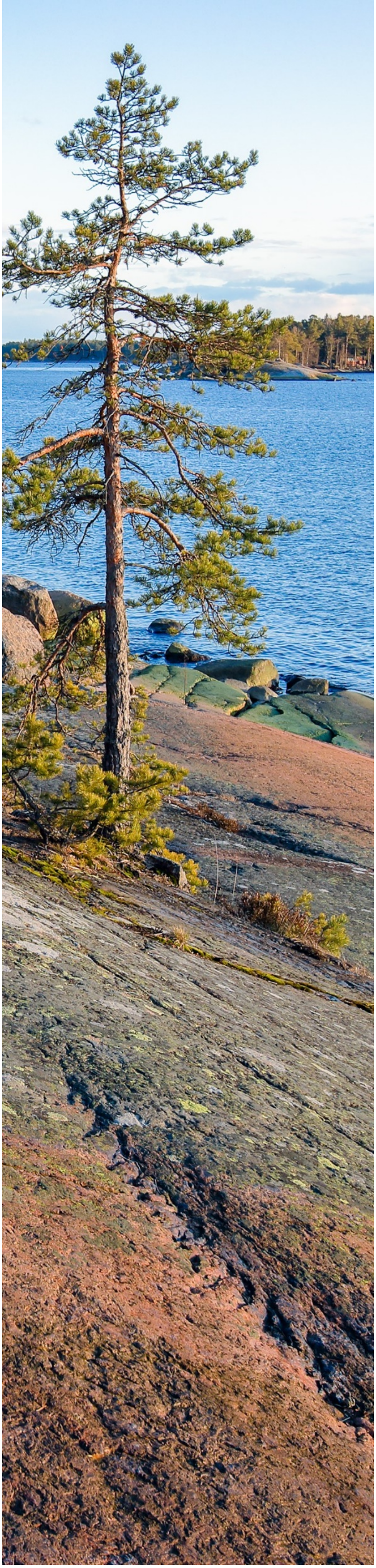

Technical report

Underground non-radioactive waste repository in Norwegian National Disposal Facility for Radioactive Waste

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ABSTRACT

The first concept description for a Norwegian National Facility for nuclear waste disposal was described by Ikonen et al. (2020). The facility is to be a final repository for all decommissioning waste from Norwegian research reactors in Halden and Kjeller (including all classes of waste from spent research-reactor fuel to non-radioactive decommissioning waste), and the radioactive waste that will be generated in Norway over the 100 years following the commissioning of the facility.

In this concept description report, an alternative positioning of non-radioactive waste is presented. Instead of landfill-type repository, the non-radioactive waste is placed in underground waste halls at the depth of 100 meters. Other waste types remain in former positions/repositories as presented in Ikonen et al. (2020).

In this report it has been assumed that the National Facility contains the following repository types:

- Intermediate depth repository for non-radioactive decommissioning waste, mainly concrete and soil,
- Intermediate depth repository for very low, low, and intermediate level waste,
- Deep geological repository (DGR) for high level waste.

Deep borehole repository for high level waste as an alternative to the DGR is only mentioned.

The underground non-radioactive waste repository concept description acts e.g., as a basis for further design of facilities and production of alternative combinations of facilities for further studies. The final concept might not include all repository types listed above.

In this report, the differences from concept description by Ikonen et al. (2020) are described - issues that have not changed are excluded. New underground openings for non-radioactive waste are designed to the depth of 100 meters where an expansion tunnel for this type of purpose was already planned. Long-term safety considerations were out of this reports scope.

The underground repositories have been designed for operations taking place at two levels: a repository for non-radioactive, very low, low, and intermediate-level waste at intermediate depth (100 metres) and a DGR for high-level waste at the depth of 400 metres. The KBS-3 type DGR could be replaced by a deep borehole with a maximum depth of approximately 3500 metres.

Packaging assumption were done based on inventory data and standard 20' standard shipping containers were assumed to be used as waste packages as previously. The non-radioactive waste is assumed to be packed outside the National Facility.

Activities related to planning, construction, operation, decommissioning and closure phases, including operational safety, required systems and overall schedule, are briefly described. Preliminary design for the required buildings and facilities above ground are also described.

The concept description maintains maximum flexibility to allow changes in the design solutions. Waste acceptance criteria or other details are not decided at this stage.

Costs have been estimated, based on general European cost levels. Total costs to construct, operate and close the non-radioactive waste repository as a part of the National Facility are:

Site investigations	1 MEUR
Investment/construction	37 MEUR
Operation	3 MEUR
Closure	2 MEUR
Total	43 MEUR

Keywords: spent nuclear fuel, non-radioactive waste, radioactive waste, disposal, repository, intermediate depth, deep geological repository, deep borehole, Norwegian National Facility, KBS-3

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1 Introduction

Norwegian Nuclear Decommissioning NND has signed a contract with Finnish AINS Group together with subconsultants VTT Technical Research Centre of Finland and BGE Technology GmbH of Germany. The group assists NND with the concept development and technical design for their disposal solution for radioactive waste in Norway.

Norway's inventory of radioactive waste is characterized by high level waste from the research reactors in Halden and Kjeller, taken out of operation. In addition, there will be non-radioactive, very low, low and intermediate level waste from the planned decommissioning of the research reactors and other nuclear facilities. Norway has also other low-level waste generated by e.g. medical sector.

According to NND's preliminary plans, the spent nuclear fuel accumulated in the research reactors in Halden and Kjeller will be disposed of in a national facility. This nuclear waste facility, called Norwegian National Facility, could consist of underground repository facilities and other underground openings as well as auxiliary facilities above ground. This report describes the proposed conceptual disposal plan for the National Facility in the case where non-radioactive waste is disposed of in underground waste halls at intermediate depth. The report reflects the situation in 2021.

The disposal facility concept description provides the following:

- tools for communicating current planning stage to stakeholders, e.g., the authorities and general public,
- initial data for the scheduling and cost estimates for setting out the financial provisions for waste management,
- initial data for the further preliminary design of facilities,
- input for planning research and development activities regarding the different areas of disposal technology,
- guidance for bedrock surveys carried out in potential sites,
- guidance for assessing the feasibility of disposal,
- a part of the overall description of the entire project.

The Norwegian National Facility is proposed to consist of the following separate disposal systems:

- Intermediate depth repository for non-radioactive decommissioning waste from decommissioning of the nuclear facilities in Halden and Kjeller, mainly concrete and soil,
- Intermediate depth repository for very low-level, low-level and intermediate-level radioactive waste (VLLW, LLW and ILW),
- High-level waste (HLW), repository: an excavated deep geological repository (GDR) (or a deep borehole repository, excluded from this report).

An alternative positioning of non-radioactive waste is presented in this report. Instead of landfill-type repository, the non-radioactive waste is in this work placed in underground waste halls at the depth of 100 meters, where the repository for VLLW, LLW and ILW as part of the Norwegian National Facility was already planned to locate (Ikonen et al. 2020). It could be beneficial to locate both repositories, the non-radioactive waste and VLLW, LLW and ILW, on the same level. The excavation could be more effective this way, if all waste halls are excavated at the same depth compared to the alternative that non-radioactive waste halls are at a different location along the access tunnel that is used for rock transports at the same time. However, it is possible to excavate the non-radioactive waste repository shallower or deeper than on the 100 meters level. If the non-radioactive waste repository would be located at shallower depth, transports of excavated rock and waste would be shorter. Impact of depth on costs and operational safety for locating the two repositories could be studied in more detail in future. No benefits have been identified in locating the non-radioactive waste repository deeper than where the intermediate depth repository will be.

In this alternative, other than non-radioactive waste types remain in former positions/repositories as presented in Ikonen et al. (2020). The final realised National Facility concept might not include all the repository types listed above, as these are now concept studies to evaluate each one's benefits and challenges. Long term safety considerations were out of this report scope.

Assumptions concerning packing the non-radioactive waste were done based on inventory data and standard 20' standard shipping containers were assumed to be used as waste packages as in Ikonen et al. (2020). The non-radioactive waste is assumed to be packed outside the National Facility.

Activities related to planning, construction, operation, decommissioning and closure phases, with regard to operational safety, required systems and overall schedule, are briefly described. Preliminary design for the required buildings and facilities above ground are also described. The concept description maintains maximum flexibility to allow changes in the design solutions. Waste acceptance criteria or other details are not locked down at this stage.

For all underground repositories, the depth will depend strongly on the site geology. The aim is to maintain maximum flexibility in designs to allow changes in the design solutions. The repository for VLLW, LLW and ILW will be in operation for 100 years, but the waste halls for the non-radioactive waste will be in operation for only couple of years. As technologies develop and more knowledge is accumulated, the disposal methods can be changed.

