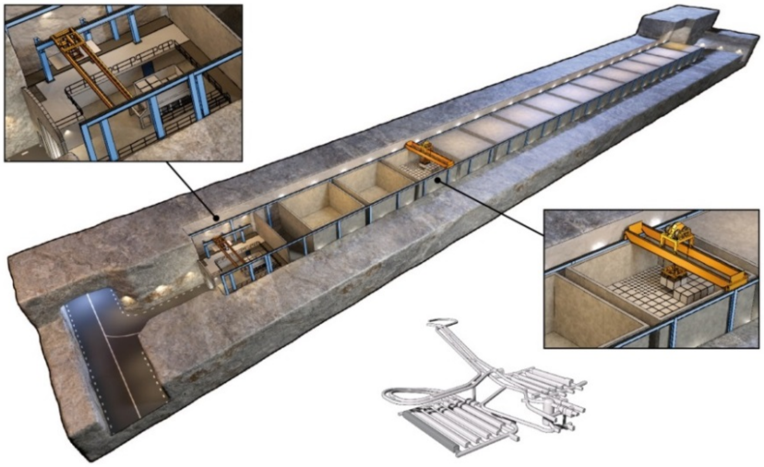

Fig. 8. 2BMA in SFR 2, rock vault for intermediate level waste.

The present plan is to deposit the BWR RPV's in one piece, thus, the extension of SFR must be designed for the size and weight of whole RPV's, but without the reactor internals, i.e. without the core components (Figure 9).

Fig. 9. 1BRT in SFR 2, rock vault for BWR reactor pressure vessels.

The rock vaults for low level decommissioning waste is planned to have a similar design as the existing low level rock vault (1BLA, cf. Figure 5). As there will be a very limited amount of radioactivity and, as showed in the safety case, there is a very limited radiation risk from this type of waste, the extra cost of designing a significant long-term safety barrier is not considered justified. However, as compared to the existing rock vault for the low level waste, there will be concrete walls alongside the waste containers, mainly as an operational safety feature (Figure 10).

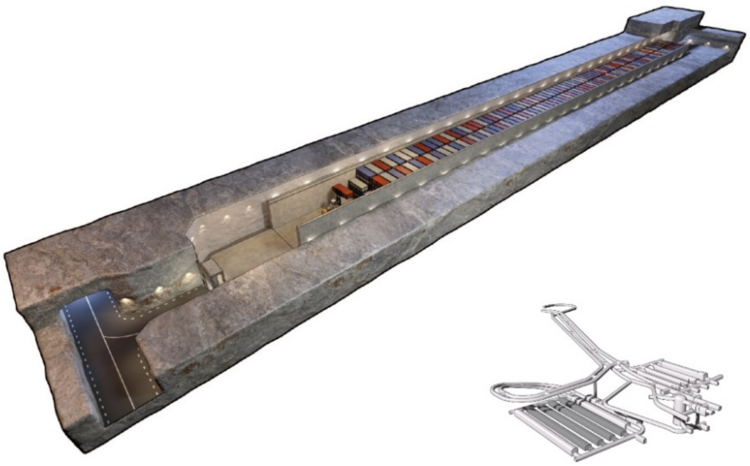

Fig. 10. 2-5BLA in SFR 2, for containers with low level waste having a surface dose rate of less than 2 mSv/h.

Site Descriptive Model (SDM)

SKB has performed site investigations (2008-2010) in the vicinity of the existing SFR in order to identify a rock volume large enough to host the repository/extension that also complies with requirements related to the long-term safety of the facility. The result from the site investigation together with experiences from earlier underground construction in the area (existing SFR and applicable parts of the NPPs) indicate that the investigated area has suitable conditions for construction of underground facilities, relatively limited need for use of grouting, shotcrete and reinforcements, and the fracture frequency observed during site investigations (~3/m) is regarded as a comparatively good rock. A new site descriptive model has been prepared using the result from the site investigation, and the hydrogeological model of the area is being updated (Figure 11).

The SDM is used to determine the preliminary layout and depth of the extension as illustrated in Figure 12. The final layout of the extension will be determined during the excavation at repository depths.

