OPERA

OUTLINE OF A DISPOSAL CONCEPT IN CLAY

OPERA-PG-COV008

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Ewoud Verhoef, Erika Neeft (COVRA N.V.)
Jacques Grupa, Arjen Poley (NRG)
First update 13 november 2014
COVRA N.V.

Contents

1. Introduction

1.1. Background

Radioactive substances and ionizing radiation are used and generated in medicine, industry, agriculture, research, education and electricity production. These activities generate radioactive waste. Current policy in the Netherlands is that radioactive waste is collected, treated and stored by COVRA (Centrale Organisatie Voor Radioactief Afval). After interim storage for a period of at least 100 years radioactive waste is intended for disposal. There is a world-wide scientific and technical consensus that geological repositories represent a safe disposal option for radioactive waste.

Geological disposal is emplacement of radioactive waste in deep underground formations. The goal of geological disposal is isolation of radioactive waste from our living environment in order to avoid exposure of future generations to ionising radiation from the waste. OPERA (OnderzoeksProgramma Eindberging Radioactief Afval) is the Dutch research programme on geological disposal of radioactive waste that starts in 2011 and will run for five years. Formations of clay as well as salt are considered as potential host rocks in OPERA.

1.2. Objectives

This report outlines the disposal concept in Boom clay which feasibility is studied in OPERA. The report is intended to help the visualisation of the geological repository for the various research groups taking part in OPERA and to provide context for external communications. The safety case structure, the safety strategy that forms the basis of the concept, and research topics are described in the OPERA Research plan [1].

For study of disposal concept in salt the concept will be used that was developed in the previous research programme Commissie Opberging Radioactief Afval (CORA) [2, 3,4].

1.3. Realization

This report is developed by COVRA and NRG. The outline of the present disposal concept in clay is based on current Belgian Supercontainer concept [5] as well as earlier concepts for disposal in clay [6, 7]. Specific assumptions for disposal in clay in the Netherlands were considered parallel to the present report [8]. Assumptions for features such as the waste inventory to be disposed of [8] are updated in the present report as well. This document was first published at COVRA's website on 5 July 2011. This first revision reflects the following developments within OPERA:

- References have been added to the updated safety strategy and safety functions;
- The provisional length of HLW supercontainers has been changed - the number of disposal galleries for non-heat generating HLW has been increased accordingly from 21 to 36;
- The HLW supercontainer will have a steel envelope;
- The report includes a description of the stacking of LILW drums used to determine the necessary gallery length;
- The conditioning of depleted uranium is now as described in OPERA-PG-COV020, which results in a reduction of requested KONRAD type II containers (18,000 to 7,700) - the number of LILW/DU galleries has been reduced accordingly from 103 to 65;
- Figure 5-1 and Figure 5-2 have been revised to accommodate the change in number of galleries;
- A choice has been made to use foam concrete as a backfill (OPERA-PG-COV020).

1.4. Explanation contents

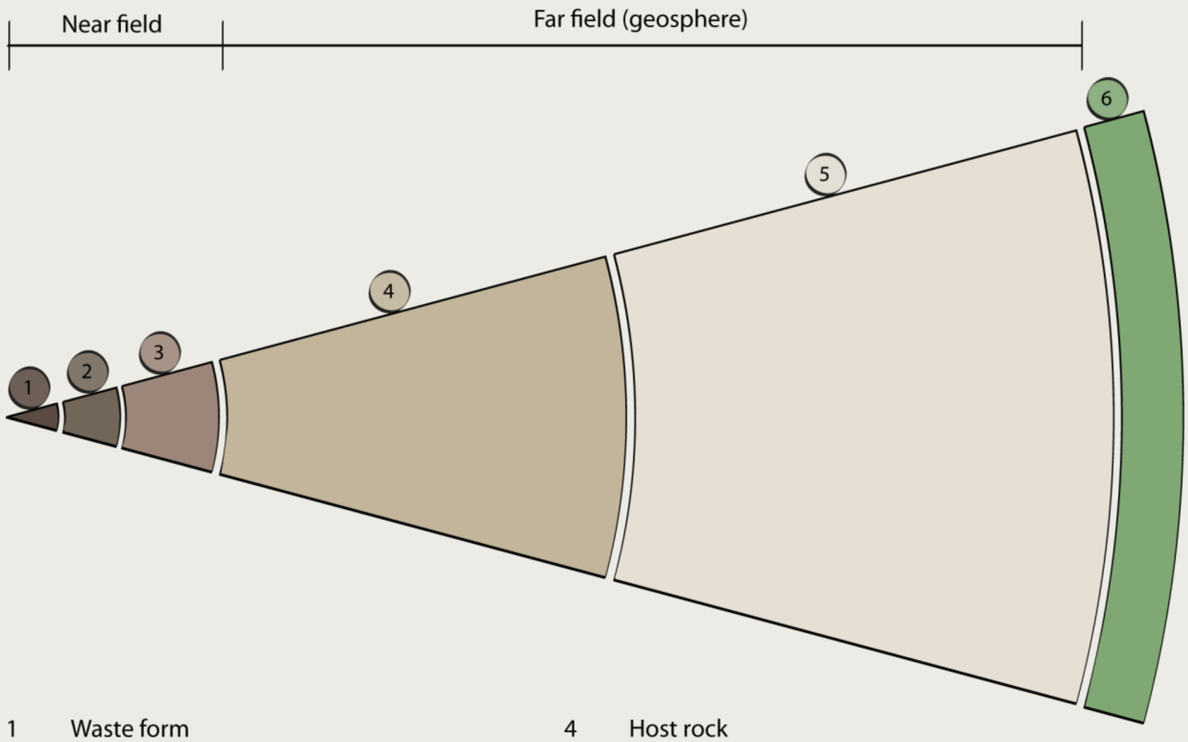
Chapter 2 describes a generic repository system. The different phases during the lifetime of a repository are illustrated in Chapter 3. Chapter 4 contains a general overview of the radioactive waste inventory to be disposed of. The outline of a repository that is used for OPERA at the start of this research programme is described in Chapter 5.