In this report the reference solution includes the following assumptions:

- The concept is assumed to rely on the existing public domain know-how.
- Waste properties and inventories, container designs and other predisposal waste handling, conditioning or treatment are out of the scope of this report. Assumptions used in Ikonen et al. (2020) are used.
- The non-radioactive waste packages are transported from packaging facilities to the National Facility.
- Waste packages will be transported via an access tunnel down to the intermediate depth repository level.
- The underground repository facilities are located on two levels: at an approximate depth of 100 meters, and 400 metres for DGR.
- The non-radioactive waste halls are backfilled using crushed rock.
- Building code type regulations are followed instead of pure mining law as is done in e.g., Finland.
- All other assumptions are used in line with Ikonen et a. (2020).

Chapter 2 of this report presents the initial material for planning and design work. It also includes the basic data of radioactive wastes to be disposed of. Chapter 3 presents a summary description of the entire facility complex and overall schedule. Chapter 4 describes the facilities above ground.

The implementation, operation, decommissioning and closure of the intermediate depth non-radioactive waste repository of the National Facility is presented in Chapter 5. This includes a presentation of facilities, systems, construction process, operational activities, backfilling and closure.

Chapter 6 includes cost estimation for non-radioactive waste repository as a part of the National Facility. Site investigations, construction, operation, and closure costs are presented.

2 Design Basis

2.1 Intermediate depth repository concept

The disposal system is conceptually divided into components as shown in Figure 2-1. The division helps in defining the safety functions for each component and modelling their evolution in the performance assessment.

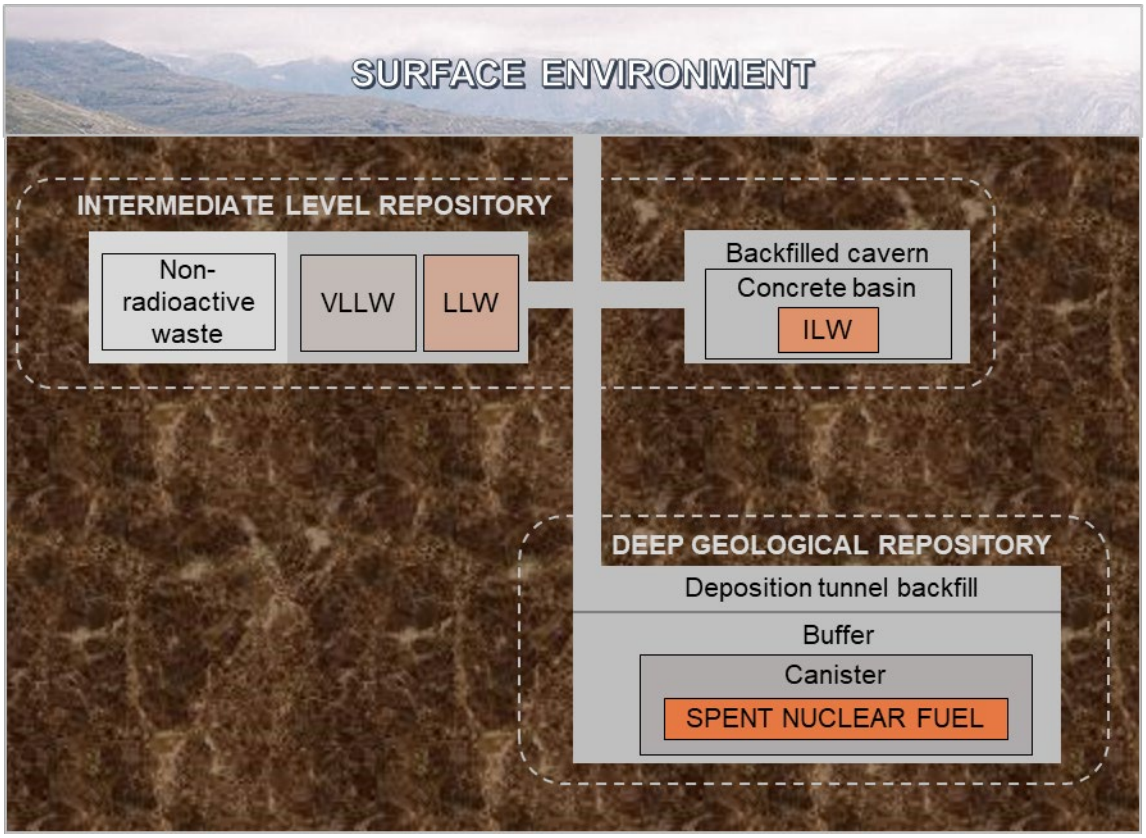

Figure 2-1. Conceptual representation of components of the disposal system. The waste halls on the left illustrate non-radioactive waste, LLW and VLLW disposed in the halls. The one on the top right is ILW, and ILW packages surrounded by concrete barriers inside a backfilled waste cavern. The deposition tunnel down illustrates HLW and canisters surrounded by buffer and deposition tunnel backfill (modified via Ikonen et al. (2020) from Posiva 2017 and Nummi 2018).

The components for non-radioactive waste repository are defined as:

- Non-radioactive waste packages: waste disposed in the repository halls without additional engineered barriers. Waste mainly consists of concrete and soil, and the waste containers are assumed to be standard containers.
- Waste halls: halls excavated in the bedrock hosting the waste (Figure 2-2).
- Closure in other openings than non-radioactive waste halls: Structures designed to separate the repositories from the surface environment. Closure includes concrete plugs and backfilling in some waste halls and tunnels.
- Bedrock: Bedrock at the disposal site hosting the repository serving as a natural barrier for radioactive waste (not for non-radioactive waste).

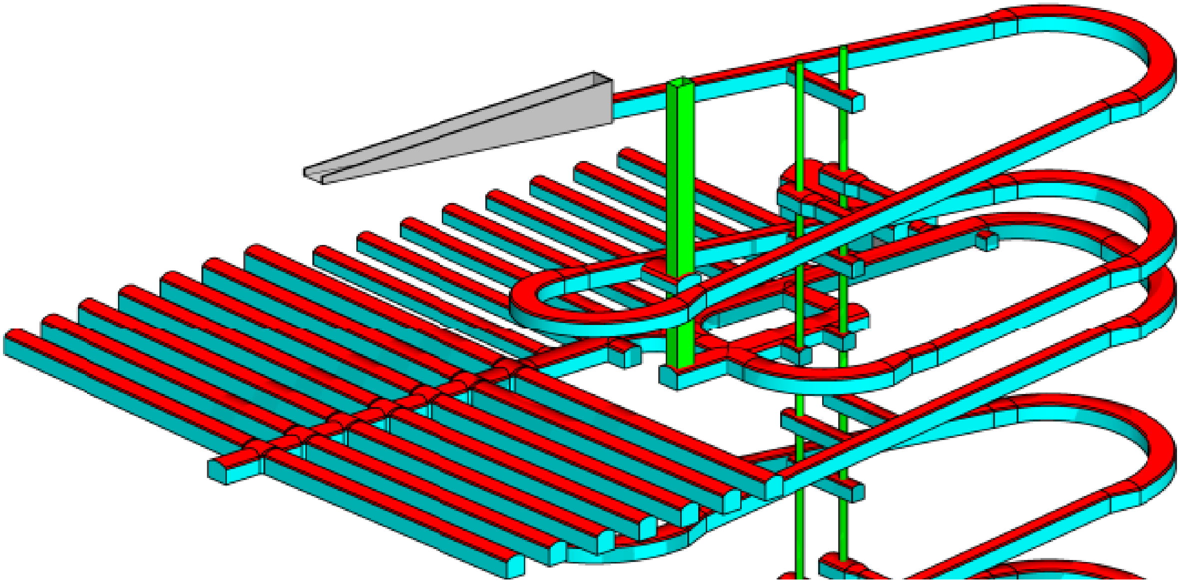

Figure 2-2. Intermediate depth repository for non-radioactive waste, VLLW, LLW and ILW waste. For details, see Figure 5-1. Figure by AINS.

The waste deposited in the non-radioactive waste repository will consist of decommissioning waste classified as non-radioactive.

2.2 Basic parameters

The basic parameters for the design of the National Facility are compiled in this section.

2.2.1 Packaging

Detailed design of packaging is out of scope of this report. Non-radioactive waste packaging option was followed according to Ikonen et al. (2020). The concept description of the National Facility is, at this point, still flexible and able to be adjusted to different waste acceptance criteria or packaging options.

Non-radioactive concrete and soil deposited in the repository will be packaged to standard 20' ISO shipping (sea) containers (outer dimensions length 6,058 m, width 2,438 m, height 2,592 m, max capacity 28 tonnes in mass). The dimensioning factor is the maximum bearing capacity of the containers. The containers will be roughly half empty and therefore this can be optimised in later stages by developing/choosing smaller containers that could be filled to the full. This would lead to smaller amount of waste halls and lower costs. The waste is assumed to be packed outside the National Facility.

2.2.2 Waste inventory

The waste is categorized by activity into non-radioactive (NRW) (i.e., below the free release limit), LLW that includes also VLLW, ILW and HLW. For the non-radioactive concrete and soil, the number for containers is 1165, as given in Table 2-1.

Table 2-1. The volume of deposited concrete and soil waste depending on the selected pre-treatment option. For packing in an ISO 20' shipping container, the dimensioning factor is the weight of the waste (Ikonen et al. 2020).