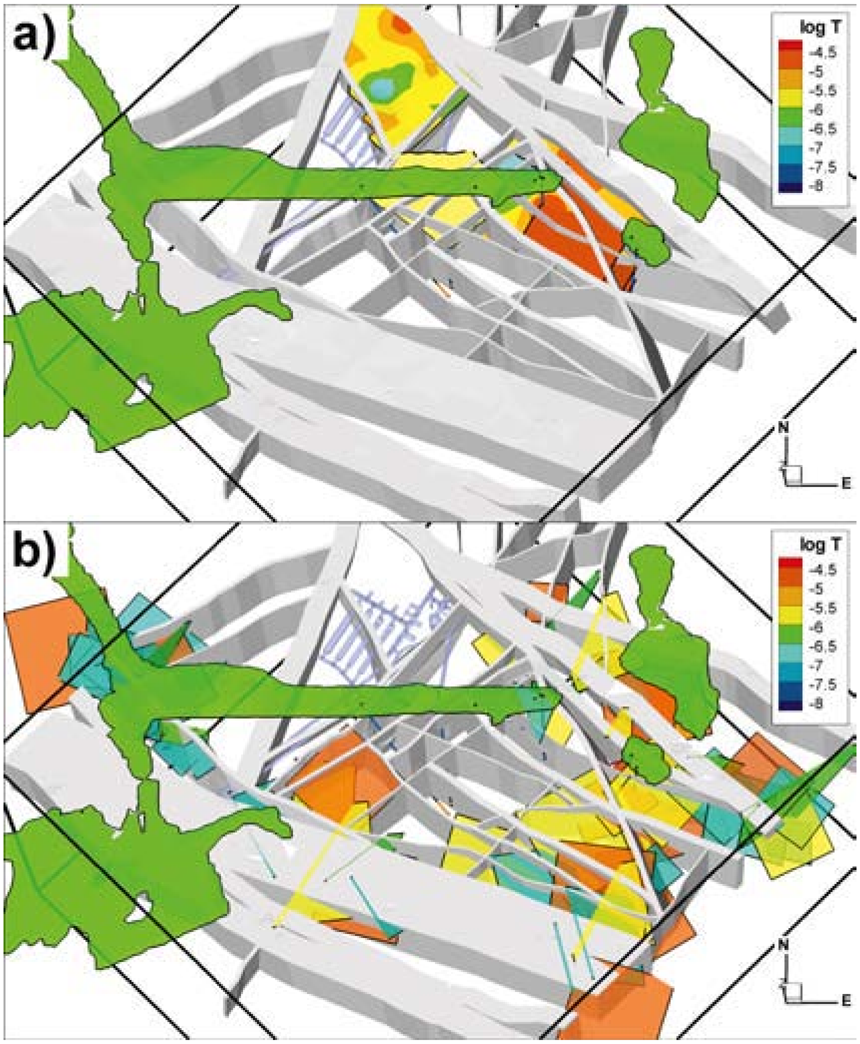

Fig. 11. Site descriptive model of SFR. Overview of the interpreted spatial pattern of the most hydraulically significant structures: a) deterministic modelled SBA-structures (SBA=Shallow Bedrock Aquifer), and b) conditioned stochastic representation of the remaining unresolved PDZs. [2]

SAFETY CASE

Flow Modelling

The mathematical model, input parameters, and the geometries required to evaluate groundwater flow on repository scale (10^2 m scale) have been implemented and solved in the commercial finite element code COMSOL Multiphysics. The COMSOL repository-scale model reads in the boundary conditions and rock hydraulic properties from a regional hydrogeological model set which is solved in DarcyTools. [3]