2. Geological disposal concept

2.1. Multi-barrier system

The objective of geological disposal is to isolate the radioactive waste from the biosphere until the radioactivity of the waste has decayed to natural levels[a] (e.g. uranium ore). The required long-term isolation can be achieved by a system of multiple barriers. Geological disposal relies on a sequence of complementary and/or redundant barriers (defence-in-depth).These barriers can be natural (geological) and man-made (engineered): the waste form, the container, the buffer/backfill, the seals, the host rock and the surrounding rock formations. These barriers should not fail through a common cause and should compensate the consequences of failure of any one barrier by the protective action of the others [e.g. 10].

The repository system is often represented by breaking it down into compartments for safety and performance analysis [e.g. 11]. In OPERA six compartments are distinguished, as shown in Figure 2-1. The compartments close to the waste make up the near field; the host rock and surrounding rock formations the far field or geosphere. Table 2-1 lists characteristics of the compartments for HLW and LILW.



1	Waste form	4	Host rock
2	Waste package	5	Overburden /Surrounding rock formations
3	Repository building & affected materials	6	Biosphere

Figure 2-1 Compartments of a design of a repository concept

[a] Note that this is just one safety argument, other arguments could also take into account the mobility of radionuclides for example [9].

Table 2-1 Characteristics of materials in compartments

<table>
<tr><th>Compartment</th><th>HLW</th><th>LILW/(TE)NORM</th></tr>
<tr><td rowspan="2">Waste form</td><td rowspan="2">HLW can consist of different materials including glass, UO_2, zircalloy</td><td>Solid form. Waste can consist of a variety of materials including glass, metal, ash, textile and plastic.</td></tr>
<tr><td>U_3O_8 conditioned with concrete</td></tr>
<tr><td>Waste package</td><td>Canister, overpack, concrete buffer, steel envelope for Boom Clay
Canister (and overpack) for salt</td><td>Concrete and galvanized, painted steel or concrete container</td></tr>
<tr><td>Repository building & affected materials</td><td colspan="2">Backfill can be composed of materials such as grout, crushed salt and bentonite. Concrete support is required in Boom Clay. Affected materials include the host rock disturbed by the presence of excavations (Boom Clay or salt formation)</td></tr>
<tr><td>Host rock</td><td colspan="2">Boom Clay or salt formation unaffected by the presence of excavations</td></tr>
<tr><td>Surrounding rock formations</td><td colspan="2">Aquifer (simplified; for not-site specific calculations)</td></tr>
<tr><td>Biosphere</td><td colspan="2">Physical media: soil, atmosphere, climate, water bodies et cetera
Living organisms: humans, animals and bacteria, interacting with physical media</td></tr>
</table>

Further information on the safety strategy, definitions of compartments and the relation between safety and performance assessment using safety functions can be found in the OPERA Research plan [1]. More details concerning the safety strategy have been published [12] and the updated safety functions published in 2009 by ONDRAF-NIRAS [13] are used in OPERA.

2.2. Disposal concept

Compared to countries such as Finland, Sweden and France, the radioactive waste disposal process in the Netherlands is at an early, conceptual phase. Even though the present amount of radioactive waste is small, it is considered necessary to show that eventually safe and acceptable (disposal) options are available. Moreover, these options must be reviewed and updated on a regular basis to take into account new scientific and technological findings, as well as societal and political developments [14,15]. Guidance to identify formations that might be suitable for geological disposal was published in 1980 [16,17,18]. Generic 'disposal concepts' have to be selected for the purpose of the OPERA study. For salt, concepts developed in the framework of CORA are available [3,4]. The disposal concept in Boom clay is based on current Belgian Supercontainer concept [5] as well as earlier concepts for disposal in clay [e.g. 6]. In both the current Belgium and OPERA concept, waste is disposed of in a Boom Clay formation with a thickness of about 100 metres [10]. Also both disposal concepts are based upon the same sets of safety functions. A notable difference is that in the OPERA concept all LILW, (TE)NORM, and HLW is disposed of in the deep clay formation. In Belgium, plans are under development for a separate surface disposal for short-lived LILW. The NORM waste from the phosphorous industry (a short-lived LILW) stored at COVRA in the Netherlands is not in intended for disposal. The OPERA concept furthers differs in the chosen dimensions (smaller containers, shorter disposal drifts) that reflect the difference in amounts and characteristics of the waste and that facilitates the Dutch requirement of retrievability of the waste. Furthermore, the Dutch waste has to be disposed of at greater depths (500 m) to account for possible erosion that might be caused by glaciers. Evidence that glaciers extended south into the east half of the Netherlands some 150,000 years ago is still clearly visible at among others the Utrecht hill ridge and the Veluwe.