Container (open top shipping container, 20´)	Value	Unit
Outer volume	38	m^3
Maximum capacity (inner volume)	33	m^3
Maximum capacity (mass)	28	tonnes
Number of containers	1,165	pieces
Total mass to be deposited	32,613	tonnes
Total volume of containers	44,572	m^3

2.2.3 Layout flexibility and constraints

The design requirements emphasise the importance of flexibility in space allocation to allow possible changes that may be caused by, for example, bedrock conditions, the amount of waste to be disposed of, or changes in schedules (Saanio et al. 2013).

The methods used for the construction, operation and sealing of repositories and other underground openings shall be chosen so that the bedrock will maintain its natural containment characteristics in an optimal fashion. The migration of materials detrimental to long-term safety, such as organic matter and oxidising agents, shall be minimised. These matters shall be taken into account when planning, designing and constructing the disposal facility.

The planned disposal depths shall have sufficiently large sparsely fractured rock volumes that are suitable for the construction of repositories. The properties of bedrock in the planned disposal site shall be established through studies carried out at the planned disposal depths to provide the necessary information for planning and designing the repositories and for producing the safety assessment.

The layout, excavation, construction, and closure of underground facilities shall be so implemented that the bedrock will maintain the properties important to long-term safety.

Target properties will be set for the bedrock to ensure long-term stability and safety of the repositories. A research, testing and monitoring programme, which will ensure the suitability of the rock for disposal, inspects bedrock characteristics. This programme will be implemented during planning/siting, construction and operation of the disposal facility. This programme (Saanio et al. 2013) typically includes at least:

- investigation into the properties of bedrock blocks to be excavated,
- monitoring of stresses, movements and transformations of bedrock surrounding the repositories,
- monitoring hydrogeology surrounding the repositories,
- monitoring groundwater chemistry at the facility site, and
- monitoring the behaviour of the engineered barriers.

A provision shall be made for a potential change in the underground facility plan. This is to ensure that in case the quality of the rock surrounding the planned repositories proves to be significantly less favourable than required the situation can be handled and excavation re-directed, if necessary. To maintain the bedrock properties that are favourable to long-term safety, the following (Saanio et al. 2013) shall be taken into account:

- the excavation method limits the excavation disturbances to the bedrock surrounding the repositories,
- the reinforcement and sealing of bedrock shall be carried out in such a manner that no significant quantities of materials harmful to the performance of release barriers enter the repositories,
- the migration of organic and oxidising matters to the repositories shall be minimised, and

- the repository openings shall be backfilled and sealed off immediately when the disposal operations and associated monitoring operations allow.

2.2.4 Implementation in phases

The implementation of disposal as a whole shall be planned with due regard to safety. The planning shall consider the set time frame and the utilisation of the best available technology and scientific knowledge.

After the planning/siting, implementation of disposal facility includes the following phases:

- Site characterisation and monitoring: research, development, testing and planning work (the site confirmation for a detailed repository design). This continues until post-closure phase.
- Detailed waste inventory.
- Updating the detailed design based on characterisation.
- Engineered barrier system design testing and demonstrations.
- Safety assessment.
- Packaging the waste outside the National Facility.
- Transfer of waste packages into their deposition positions and installation of wall structures in each non-radioactive waste hall.
- Closure of other underground openings.
- Post-closure monitoring, if required.

These phases, which are partly parallel, shall be scheduled and implemented with regard to long-term safety of different repository types. In doing so, the following aspects (Saanio et al. 2013), among others, are considered:

- reduction of the activity and heat generation in waste prior to disposal,
- introduction of the best available technique or a technique that is becoming available,
- acquisition of adequate experimental knowledge of the disposal site and other factors affecting long-term safety,
- potential surveillance actions related to ensuring the long-term safety or to non-proliferation of nuclear materials,
- aim of preserving the natural features of the host rock and other favourable conditions in the repositories, and
- aim of limiting the hazards and other burdens to future generations due to long-term storage of waste.

An appropriate quality system is deployed in implementing the disposal and its associated research and development work and safety assessments, and it is extended to all organisations having an impact on the long-term safety of the disposal project.

Construction and operation phases

During the construction and closure of the repository, efforts are made to maintain the bedrock's original properties and, if possible, limit the occurring changes to part of the volumes only. Accordingly, the impact of excavation on the surrounding bedrock can be maintained at an insignificant level with correct excavation method. Water ingress can be limited by avoiding water-bearing structures and by grouting. The amount of grout can be minimised with correct characterisation, design and implementation (e.g., pilot hole investigations and pre-grouting).

Closing phase and post-closure period

As already mentioned, the migration of materials detrimental to long-term safety of different waste types shall be minimised. Structures and systems utilised during operation will be dismantled from the underground facilities as well as possible with the occupational safety in mind. The backfilling of openings and construction of sealing structures will begin simultaneously with the dismantling work. The facilities located at the disposal depths and the vertical shafts will be backfilled. The upper parts of the shafts and the access tunnel will be closed with concrete structures (similar as in Saanio et al. 2013).

Disposal shall be planned so that no monitoring of the disposal site is required for ensuring long-term safety after closure.

2.2.5 Safeguards of nuclear materials

Safeguards of nuclear materials shall be considered in the design of the DGR. The safeguard requirements do not apply to non-radioactive waste, VLLW, LLW and ILW. The aim of the nuclear material safeguards in the disposal facility is to ensure that the facility, especially in its underground part, has no rooms, materials or operations other than those for disposal purposes and that the HLW canisters remain in their declared positions during the operation and after the closure of the facility (Saanio et al. 2013).

2.2.6 Waste flows

The main waste flows are illustrated in Figure 2-3. Waste flows are more discussed in Ikonen et al. (2020).

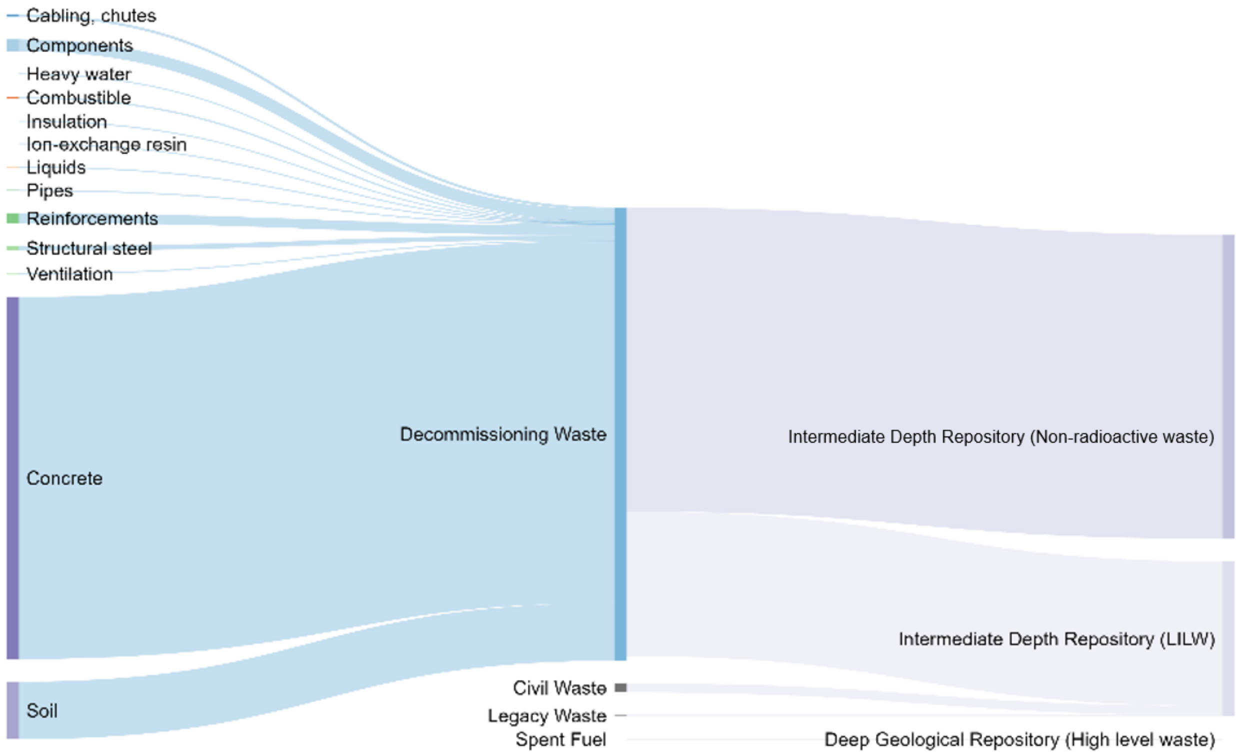

Figure 2-3. The main radioactive waste flows of the National Facility, by mass. The majority of waste is decommissioning waste and specifically non-radioactive concrete and soil. Modified from Ikonen et al. (2020).