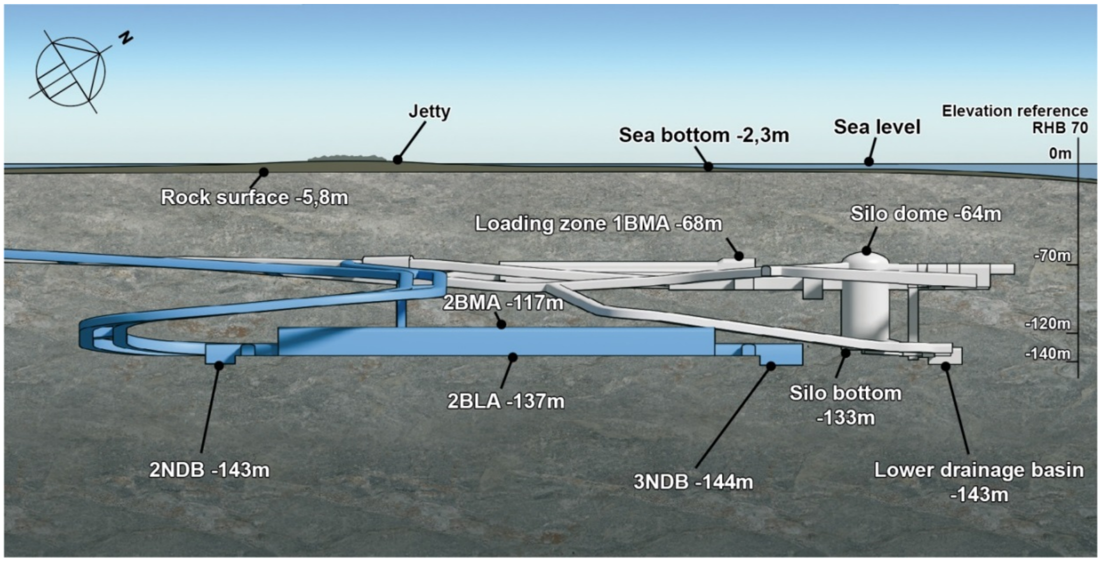

Fig. 12.Planned layout and repository depth of the extension (in blue).

Once solved, the COMSOL repository-scale model produces tables of groundwater flow rates for specified control volumes representing different parts of the repository vaults and waste. These tables serve as input to the radionuclide transport model that is set up and solved in the commercial software Ecolego.

In the Comsol model, SFR 1 and SFR 3 have been modeled separately. A base case has been defined for each model using a reference description of the rock and hydraulic parameters representing the initial state of the repository. Three steady-state flow fields have been calculated from the regional hydrogeology model for each repository-scale model, representing three different positions of the repository relative to the shoreline: a case (1) with the repository being submerged, a case (2) with the shoreline passing over the repository, and a case (3) where the repository footprint is well above the shoreline. In addition to the base case, a set of cases investigating different hydraulic properties of repository components have been simulated to assess the impact on groundwater flow in the repository.

The Extension of the Repository, SFR 3

Shoreline position 1 (submerged repository, 2000 AD)

For base case and shoreline position 1 (i.e. the repository submerged) the flowpaths followed by the groundwater reaching each individual vault are illustrated in Figure 13 *(right)* (Note that the figure shows the result of one run and is only given as an example of the results). The color of the lines represents the destination vault while their thickness is proportional to the groundwater flow. At the submerged case groundwater flowing upwards from the south through a fault zone reach the southernmost end of the vaults (Figure 13, *right*). Vaults 2BLA and 3BLA get infiltration from a vertical source further north, while 3BLA and 5BLA also receive water at its north extreme. Outflow from the vaults (Figure 13, *left*) can be roughly divided in two zones. At the south end of the vaults there is vertical upward outflow from vaults BRT, 5BLA, 4 BLA and 3BLA. The half north part of the vaults has a diffuse outflow, with a NE direction in the case of the 2BMA and NW for the rest of the vaults (2BLA, 3BLA, 4BLA and 5BLA).