2.3. Retrievability

In 1993, the Dutch government introduced the requirement of retrievability for waste disposal [19]. Retrievability is the possibility of reversing the action of waste emplacement. In many other countries the possibilities for incorporating the concepts of retrievability and reversibility have been considered. Retrievability may be facilitated by repository design and operational strategies, by for example, leaving underground access ways open and emplacement/retrieval systems in place until a late stage, through the development and use of durable containers and easily excavated backfill [20]. As the term retrievability has acquired different meanings in different countries, it is important to specify: what need to be retrieved, for what period it needs to be retrievable, and for what reason (also with respect to monitoring). This is a topic of study within OPERA [1].
In OPERA, it is anticipated that the waste emplacement process will proceed for more than a decade. After emplacement a post-operational phase is foreseen in which recovery of the waste or waste packages is possible [2]. During this period, which may continue for decades up to several centuries, monitoring is needed as well as regular maintenance of access ways and emplacement/retrieval systems. On a regular basis, e.g. every 10 to 20 years, it should be decided whether to extend the post-operational phase, or retrieve the waste, or to close the facility. This decision process should be guided by a legally established procedure which must be transferred from government to government or even over generations.

2.4. Clay as a host rock

The geological disposal of radioactive waste in clay host rock is considered by several countries (Figure 2-2, [21]). The age and properties of the clay sediments in these countries differ considerably. In Switzerland, France, and Germany the clay sediments primarily consist of consolidated, indurated clay (claystone) [22, 23, 24]. The clay sediments considered in other countries like Spain and Belgium consist of less consolidated clay layers [25, 26]. The different clay sediments have their specific properties which have impact on the designs of the national disposal facilities as well as their safety strategy. An example is the design of the required support to prevent tunnel collapse. Tunnels in consolidated Opalinus Clay of the Rock Laboratory at Mont Terri in Switzerland require only 15 centimetre of shotcrete [e.g. 27]. The Boom Clay in Belgium is less consolidated and consequently much thicker prefabricated not reinforced concrete wedge blocks are required for tunnel support in the High Activity Disposal Experimental Site (HADES) at Mol [e.g. 10].

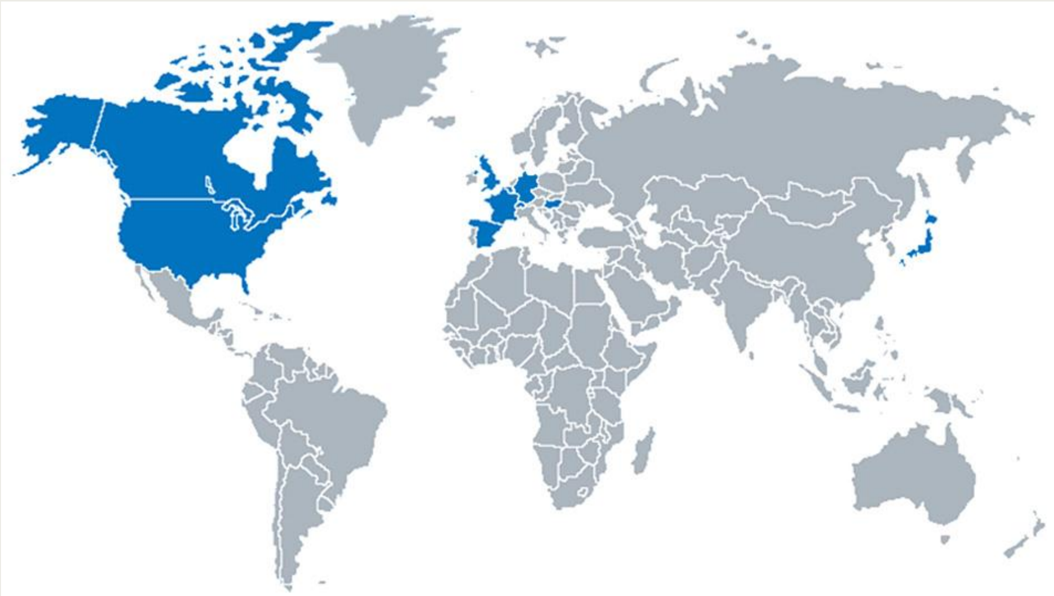


Figure 2-2 Overview of countries considering clay sediments as host rock for geological disposal of radioactive waste [21]

The favourable properties of the clay formations for disposal of radioactive waste include [21]:

- low permeability and low hydraulic gradients;
- chemical buffering capacity;
- propensity for plastic deformation and self-sealing of fractures;
- geochemical characteristics that favour low solubility of radionuclides; and
- high capacity to retard the migration of radionuclides towards the accessible environment, e.g. through sorption capacity and due to a diffusion-dominated transport.