3 NATIONAL FACILITY COMPLEX AND OVERALL SCHEDULE

3.1 Facility complex

As site selection has not taken place yet, the National Facility is assumed to be situated on a site that has existing infrastructure connections (roads, electricity network, sewage, water supply, district heating, explosive storage and supply etc.). The site has surface facilities above the underground repositories and openings built in crystalline rock.

Waste halls at the -100 metres level are called intermediate depth repository for non-radioactive waste, VLLW, LLW and ILW. Connections to the ground level from this disposal level are via the access tunnel running at a slope of 1:10, and via three vertical shafts. A personnel shaft reaches the repository depth of 100 metres. Inlet and exhaust air shafts reach the depth of 100 metres or, if the DGR is constructed, all the way to the depth of 400 metres.

DGR consists of a spiral-shaped access tunnel and inlet and exhaust air shafts as well as auxiliary rooms at the depth of 400 metres There are two deposition tunnels and deposition holes drilled in their floors. An alternative to the DGR is deep borehole disposal with one borehole of a few thousand metres depth with the canister disposal zone in its lower part (Fischer et al. 2020).

A ventilation building will be constructed at the top end of the inlet and exhaust air shafts and operation building for later use for personnel shaft reaching the intermediate depth level (-100 m). A tunnel portal building for the technical systems of the access tunnel will also be constructed. For the operation, a packaging plant for VLLW, LLW and ILW from medicine, research, industry etc. and a waste reception building are also constructed. Waste reception building is first for HLW, then for ILW and finally for VLLW and LLW receive control, contamination test, transfer from road transportation equipment to canister/waste transfer vehicle and temporary storage.

Some other auxiliary buildings and structures are also constructed. Examples of these are a maintenance and storage hall, storage/construction area, refuelling station and a so-called research building for the research equipment and personnel. If a deep borehole repository will be constructed, an area with an emplacement building for the borehole activities is also reserved. Office building and visitor centre are located outside the facility fence.

Figure 3-1 illustrates example of placement of all nuclear waste from Norway underground within the National Facility. Chapter 4 contains a detailed description of the underground parts of the intermediate depth repository.

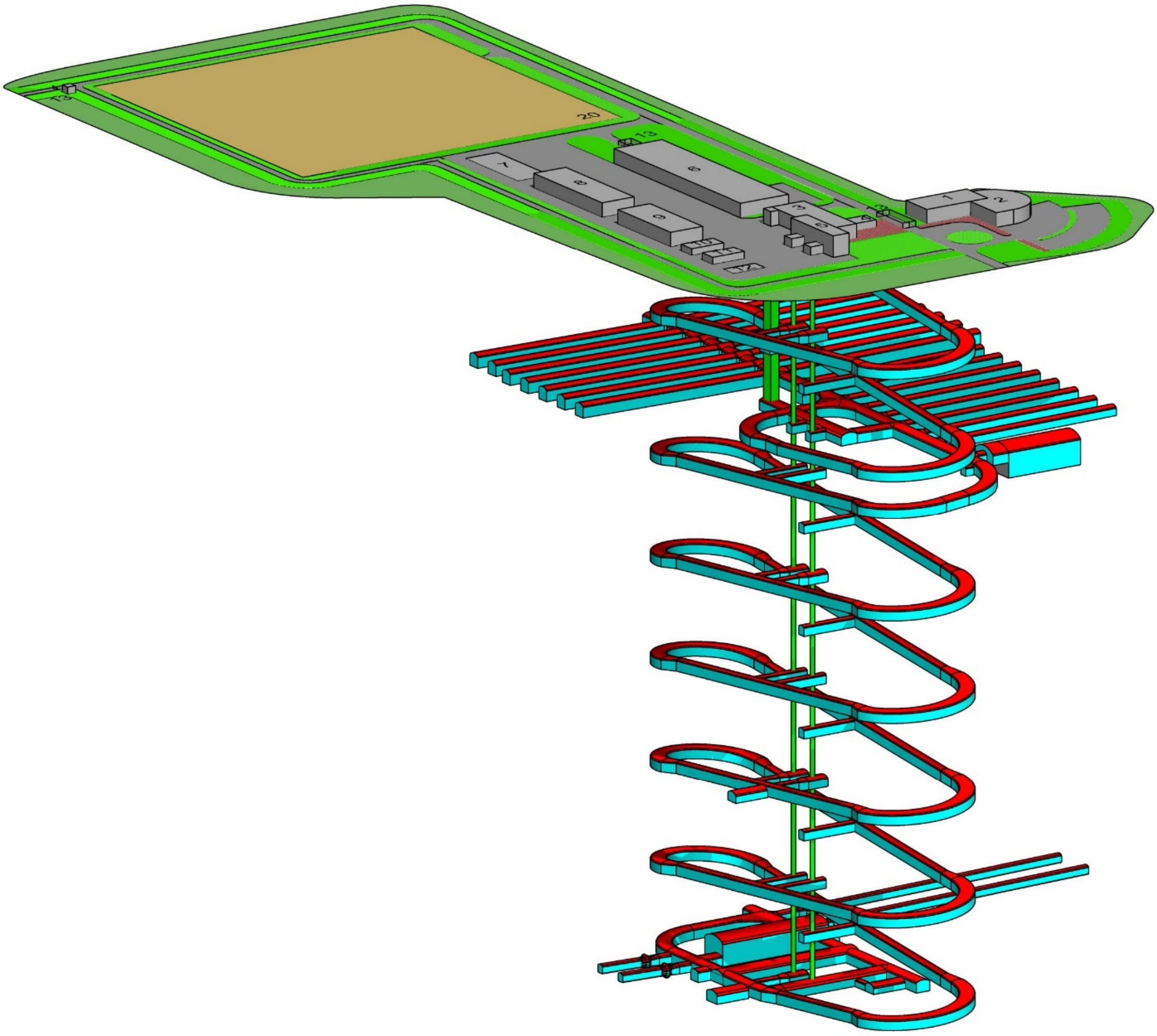

Figure 3-1. Illustration of the National Facility if non-radioactive waste is disposed in intermediate depth repository and DGR is used for HLW disposal. Figure 4-2 lists the names and indexes of the different buildings. Figure by AINS.

3.2 Overall schedule

According to the general schedule for the whole National Facility, it is assumed that around 25 years are needed for preparations, construction, and licensing of the facility (Ikonen et al. 2020, Figure 2-13). Preparations include e.g., political decisions, development of the concept and safety case. After construction and testing, the operation can start. Start of the operation is assumed for 2050, Figure 3-2.

Operations will start by disposing of the spent fuel either in the deep geological repository or in the deep borehole repository. This operation will take roughly 2 years.

Non-radioactive waste will be emplaced to the intermediate depth repository in non-radioactive waste halls. Deposition of the non-radioactive waste will be done after disposal of the spent fuel and will take a couple of years.

An alternative place for non-radioactive waste in the intermediate depth could be, in theory, as part of backfill material. In that alternative some of the openings between -100 m and -400 m levels could be backfilled with the non-radioactive waste. If the DGR is not constructed, most of the non-radioactive waste should be stored for 100 years before using it as a closure material between the -100 level and the surface, and that is not reasonable because of harmful organic materials that could intrude the waste during the storing period (in surface environment).

The next phase in the overall schedule is the disposal of radioactive decommissioning and legacy waste. The emplacement of existing radioactive decommissioning and legacy waste will take roughly three years. After that, the disposal of waste from different sources, e.g., hospitals and industry can be started. This can be done in campaigns that will be defined and decided later or when suitable waste amount is accumulated.

When all waste is disposed, closure of the National Facility can start. All the underground openings are backfilled and plugged and above ground structures can be removed. This will take a couple of years.

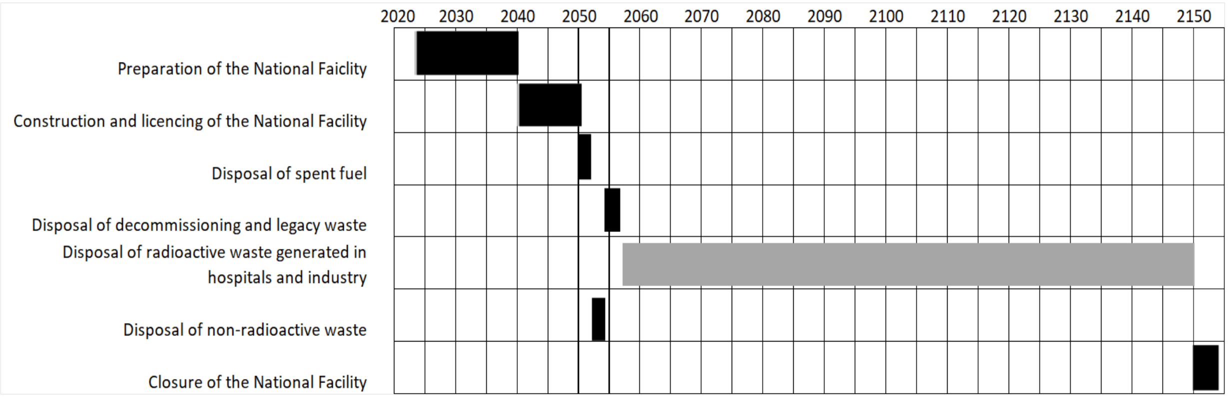

Figure 3-2. Overall schedule, (Ikonen et al.2020)

4 FACILITIES ABOVE GROUND

The location of the surface buildings and structures are illustrated for the case, where non-radioactive waste is placed at the depth of 100 meters, Figure 4-1.