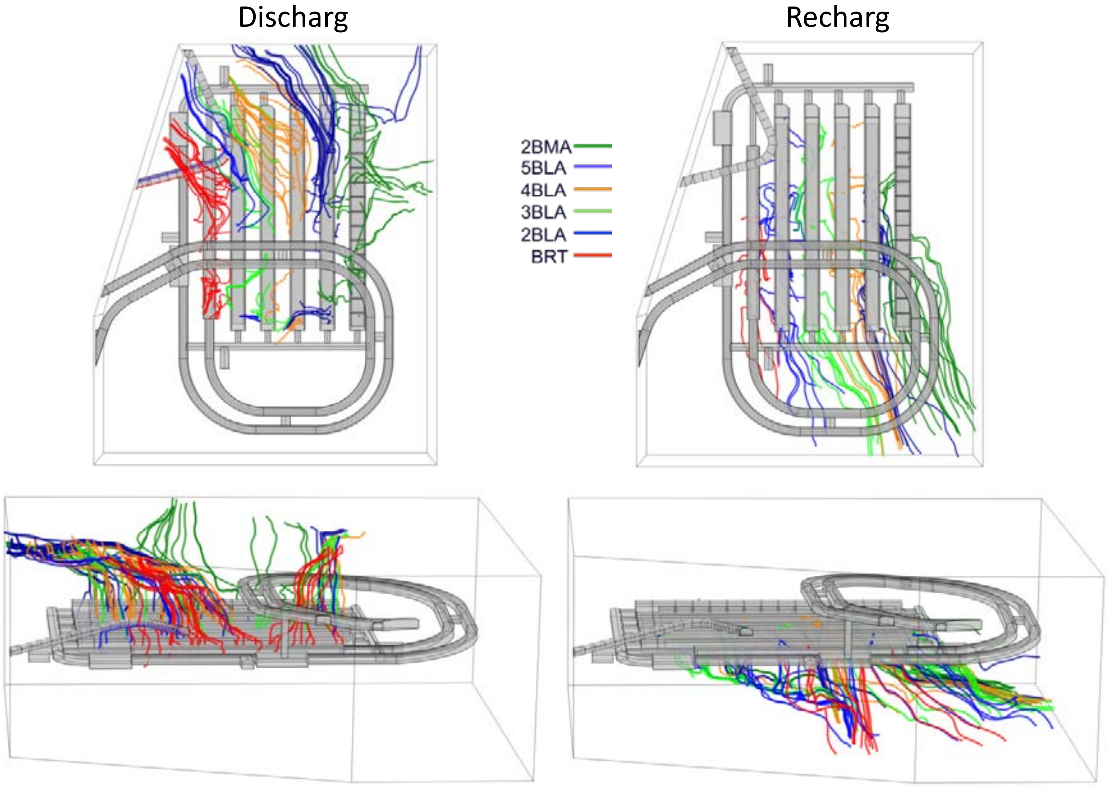

Fig. 13. Groundwater streamlines leaving (left) and reaching (right) individual vaults (color tubes) for the Base case and the shoreline position 1. [3]

Shoreline position 3 (repository footprint well above the shoreline, 5000 AD

For the shoreline position 3, a rather distributed recharge to all vaults form the top boundary is observed (Figure 14, *right*). (Note that the figure shows the result of one run and is only given as an example of the results). Groundwater moves horizontally through the most permeable structures at the surface and penetrates vertically through small fault zones towards the repository. Part of the inflow to 2BMA and 5BLA comes from the access ramp. The outflow moves downwards vertically from the vaults until the sub-horizontal fault is reached and then moves north from the repository following mainly two alignments (Figure 14, *left*). The first one, towards the NE corresponds to the outflow from 2BMA, 5BLA and 4BLA and part of the 3BLA. The second deeper alignment towards the NW carries the discharge from 2BLA and 3BLA.

Exit locations

Exit locations [4] for flow across rock vaults were simulated by means of forward particle tracking. The spatial distribution of these locations was quantified in terms of areal density, number of particles/m^2, based on 1,000,000 particles released uniformly within the rock vaults of SFR 1 and SFR 3, respectively. The starting points of trajectories were defined at the tunnel-wall passage, and the termination points were defined at the bedrock/regolith interface passage. The patterns in exit locations of SFR 1 and SFR 3 were compared over time, in terms of the six selected time slices (Figure 15). In the present report only the exit locations for Bedrock case 1 is shown, however calculations has shown that the different Bedrock cases have similar exit locations. A couple of characteristics could be noted:

- Shoreline displacement successively forces the exit locations further away from the release points. Before the time slice 3500 AD, exit locations are essentially below the shoreline. The flow regime changes from being mainly upward-directed under early time slices, to be more horizontal at later time slices.
- The density of exit locations is strongly correlated to ground intercepts of deformation zones (most likely, also transmissive stochastic DFN fractures).