The distribution and depth of the Boom Clay formations in the Netherlands were investigated in CORA [2]. These formations are named in the Netherlands as Rupel formations [28]. The age of these formations range from 30 until 34 million years (the epoch Oligocene [29] in the Cenozoic era).

3. Repository phases

Considering the large time spans involved in the geological disposal of radioactive waste, the disposal process is based on step-wise, incremental decisions. This chapter summarizes the foreseen subsequent phases of the disposal process in the Netherlands.

3.1. Phases and decision points

In the lifetime of a repository generally three phases can be distinguished (Figure 3-1):

1. Pre-operational phase;
2. Operational phase;
3. Post-operational phase.

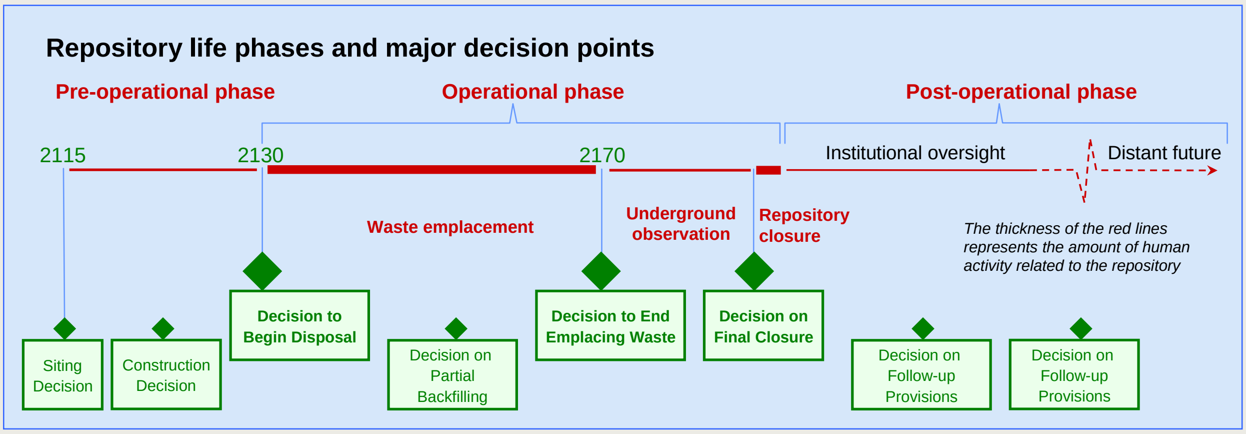


Figure 3-1 Repository phases for the Dutch situation (adapted from [30])

Estimates of the time spans needed for the construction, operation and closure of a facility were made using the knowledge can be found elsewhere [7].

3.2. Pre-operational phase

Activities in the pre-operational phase relate to [11]:

- concept development
- site investigation and selection
- design and construction.

The radioactive waste disposal programme in the Netherlands is currently in the stage of concept development. The operational phase is not expected to start before 2130.

3.3. Operational phase

The **operational phase** of a geological repository includes all aspects of the transport, emplacement, and the possibility of retrieval of the waste packages. After emplacement, the underground access ways can be kept open and emplacement/retrieval systems in place for a certain period to facilitate recovery of the waste or waste packages.

When the facility is closed and the shafts (and ramp) are refilled and sealed, the ***post-closure phase*** starts. After a disposal site has been closed, the operator is expected to remain responsible for maintenance, monitoring and control, reporting, and corrective measures on the basis of an authorised post-closure plan. The responsibility for the storage site, including specific legal obligations, can be transferred to the competent authority, if and when all available evidence indicates that the disposed waste will be completely and permanently contained.

3.4. Post-operational phase

After the transfer of responsibility, monitoring can be reduced to a level which still allows for identification of leakages or significant irregularities, but should again be intensified if leakages or significant irregularities are identified. This phase, that can last many decades, or longer, is also referred to as the *institutional control period*. During the post closure phase the retrieval of the waste would still be possible, but it would again require drilling operations and a return to reconstructing the facility. The repository itself no longer needs any maintenance or other supporting activities, since all excavations have been backfilled and closed.

At some point in time it may be decided to further reduce or even stop the monitoring. At that time, all the former galleries and disposal sections have developed into a so-called *post-closure* condition, and the system will evolve as a result of natural processes. This evolution is referred to as normal evolution in the assessment of the long-term safety.

4. Waste inventory

The future waste inventory depends on the future utilisation of nuclear energy. The OPERA waste inventory is based on the Dutch base scenario: no new nuclear power plants and operation of the present nuclear power plant until its intended closure in 2033 (Scenario 1a in [31]). A detailed description of waste characteristics including the different radionuclides will be developed in OPERA [1].