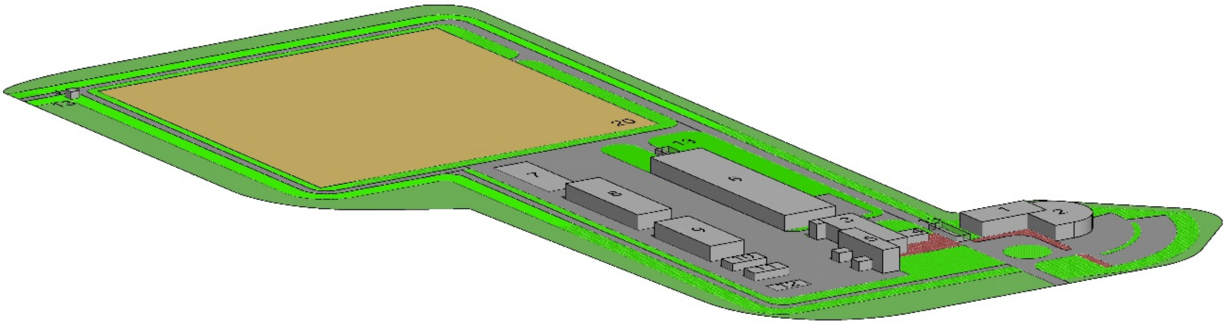

Figure 4-1. Above-ground arrangements of the National Facility and a 14 hectares footprint for the case where HLW is disposed in a DGR and non-radioactive waste is placed at the depth of 100 meters. The same arrangements would be needed solely for the intermediate depth repository even without the DGR or underground non-radioactive waste halls. Figure by AINS (Ikonen et al. 2020).

The presented surface layout is an example, and slight conservatism has been followed in production of the descriptions for the areas and volumes for all concepts and parts. The example layout is adaptable to more strict boundary conditions, and they can be varied and fitted to e.g., a narrow valley/property. In the previous Figure 4-1, the surface arrangements related to the intermediate depth repository are included.

The buildings are inside the facility fence, except the office building and the visitor centre. New roads will be built inside the facility fence. The excavated material from disposal facility excavation and construction work is transported out of the facility (Ikonen et al. 2020).

Figure 4-2 shows the buildings and areas at the disposal site. Storage/construction area (index 20 in Figure 4-2) will also be used as a lay down area for containers before emplacement to the intermediate depth repository.

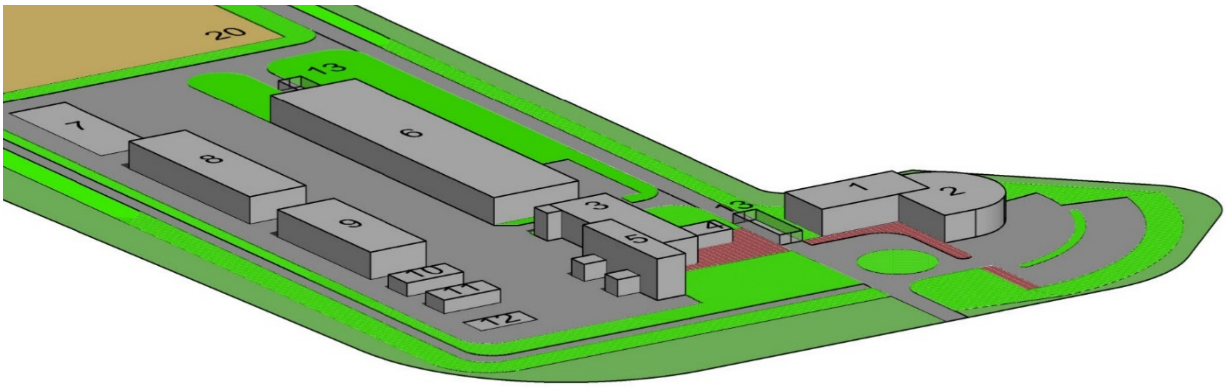

Figure 4-2. Buildings at the disposal site: 1) Office building 2) Visitor centre, 3) Operation building, 4) Guard, 5) Ventilation building, 6) Tunnel portal building, 7) Packaging plant area, 8) Waste reception building, 9) Maintenance and storage hall, 10) Research building, 11) Backup power supply, 12) Refuelling station, 13) Control, 20) Storage/construction area (also for container laydown purposes). Figure by AINS.

Principles of facility layout, supply of electricity, heating, water supply, drainage/ sewage system, traffic arrangements and personnel arrangements are presented in Ikonen et al. (2020). Using underground waste halls instead of landfill for non-radioactive waste does not bring changes to these principles. Also, the functions of site buildings and structures are the same even if underground waste halls would be used for non-radioactive waste instead of landfill.

5 INTERMEDIATE DEPTH REPOSITORY

5.1 Implementation

5.1.1 Overall description

The openings on the intermediate depth repository level and above (Figure 5-1) are such that are needed for non-radioactive waste, VLLW, LLW and ILW disposal. They include repository halls, access tunnel, inlet and exhaust air shafts and auxiliary rooms including control and maintenance rooms (which form an over pressurized safety centre for the case of fire or cave in), electrical rooms, vehicle parking hall, sedimentation pool and pumping station for water seeping into the tunnel system. Openings other than the actual intermediate depth repository (i.e., waste halls) are also discussed in this chapter.

Before the disposal operations are started all above-mentioned openings will be built.

Figure 5-1 presents the layout example for the facility for all Norwegian waste inventory excluding HLW. Example is designed for a generic site. The VLLW, LLW and ILW waste halls are tailored for NND based on experience and dimensions of the existing disposal facility in Loviisa, Finland (see Ikonen et al 2020, Figure 6-6 and Figure 6-7). The span for non-radioactive waste, VLLW and LLW halls has been minimized in this example.

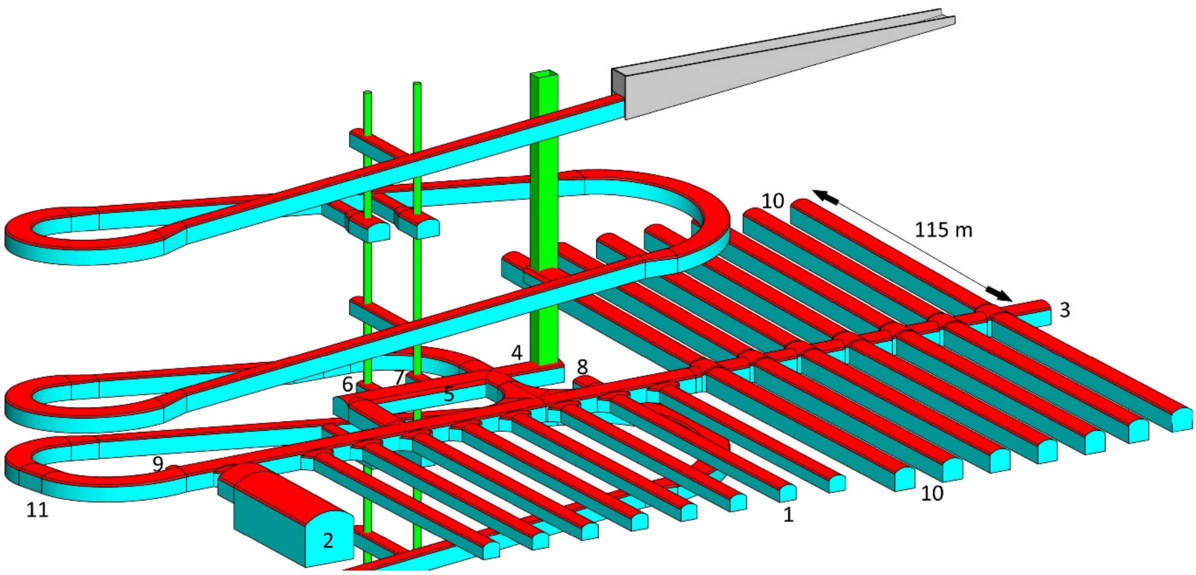

Figure 5-1. There will be eight VLLW/LLW halls (1) and one ILW hall (2) along the access tunnel and its side tunnel (3). Control and maintenance rooms (4) are located at the personnel shaft connection and parking hall (5) at the front of the inlet air shaft connection (6) and exhaust air shaft connection (7). There are also electrical rooms (8) and a sedimentation pool with a pumping station (9) at this intermediate depth repository level. Fourteen non-radioactive waste halls (10) have been added to this design. The spiral access tunnel (11) runs further down heading to the DGR. The length of the straight basic access tunnel section is roughly 170 metres and the indicated non-radioactive waste hall 115 metres. Figure by AINS.