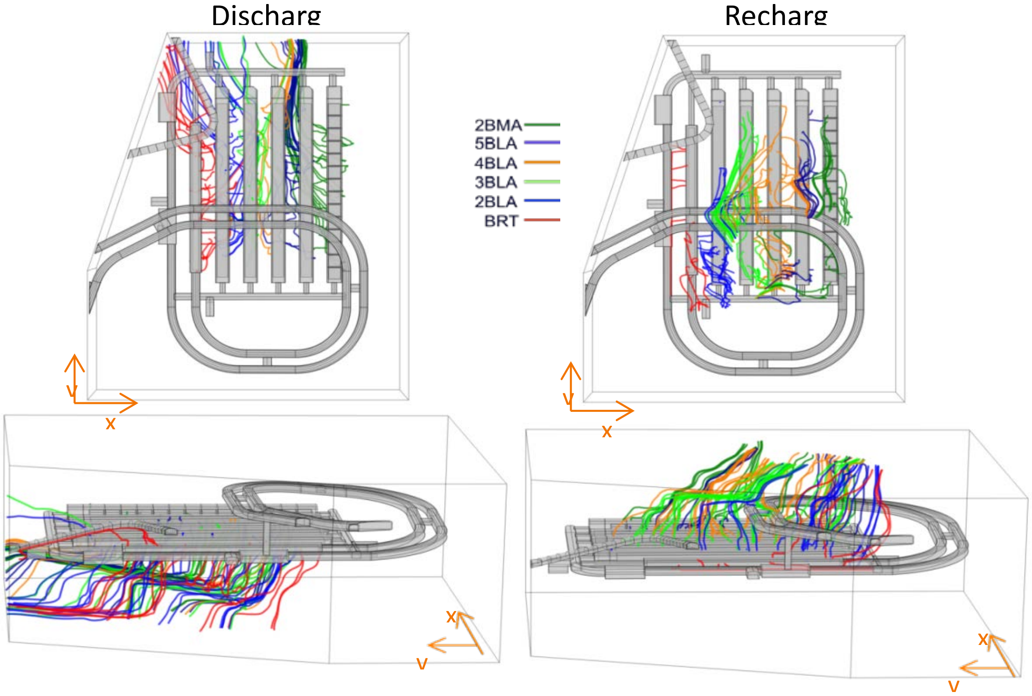

Fig. 14. Groundwater streamlines leaving (left) and reaching (right) individual vaults (color tubes) for the Base case and the shoreline position 3. [3]

Dose Calculations

Figure 16 shows the nuclide contribution to the calculated dose from the combined extended repository. As can be seen in the figure the main contribution to the long-term dose comes from long-lived low energetic activation products. Further, as expected, these are mainly low or non-sorbing anions, and some low sorbing cations like nickel-59. If legacy waste containing uranium and transuranic elements, these will also contribute to the long-term risk of the repository.

Figure 17 shows the relative risk per rock vault as a function of time up to 100,000 years. The analysis indicates that the disposal strategy with the major part of the radioactivity stored in the silo, second most radioactive in the BMA-vaults and less activity in the BTF and BLA-vaults works also in practise. This is of course very comforting and shows that the method for handling and disposal of low and intermediate level radioactive waste is safe both in the short term as well as long term perspective.