The CORA waste inventory [2] was updated to reflect the changes in waste generation over the past 15 years: the generation of some waste declined over time (e.g. LILW generation from hospitals, industry and research institutes), increased due to the extension in operation period (e.g. waste from Borssele nuclear power plan) and new wastes have emerged (e.g. depleted uranium).

In the Netherlands, the radioactive waste is classified into Low and Intermediate Level Waste (LILW), (Technically Enhanced) Naturally Occurring Radioactive Materials ((TE)NORM) and High Level Waste (HLW)[32]. The expected inventories intended for disposal for these three categories of waste are shown in the Appendix.

4.1. LILW

Low and intermediate level radioactive waste (LILW) arises from activities with radioactive materials or radioisotopes in among others industry, research institutes and hospitals. It includes lightly contaminated materials, such as plastic, metal or glass objects, tissues and cloth. The size of the LILW containers is standardised. The size is optimized to ease their handling. Four types of packages with volumes of 200, 600, 1000 or 1500 litres are stored at the COVRA site. The 200 and 600 litre drums consist of painted, galvanised steel with inside a layer of cement, embedding the waste. The 1000 and 1500 litre packages are full concrete packages wherein a cemented waste form is contained. In each package there is at least as much cement as waste volume. The larger part of the LILW packages can be handled easily and transferred to a geological disposal facility without significant additional shielding. The LILW is conditioned with concrete and is expected to be suitable for disposal without further packaging or conditioning.

4.2. (TE)NORM

Waste from ores – and other raw materials – generated in processing industries sometimes have natural radioactivity concentrations far in excess of the exemption levels [33]: (Technically Enhanced) Naturally Occurring Radioactive Materials (TE)NORM includes radioactive waste originating from the uranium enrichment facility of URENCO. Depleted uranium (DU) is intended to be disposed, but it is not conditioned to allow reuse of the material in the future. The DU is converted to a stable oxide and stored in standardized container (DV-70). For the purpose of this study it is assumed that a KONRAD type II container can be used for conditioning of the DU for disposal. The volume of waste is estimated to be 30.000 m^3. The conditioned volume will be 33.784 m^3 using the concrete for containment as recently published in which DU is considered to be a fine aggregate [34].

4.3. HLW

The high level waste consists partly of heat-generating waste (vitrified waste from reprocessed spent fuel from the Nuclear Power Plants in Borssele and Dodewaard, conditioned spent fuel from the research reactors and spent uranium targets from molybdenum production) and partly of non-heat-generating waste (such as hulls and ends from fuel assemblies).

Heat generation is a result of the continuing radioactive decay of the contained radionuclides. As time progresses, the heat output decreases due to the ongoing decay. The amount of heat generated depends on the type of waste, the composition of the waste, and/or the burn-up.

It is expected that other non-heat-generating HLW is generated including waste from dismantling and decommissioning nuclear facilities or historical wastes not yet stored at COVRA. The amount is presently estimated as 600 m^3. For the purpose of this study it is assumed that this waste is packaged is the same kind of canisters as used for spent fuel from research reactors and conditioned with concrete. HLW is expected to require further packaging and/or conditioning prior to disposal.

5. Repository outline

Figure 5-1 gives an outline of the surface and underground facilities of the OPERA disposal concept in Boom Clay. The OPERA disposal facility consists of both surface and underground facilities, connected by vertical shafts and (optionally) an inclined ramp.

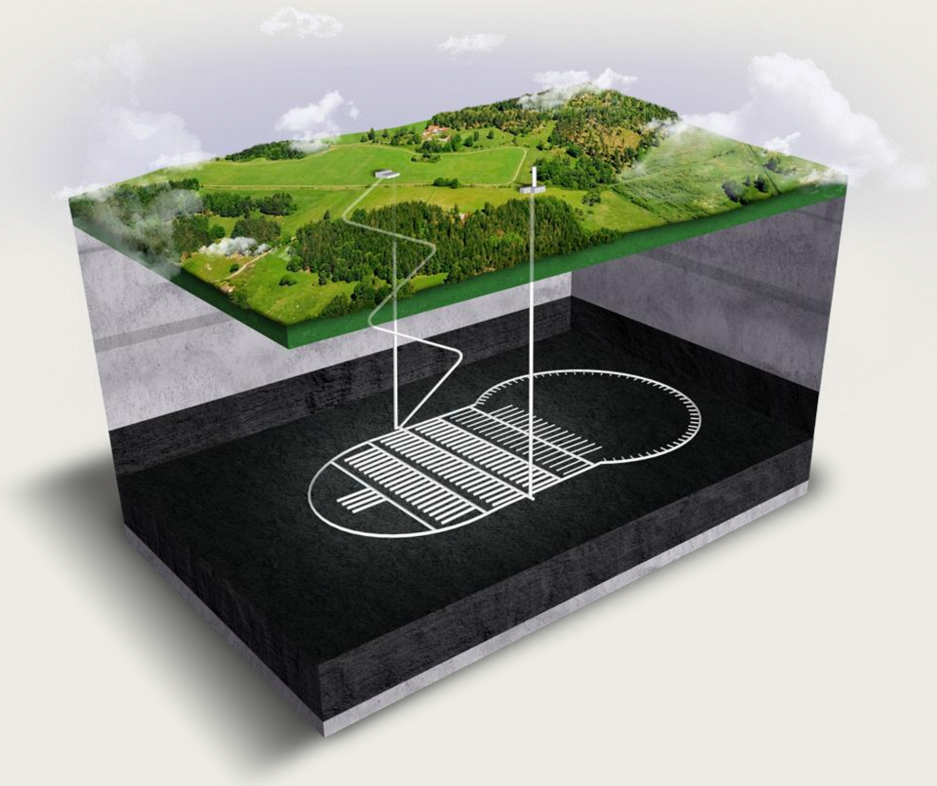


Figure 5-1 Artist impression of a geological repository for the disposal of radioactive waste in Boom Clay.