5.1.2 Tunnel in front of the waste halls

There will be one ILW hall, eight VLLW/LLW halls and fourteen non-radioactive waste halls along the access tunnel and its side tunnel. This tunnel area at the depth of 100 metres is almost horizontal and, *together with the parking hall, it is dimensioned for the waste package and backfill transfer vehicles and other vehicles manoeuvring. The width of this tunnel will be 8,5 m, and the vehicle clearance height is 4,5 m. For extending the intermediate depth repository, there is a short niche at the end of the non-radioactive waste halls (Figure 5-1*

Figure 5-1, index number 3). By extending this tunnel, it is possible to excavate more waste halls later at the depth of 100 metres. It is also possible to extend the length of the waste halls.

5.1.3 Non-radioactive waste halls

Non-radioactive waste is packed in sea containers and emplaced with a forklift to waste halls excavated for them (dimensions are presented in Figure 5-2). The span of the halls in this example description is minimized to limit the need for ground support, and wider halls could also be used. The centre-to-centre distance between the halls is 17,3 m and the length of halls varies between 115 and 120 metres from the access tunnel wall line. In each hall, there is first 13 meters reserved for forklift operation and turning – rest is for waste containers and wall structure. With this length there are no remarkable challenges related to excavation technology, occupational safety, or additional ventilation fans. The estimated total quantity of Norwegian non-radioactive waste (1165 containers) will be disposed of in fourteen halls presented in Figure 5-3.

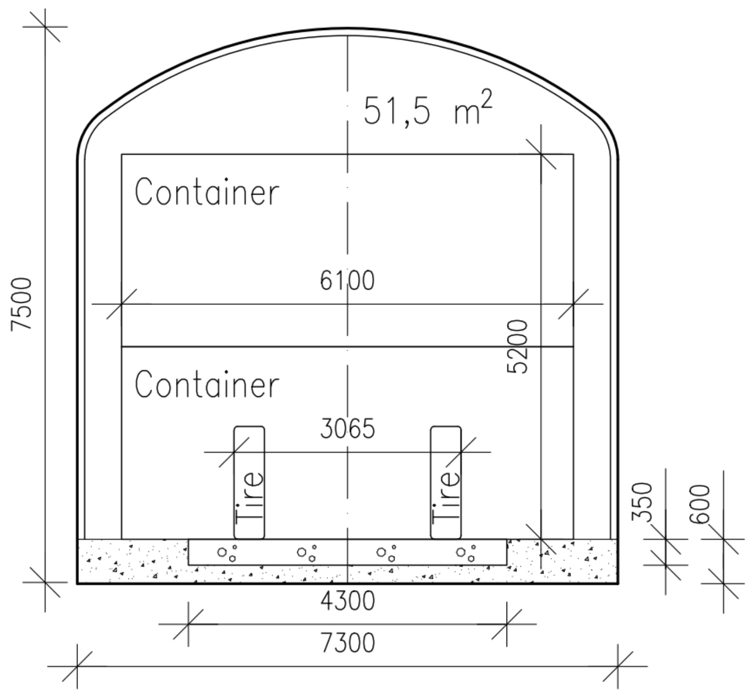

Figure 5-2. Non-radioactive waste cross section. Figure by AINS.

5.1.4 VLLW, LLW and ILW halls

VLLW, LLW and ILW halls are described in Ikonen et al. (2020) and they do not differ from this facility version, where there are also halls for non-radioactive waste at the same depth level.

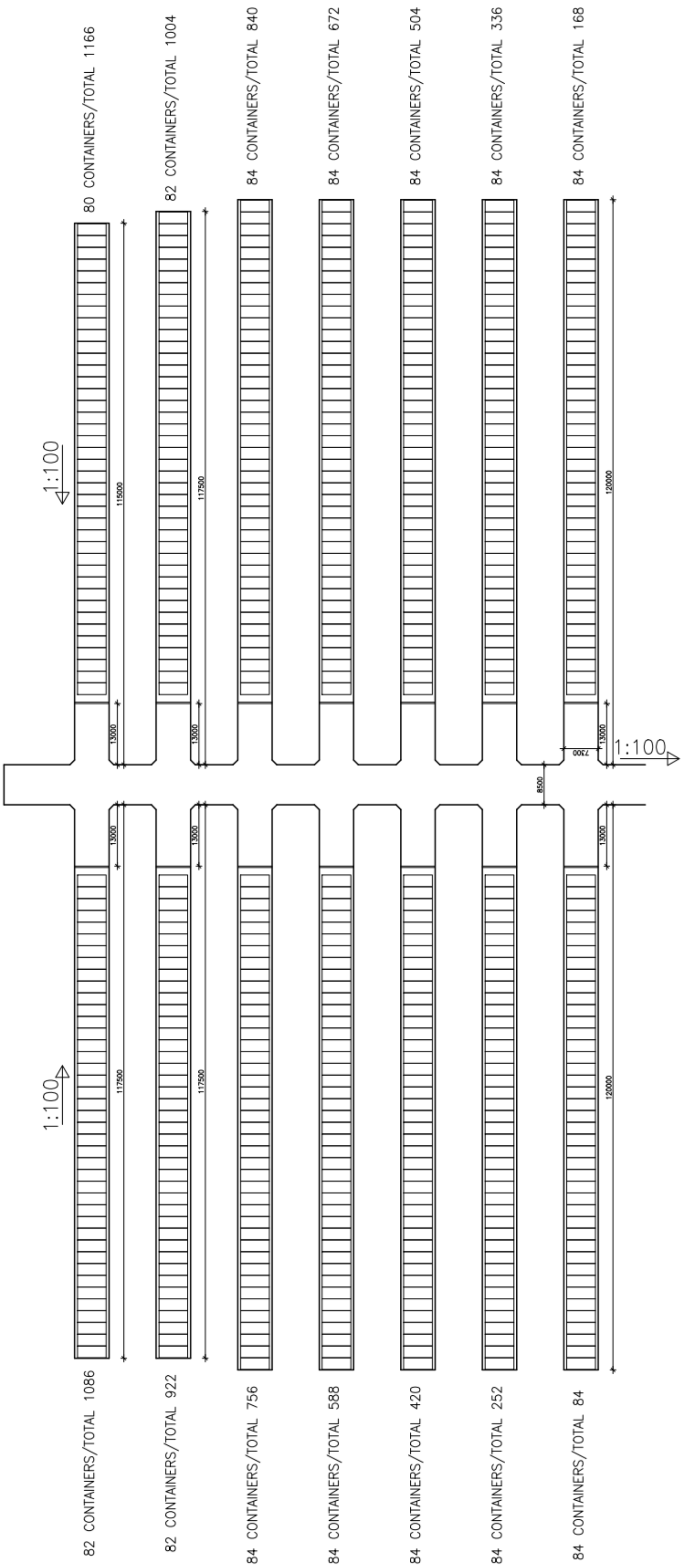

Figure 5-3. There will be 1166 container positions (presented in cumulating numbers) for inventory of 1165 containers of non-radioactive waste. Figure by AINS.

5.1.5 Systems

Heating, ventilation, water, seepage water, electrical, fire safety, monitoring and control systems as well as safety classification are described in Ikonen et al. (2020) and their operating principles do not differ from this facility version, where there are also halls for non-radioactive waste at the same depth level. For example, ventilation principle is same for all waste hall types and it is assumed that system dimensioning is the same because of alternating operation of waste halls.

Transfer systems for personnel, backfill, VLLW, LLW and ILW are presented in Ikonen et al. (2020).

The non-radioactive waste containers are transferred with a vehicle from surface via access tunnel to the intermediate depth level. The forklift will then lift the container and position the container to the furthest vacant container position in the operated waste hall. An example of a working forklift solution is presented in Figure 5-4.

Figure 5-4. An example of a working forklift solution for non-radioactive waste container handling (Konecranes 2020).

5.1.6 Underground facility construction in phases

It is assumed that, because of very limited amount of waste and easy separation of the construction and operating stages, all underground openings will be excavated in one phase (assuming that no DGR is built). If wanted, the last waste halls can be furnished later in parallel with the operation of the intermediate depth repository.

5.1.7 Underground facility production

The underground openings production principals and individual methods for other intermediate depth repository openings than non-radioactive waste halls are presented in Ikonen et al. (2020). For the non-radioactive waste halls, no separate demonstration waste halls are needed. For non-radioactive waste halls, the production method is drilling and blasting. Traditional rock support and grouting methods will be used according to the lifecycle of each underground opening.

5.2 Operation

Different types of waste are disposed of in campaigns of suitable duration. Due to technical aspects concerning backfilling, it appears preferable to implement the disposal activity campaigns on the basis of waste type. The total amount of seepage water flow is also limited by closing openings as soon as possible after the waste packages have been placed.