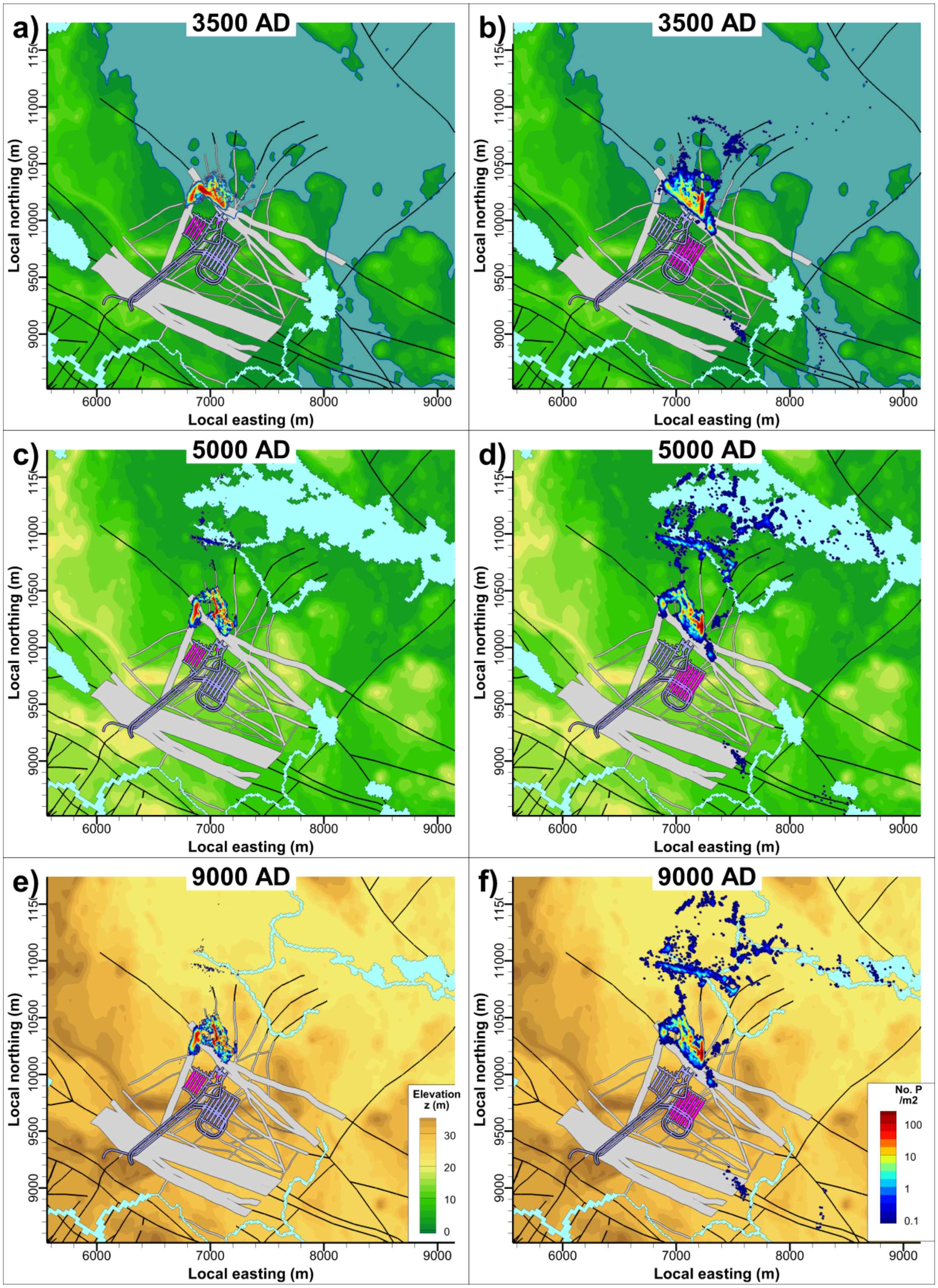

Fig. 15. Exit locations for particles starting in the SFR 1 rock vaults (pink shade; left) and in the SFR 3 rock vaults (pink shade; right), Bedrock case 1, time slices 3500 to 9000 AD. [4]