5.1. Surface facilities

The surface facilities are required for receiving, inspecting and conditioning the different waste types, i.e. the Waste Conditioning Facilities (WCF). Surface facilities also include support infrastructure for construction, operation and closure activities in the underground disposal facility, i.e. the Construction and Supply (C&S) facility. The surface facilities will be split into a (radiological) controlled area where all waste handlings will take place and a non-controlled area, mainly involved in the constructional works. Since the OPERA programme concentrates on the feasibility as well as the long-term safety of geological disposal in the Netherlands, no detailed design considerations will be given to the surface facilities.

5.2. Underground facilities

The underground facilities contain separate disposal sections for the different types of wastes, a pilot facility and a workshop for maintenance work, all connected by the main gallery. The main gallery is an orbicular structure, which connects with the ground level via two access shafts and/or an (optional) inclined ramp.

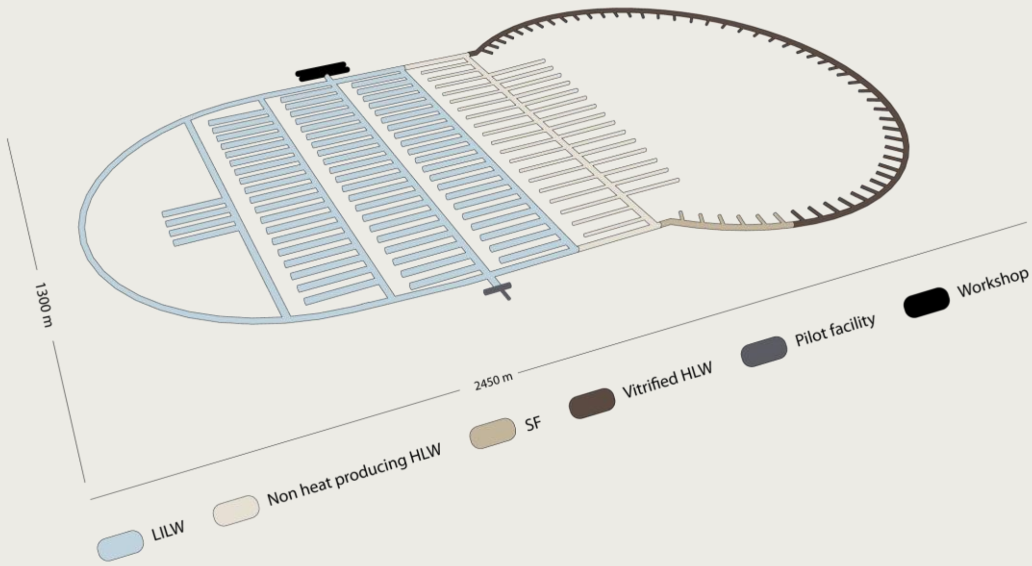


Figure 5-2 Disposal sections of the underground facility.

The facility contains four waste disposal sections: for vitrified HLW, for spent fuel from research reactors, for non-heat-generating HLW and for the disposal of ILW/LLW and depleted uranium (
Figure 5-2). Each section is optimized with regard to dimensions and modes of transport of the waste containers through the galleries.Both shafts lead to the horizontal **main gallery**, which consists of an excavated single loop. The main gallery is intended for transport of waste containers, excavated clay, and other materials as well as transport vehicles and personnel. The curved part of the main gallery directly leads to the HLW disposal drifts.

The six **secondary galleries** are branches of the main gallery and lead to the waste disposal drifts in the various waste sections. The proposed dimensions of the secondary galleries in the OPERA disposal concept are summarized in the appendix.
In order to guarantee the safety in case of anomalies during the operational phase and during the period where a possible retrieval of the waste is foreseen, a layout has been selected in which all disposal drifts have a dead-end topology. Because of the dead-end topology, even in case the repository is flooded and water infiltrates the galleries, no flow circulation through the disposal drifts can occur.

The layout of the **disposal sections** depends on the type of waste involved. For non-heat-generating waste sufficient spacing between disposal drifts is necessary to have a mechanically safe barrier between adjacent zones and to support the overburden [6]. For heat-generating waste thermal loading is also a consideration. Packages and drift spacing are chosen to limit the temperature in the host rock (typically below 100°C) and engineered barriers as well as well to minimize temperature rise at the interface between the aquifer and Boom clay.