If a DGR is not constructed, in 100 meter depth the disposal of existing non-radioactive waste will be done in the first disposal campaign and already existing ILW in the second campaign. The third disposal campaign will be disposal of the already existing VLLW and LLW and closure of these rooms at the depth of 100 metres.

The fourth campaign will be the disposal of VLLW/LLW and ILW accumulating between 2050 to 2150 to the last two VLLW/LLW openings and ILW concrete basin. This will be followed by decommissioning of the packaging plant and other necessary decommissioning works. Finally, closure and plugging for the rest of the underground openings will be done. The remaining buildings and the site above ground can be changed to some other use or dismantled.

5.2.1 Activities and schedule

The emplacement of non-radioactive waste takes roughly a couple of years and ILW roughly one year. The emplacement of VLLW and LLW and backfilling the first six waste halls with plug productions takes roughly two years. The remaining two waste halls will be filled with waste accumulating in Norway until year 2150.

5.2.2 Transfer and installation of waste packages

The VLLW/LLW and ILW package transfers and installation are described in Ikonen et al. (2020). The non-radioactive waste containers are transferred with a vehicle from surface via access tunnel to the intermediate depth level and reversed to the junction of the operated waste hall. The forklift is waiting for container in opposite waste hall entrance, Figure 5-5. The forklift will then lift the container and the transfer vehicle drives away. The forklift will position the container to the furthest vacant container position in the operated waste hall and reverses back to the opposite waste hall entrance to wait for the next container transfer. An example of a working forklift solution is presented in Figure 5-4.

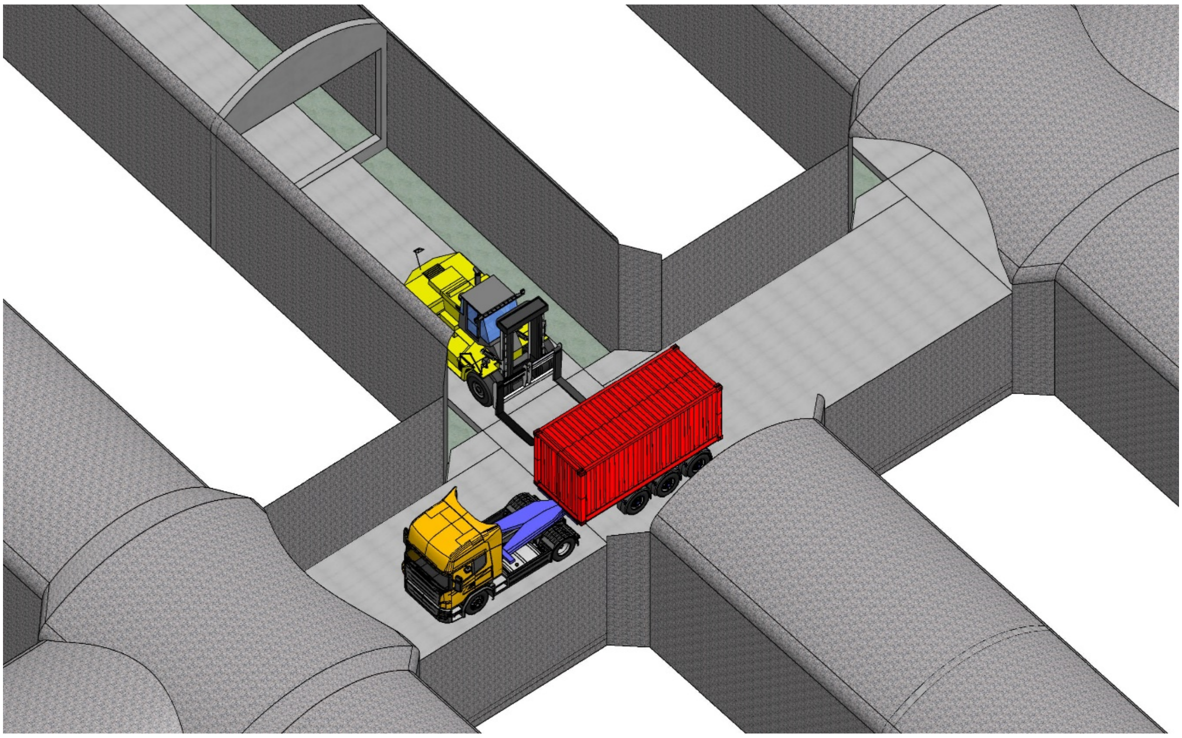

Figure 5-5. The forklift is lifting the container from the transfer vehicle to be transferred to the waste hall.

5.2.3 Backfilling the intermediate level repository

This section briefly describes an example of the backfilling and plugging of the non-radioactive waste, ILW and VLLW/LLW halls.

Backfilling with crushed rock is used in the ILW hall, which contains engineered barriers that need to be protected from mechanical impacts and have a large span (width) and is more susceptible to rock damage. The possible void between the ILW packages is filled with concrete. Non-radioactive waste halls and VLLW/LLW halls are assumed to be backfilled with crushed rock, too, but it is not obligatory. Plugs of reinforced concrete are positioned at the entrances of the radioactive waste halls (as in Nummi 2018). Full non-radioactive waste halls are isolated from other openings with leca-block walls or similar structures.

5.2.4 Controlled and uncontrolled areas and phases

The difference between a controlled and uncontrolled area or phase is an issue of being able to measure the radiation doses to which personnel are exposed.

Waste packages are either non-radioactive waste or, in the case of radioactive waste, uncontaminated when they are transferred and emplaced underground. VLLW, LLW and ILW halls in the intermediate depth repository are defined as controlled areas always when there is radioactive waste present, radioactive waste is emplaced there, or backfilling is implemented in them. During radioactive waste transfer, the whole underground tunnel system is a controlled area – not only the radioactive waste halls. The previous excavation and construction work as well as non-radioactive waste emplacement and plug construction works are done in the uncontrolled phase/area. The purpose of this division is to control the movements of personnel in an area where there is a possibility of direct radiation and to measure the radiation doses they receive. During the uncontrolled phase and working in uncontrolled area, access is still controlled but not because of reasons of radiation protection. In uncontrolled areas radiation doses of people are not measured, except if radon amount requires it.

5.2.5 Radiation protection

The purpose of radiation monitoring is to measure and monitor the activity of disposal facility air and the radiation doses received by personnel. The major source of airborne radioactivity is assumed to be naturally occurring radon. If the radon content of the air exceeds the permitted limit, ventilation is increased. Besides radon gas, the employees are exposed to radiation doses emanating from radioactive waste packages. The non-radioactive waste emplacement, periodic services, maintenance, and cleaning that take place in the disposal facility normally cause no radiation doses to personnel (Saanio et al. 2013).

5.2.6 Safeguards, monitoring, incidents and accidents

Safeguards do not apply to the intermediate depth repository. The fundamentals of safeguards apply only to high level waste.

Monitoring, incidents, and accidents are described on general level in Ikonen et al. (2020) and those do not differ from this facility version, where there are also halls for non-radioactive waste at the same depth level.

5.3 Decommissioning and closure

The closure phase extends from the intermediate depth repository level to the ground level and is done after all non-radioactive waste, VLLW/LLW and ILW packages are emplaced and all waste halls are backfilled and plugged/sealed.

The requirements regarding closure of access tunnel, shafts and auxiliary rooms differ from those set for backfilling and closure of the waste halls. One key purpose of engineered release barriers, such as the backfilling and closure structures, is to limit the migration of radioactive materials via excavated facilities. The backfill materials and closure structures must prevent the formation of significant flow routes between ground level and the waste halls. The backfill materials and closure structures must also support the surrounding bedrock and prevent the inadvertent entry of people into the facilities. In addition to this, the materials used for closure must not have a detrimental impact on the performance of the multi-barrier system (Saanio et al. 2013).

It shall be controlled that no significant quantities of materials harmful to the performance of release barriers enter the repositories. The migration of materials detrimental to long-term safety of also HLW disposed in the same area shall be minimised. For this purpose, estimates and analysis about the masses of foreign materials, including non-radioactive waste, that remain in the disposal facility after it has been closed need to be done.

Dismantling work and closure are described on general level in Ikonen et al. (2020) and those do not differ from this facility version, where there are also halls for non-radioactive waste at the same depth level.

6 NON-RADIOACTIVE WASTE REPOSITORY COSTS

This chapter includes costs for non-radioactive waste repository located in 100 meters depth, Figure 5-1. Non-radioactive waste repository consists of 14 waste halls and corresponding part of the access tunnel.

All costs are calculated and presented in Euros. The prices do not include the value-added tax (VAT).

Cost estimation is based on working methods used in EU-countries and average EU-prices of materials and labour costs are applied. It should be noted that the price level in Norway differs from the price level in EU-countries.

The cost level is 1/2020. The interest rate of the money has not been taken into account.

Owner costs are included in the investment costs, closure costs and partly in the operational costs. Owner costs contain developing costs, design costs, project costs and license costs. Developing costs include only “normal level costs”, which are the costs that are needed for construction in normal case, for example grouting development in particular rock conditions.