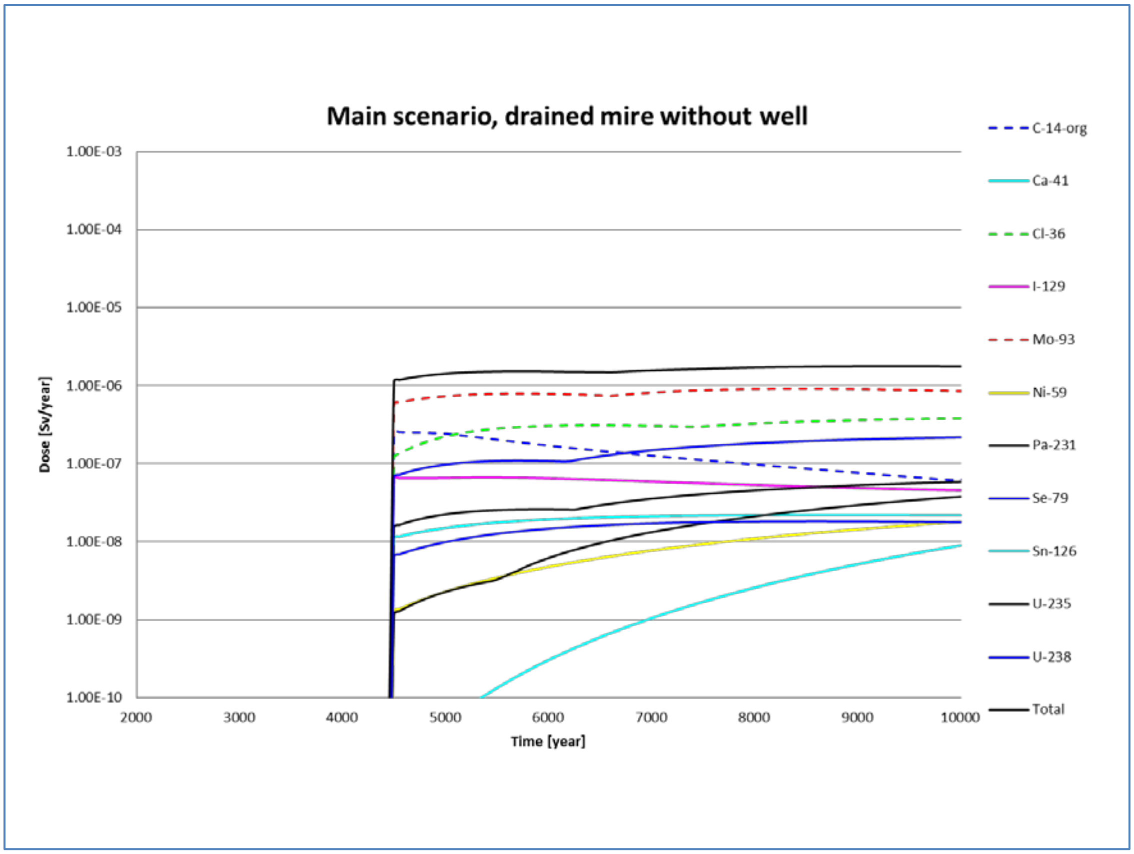

Fig. 16. Preliminary dose calculations from the combined extended repository (Main case). [5]

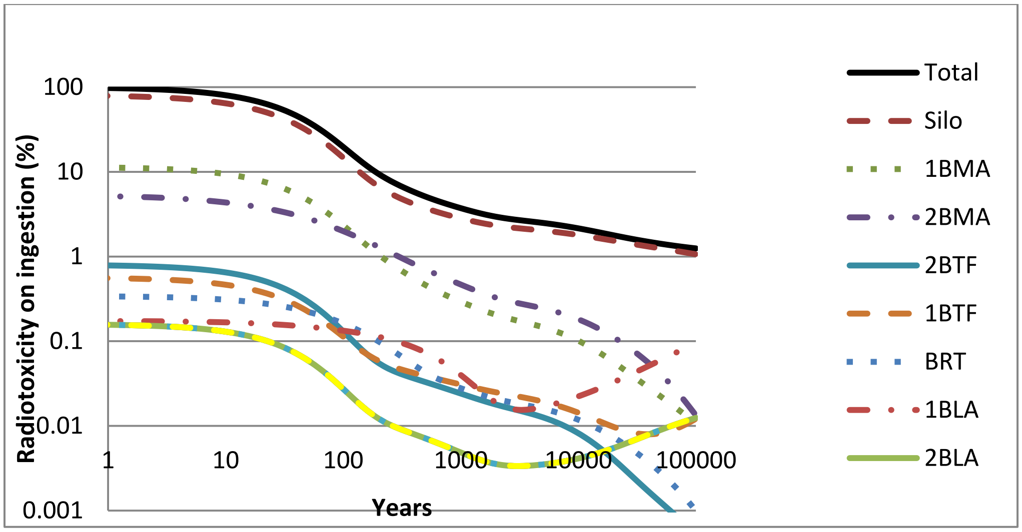

Fig. 17. Contribution (in percentage) from the rock vaults to the total calculated risk from the SFR repository. The increase from the BLA-vaults after long time is due to the U-235 decay chain from legacy waste. [5]

CONCLUSIONS

An extension of the existing SFR repository for low and intermediate level waste has been designed and the long-term safety of the extended repository was analyzed. Valuable experience from 25 years of operation of the existing repository was used in the design of the new rock vaults.

Groundwater flow through the extended repository was simulated and nuclide exit locations in the biosphere calculated. Dose calculations for nuclides contributing significantly to the repository long-term risk, given as Sv/year, indicate as expected that the highest dose is received due to releases from the silo, followed by releases from the BMA rock vault for intermediate level waste, with the lowest radiological risk caused by the waste in the low level waste vaults.

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