The vitrified heat-generating HLW and spent fuel (from research reactors) will be packed in supercontainers (see 5.4) and placed in disposal drifts with a length of 45 m. The heat-generating HLW section is situated on the inside of the curved part of the repository (see Figure 5-2). This would allow for modular extension of the HLW section on the outside of the curved part. The non-heat-generating HLW section is larger in size than the heat producing HLW section and located between the shafts and the curved part of the main gallery. The overpacks with the non-heat-generating HLW are envisaged to be emplaced in 200 m long disposal drifts.
The layout of the disposal section for LILW and (TE)NORM waste is comparable to the non-heat-generating HLW section, except that the diameter of the disposal drift is larger (3.7 m vs. 2.2 m for HLW). To accommodate for the larger inventory of LILW/(TE)NORM waste the number of 200 m long disposal drifts is five times as large as that of the non-heat-generating HLW section. Again, the disposal drifts are designed as horizontal dead-end drifts, in order to avoid any circulation in the unlikely case of flooding of the facility.

The construction of a **pilot facility** is an important feature of the OPERA disposal concept. The OPERA pilot facility consists of a short disposal drift with a comparable layout as foreseen for HLW, but it will contain only one single OPERA Container with vitrified HLW. The pilot facility will be constructed in the beginning of the operational phase and will be equipped with sensors. The pilot facility will serve as a demonstration disposal drift to demonstrate the procedures anticipated for the actual large-scale emplacement of waste packages, to assess the behaviour of the engineered barriers and the host rock under in-situ conditions, and to support the performance models used to evaluate the behaviour of the waste package, the enclosing backfill, the drift liner, and the enclosing host rock. In addition, a pilot facility may have a relevant role in increasing public confidence in the safety of the disposal facility and therefore can become an important cornerstone for the public acceptance of the waste disposal process.

5.3. Disposal drifts

The **disposal drifts** in the separate waste disposal sections are horizontal boreholes that are directly connected to the main gallery in case of vitrified waste and spent fuel or can be accessed through the secondary galleries (other waste types). The disposal drifts are supported by concrete wedge-shaped blocks. After the emplacement of the waste packages, the disposal drifts are backfilled with grout and hydraulically sealed off using a plug.
An important characteristic for further development of the backfill is its capacity to provide additional support to the disposal drifts, and, in a later stage, the secondary galleries. Backfill material should not impede the possibility to retrieve the waste packages. Furthermore, the backfill material in the heat-generating HLW-section should match the thermal properties of the surrounding clay and enable sufficient dissipation of the decay heat from the container into the Boom Clay. The suitability of foam concrete as a backfill material is investigated in OPERA [34].

Figure 5-3 Artist impression of the HLW waste sections

The length of a single disposal drift in the HLW section is taken here as 45 m, including the plug. Considering the dimensions of the OPERA Containers, each disposal drift can hold 15 supercontainers with a length of 2.5 meter. For the supercontainers with a length of 3 meter, 12 supercontainers for each disposal drift are considered.

Figure 5-4 Artist impression of the LILW section for 1,000 l containers[b]

For LILW, to save spacing, the waste containers in Table A-1 are stacked on top of each other in the disposal gallery. A concrete container support may be necessary to provide stability to the stacks of containers. After the emplacement of the waste containers, the disposal drifts will be backfilled with grout and hydraulically sealed off. Figure 5-4 shows a general lay out of this section for 1,000 litre containers: 3-3-2 for stacking 8 containers.For the same gallery diameter, the layout is presumed to be 5-6-6-4-3-2 for stacking 31 200 litre drums and 4-4-3-2 for stacking 13 600 litre drums per section. For depleted uranium, two KONRAD type II containers will be emplaced per gallery section.

5.4. Waste packages

For storage and disposal as much as possible uniform, standardized waste packages are used. The LILW is conditioned with concrete and is expected to be suitable for disposal without further packaging or conditioning. The (TE)NORM is disposed of in KONRAD type II containers. HLW is overpacked in supercontainers. In the supercontainer concept the waste canister, overpack and buffer are transported and disposed of as one entity. Advantages of the use of supercontainers include:

- All HLW fractions are enclosed in one standardized container.
- The construction, assemblages and quality assurance of the supercontainer can be done above ground.
- The concrete buffer provides shielding to the workers during the operational phase.
- The decay heat is spread over a larger outer surface, simplifying the handling of the heat producing HLW.
- The concrete buffer impedes the corrosion of the stainless steel canisters.

The OPERA supercontainer is adopted from the Belgian supercontainer concept, which consists of a carbon steel overpack, a concrete buffer and stainless steel envelope and can hold two HLW canisters or one SF canister [35]. In OPERA a uniform supercontainer is used for the heat-generating HLW, spent fuel from research reactors as well as the non-heat-generating HLW. Figure 5-5 shows an artist impression of the OPERA supercontainer for heat-generating HLW.

Figure 5-5 Artist impression of OPERA supercontainer for heat-generating HLW.