Generally, owner costs are estimated as:

- Initiation fees to systems such as electric network, IT network, water distribution, sewage system and district heat distribution 1%
- Construction supervision costs 2%
- Developing and licence costs 2,2 - 4,8%
- Design and survey costs 4,3 - 7,4%
- The usage costs of the construction site 1 -2 %.

In this report owner costs are assumed to be 15% of the corresponding investment costs.

Different costs are calculated with different methods considering that the current design maturity of specific items differ from each other. For example, backfilling technique and materials are not defined in detail yet and hence the costs cannot be calculated in detail.

Contingencies for unspecified costs are included in the summary tables. Contingency includes different kind of uncertainties. Reasons for uncertainties are:

- Very early design phase, conceptual description. There may be systems that are not yet well designed, defined or known. Designs may change in later design phases. Usually also costs will change.
- Technology and working methods may change and this may change the costs as well.
- The price of some materials may change differently from the normal inflation rate. For example, the price of bentonite could change, and this would have a strong impact on the total costs.
- Geology, fracturing, fracture zones, groundwater conditions, groundwater geochemistry, rock mechanical conditions and meteorological conditions may be different from what was assumed.

Contingencies are supposed to increase the costs, not to decrease the costs.

Contingency for uncertainty does not include changes in the amount of waste or changes in the actual repository concept.

6.1 Site investigations, planning

After the site is selected for the National Facility and exact place is decided for the intermediate depth repository, more detailed site investigations are still needed to locate the non-radioactive waste halls exactly and to decide exactly the length of each hall. These detailed site investigations include drilling, borehole investigations, hydrogeological investigations, rock mechanics and other investigations. A rough estimate of the site investigations is presented in Table 6-1.

Table 6-1. Site investigation costs for locating the non-radioactive waste halls in the Intermediate depth repository (EUR).

Site Investigations	EUR
Detailed site investigations on the site	1 000 000
Sub-total	**1 000 000**

6.2 Investments / construction

Investment costs for non-radioactive waste repository are summarized in Table 6-2.

Table 6-2. Investment costs (EUR).

Investment / construction	EUR
Excavation	14 050 000
Construction	5 843 000
Systems	3 000 000
Equipment	1 000 000
Investigations during construction	1 000 000
Owner costs	3 734 000
Sub-total	**28 627 000**
Contingency for uncertainties, 30%	8 588 000
Total	**37 215 000**

Excavation costs include waste halls for non-radioactive waste and corresponding access tunnel. This cost item includes also rock support and grouting of the tunnels.

Construction costs include all construction in the non-radioactive waste repository. This cost item covers floors, walls and doors.

Costs for systems are rough estimates. HVAC systems are assumed to include for example the heating, plumbing, drainage and ventilation systems and building automation. Electrical systems are assumed to include for example power supply, lighting, telecommunication, telephone, loudspeaker, antenna, mobile phone network, fire detection, camera control, access control and alarm systems.

Equipment include forklift for non-radioactive waste handling, transfer vehicles and other unidentified equipment that are assumed to be needed for the operation of non-radioactive waste repository.

Costs for the investigations during construction are estimated assuming one year period for the excavations.

In this report owner costs are assumed to be 15% of the other investment costs. Typically, owner costs include design and survey costs, developing and license costs, construction supervision costs, the usage costs of the construction site and initiation fees to systems as electric network, IT network, water distribution, drainage system and district heat distribution.

6.3 Operating

Dominating operating costs are personnel costs because of very long operation period. All personnel costs are allocated for above ground facilities in the cost estimation for the National Facility and the costs are therefore not observed in this cost estimation. Some cost items are calculated based on the costs per year and assuming a 2-year operational period for the disposal of non-radioactive waste in the repository.

Operating costs are presented in Table 6-3.

Table 6-3. Operating costs (EUR) per year and for 2 years period.

Operating	EUR / Year	EUR Total
Backfilling		1 473 000
Energy	30 000	60 000
Water and water treatment	10 000	20 000
Maintenance and reparation	98 000	196 000
Insurance	48 000	96 000
Owner costs		221 000
Sub-total	186 000	2 066 000
Contingency for uncertainties, 30%	56 000	620 000
Total	**242 000**	**2 686 000**

Backfilling costs in the operation phase include the backfilling of the waste halls. Backfilling costs for the access tunnel are included in the closure costs. The unit cost for the backfilling is assumed to be 65 EUR/m^3.

Rough estimate for the energy costs of the non-radioactive waste repository is 30 000 EUR/year.

Rough estimate for the water and water treatment costs of the non-radioactive waste repository is 10 000 EUR/year.

The maintenance and reparation costs are 1% of the construction costs, of the equipment and of the systems per year. Costs are calculated for 2 years operation period.

The insurance cost includes the insurance for the building. In this case the building means the non-radioactive waste repository. The insurance covers fires, water damages, electrical damages etc. The insurance cost is 0,2% of the investment costs per year. Costs are calculated for 2 years operation period.

6.4 Closure

Closure costs include costs for the closure phase and are presented in Table 6-4.

Table 6-4. Closure costs (EUR).

Closure	EUR
Dismantling of the structures	150 000
Backfilling	1 128 000
Plugs	266 000
Owner costs	231 000
Sub-total	1 775 000
Contingency for uncertainties, 30%	532 000
	2 307 000

Dismantling costs include removal and transfer of the systems that have been constructed and installed in the non-radioactive waste repository. Generally, all the systems will be removed before closure of the tunnels. Costs for dismantling of the systems before backfilling is estimated to be 5% of the investment costs for systems.

Backfilling costs in the closure phase include the backfilling of the access tunnel. Unit costs for the backfilling are assumed to be 65 EUR/m^3.

Access tunnel between non-radioactive waste repository and low-level waste repository is assumed to be plugged with a concrete structure, with a unit cost of 1000 EUR/m^3.

Owner's costs, 15%, consist of developing costs, design costs, project costs and license costs. Owner costs are calculated for dismantling of the structures, backfilling and plugs.

6.5 Total costs

Total costs to construct, operate and close the non-radioactive waste repository as a part of the National Facility are presented in Table 6-5. The operational period is assumed to be 2 years. Post-closure costs are not included.

Table 6-5. Total costs of the non-radioactive waste repository (EUR).

Total costs	EUR
Site investigations	1 000 000
Investment / construction	37 215 000
Operating	2 686 000
Closure	2 307 000
Total	**43 208 000**

7 SUMMARY

The first concept description for a Norwegian National Facility for nuclear waste disposal was described in report by Ikonen et al. (2020). The facility was described to act as a final repository for all radioactive (and non-radioactive) waste generated so far, mainly the decommissioning waste from Norwegian research reactors in Halden and Kjeller, and the waste that will be generated in Norway over the 100 years following the commissioning of the facility.

In this concept description report an alternative positioning for non-radioactive waste was presented. Instead of landfill-type repository, the non-radioactive waste is placed in underground waste halls at the depth of 100 meters. The other waste types are assumed in former positions/ repositories as presented in Ikonen et al. (2020).

In this report it has been assumed that the National Facility contains the following repository types:

- Intermediate depth repository for non-radioactive decommissioning waste, and
- Intermediate depth repository for very low, low and intermediate level waste.

Deep geological repository (DGR) for high level waste was mentioned as part of the National Facility, but not fully described in this report. For the DGR description, see Ikonen et al. (2020). Deep borehole repository for high level waste as an alternative to the DGR is only mentioned in this report.

The underground non-radioactive waste repository concept description acts e.g., as a basis for further design of facilities and production of alternative combinations for selecting the types of repositories for further studies. The final concept might not include all investigated repository types.

In this report the differences from concept description by Ikonen et al. (2020) were described - issues that have not changed were excluded (such as the description of the DGR). New underground openings for non-radioactive waste are designed to the depth of 100 meters where an expansion tunnel for this type of purpose was already earlier planned. Long-term safety considerations were out of scope of this report.

The underground facility has been designed for operations taking place at two levels: a repository for non-radioactive, very low, low and intermediate level waste at intermediate depth (100 metres) and a DGR for high level waste at the depth of 400 metres.

Non-radioactive waste packaging assumptions were based on inventory data and standard 20’ sea containers were assumed to be used as waste packages as in Ikonen et al. (2020). The dimensioning factor is the maximum bearing capacity of the containers. The containers will be roughly half empty and therefore this can be optimised in later stages by developing/choosing smaller containers that could be filled to the full. This would lead to smaller amount of waste halls and lower costs. The non-radioactive waste is assumed to be packed outside the National Facility.

Activities related to planning, construction, operation, decommissioning and closure phases, with regard to operational safety, required systems and overall schedule, were briefly described. Preliminary design for the required buildings and facilities above ground are also described.

The concept description maintains maximum flexibility to allow changes in the design solutions. Waste acceptance criteria or other details were not locked down at this stage.

Total costs to construct, operate and close the non-radioactive waste repository as a part of the National Facility are:

Site investigations	1 MEUR
Investment/construction	37 MEUR
Operation	3 MEUR
Closure	2 MEUR
Total	43 MEUR

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