The OPERA supercontainer is smaller than the Belgian container. The size of container is mainly determined by the concrete buffer and size of the waste canister. The supercontainer can accommodate three types of HLW waste: containers for heat-generating HLW, spent fuel and non-heat-generating HLW . Note that the supercontainers with a length of 2.5 meter hold *one* CSD-V and CSD-C canister respectively, whereas the supercontainers with a length of 3.0 meter holds *two* containers with either spent fuel or other non heat generating waste.
Buffer thickness is a balance between among others (1) transportability and handling inside the facility, also with respect to retrievability; (2) radiation shielding and heat dissipation, as well as (3) buffer stability. Because of the longer interim storage in the Netherlands, heat production and radiation are lower and package dimensions can be reduced. The container is dimensioned on the heat-generating HLW. The concrete shielding of the OPERA supercontainer is designed to limit the dose rate of the heat-generating HLW to a maximum of 10 mSv per hour (maximum dose for transport of a collo [36]). The main properties of the OPERA container are summarized in a table presented in the Appendix 1.

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Appendix

Table A-1 Expected inventory of LILW intended for disposal

Container Type at storage	Waste classification [1]	Dimensions [m] [2]	Number of containers	Max Dose rate [mSv/h]	Max. weight [kg]	Container material
200l	A/B/C/D	0.59 × 0.88	140,000	10	1,900	Galvanized steel/ concrete container
600l		0.85 × 1.23	180			
1000l		1.00 × 1.25	12,000			
1500l		1.00 × 1.90	280			

[1]Category A is waste contains alpha emitting radionuclides | Category B is contaminated waste from the nuclear power plants Borssele and Dodewaard | Category C is waste contaminated with solely beta and gamma emitters with a half life longer than 15 years | Category D is waste contaminated with solely beta and gamma emitters with a half life shorter than 15 years. This classification can be found in the Joint Convention report [1] For the purpose of this study it is assumed all LILW is intended for geological disposal even though some of the waste will have decayed below exemption levels after 100 years of interim storage.
[2] diameter × length of package suitable for disposal

Table A-2 Expected inventory of (TE)NORM Intended for disposal

Container Type at storage	Waste classification	Dimensions [m][1]	Number of containers	Max Dose rate [mSv/h]	Max weight [kg]	Container material
KONRAD Type II	Depleted uranium (U_3O_8)	1,7 * 1,7 * 1,6	7,700	10	20,000	Steel, Concrete

[1] Height × length x width of package suitable for disposal

Table A-3 Expected inventory of HLW intended for disposal

Container type at storage	Waste classification	Dimensions [m]	Number of containers *(supercontainers)*	Dose rate [Gy/h]	Weight [kg]	Container material
ECN	Spent fuel, uranium filters	0.74×0.95	150 *(75)*	60	≤1,000	Stainless steel type 304
CSD-V	Vitrified waste	0.43×1.34	625 *(625)*	600	500	Stainless steel type 316
CSD-C	Compacted hulls and ends	0.43×1.34	1,250 *(1250)*	10	≤850	Stainless steel type 316
Not yet specified	Other non-heat-generating HLW	0.74×0.95	2,000 *(1000)*	10	≤1,000	Stainless steel type 304

ECN = container designed by Energieonderzoek Centrum Nederland | CSD-V= Colis Standard de Déchets – Vitrified ; containers designedby the French company COGEMA (CompagnieGénérale des MatièresNucléaires) as well as glass matrix, presently AREVA | CSD-C= Colis Standard de Déchets – Compactés ; containers designedby the French company COGEMA (CompagnieGénérale des MatièresNucléaires)

Table A-4 Dimensions of the shafts, galleries and tunnels

	Number	Length [m]	Diameter[1] [m]	Concrete Support Thickness [m]	Gallery Spacing [m]
Shaft	2	500	6.2/5.0	0.60	1110
Main Gallery	1	7200	4.8/3.7	0.55	N.A.
Secondary Galleries	5	1100	4.8/3.7	0.55	260
Disposal Tunnels					
Heat-generating HLW	47	45	3.2/2.2	0.50	50
Spent fuel	6	45	3.2/2.2	0.50	50
Non-heat-generating HLW	36	200	3.2/2.2	0.50	50
LILW and DU	65	200	4.8/3.7	0.55	50

[1] Excavated diameter/Inner diameter of the gallery support

Dimensions of the shafts, galleries and tunnels in the OPERA disposal concept are comparable to TRUCK-I [2], which were calculated using (corrected) geotechnical properties of Boom Clay at 225 meter. Further information on the dimensions of Boom Clay disposal concepts can be found elsewhere [3, 4].

Table A-5 present provisional data on the OPERA supercontainer. The safety functions of this canister (such as radiation shielding, heat transfer, chemical and gas buffer properties) have to be confirmed by further analyses in the OPERA research program.

Dimensions of the concrete and overpack thicknesses are equal to the Belgian supercontainer concept [5]. From a study by S. Poyet (CEA) described in the PhD thesis by Craeye [5] it can deduced that a concrete thickness of 70 cm and 30 mm of steel was calculated to provide sufficient radiological protection for (irradiated) fissile materials that were cooled for a period of at least 50 years. For the Netherlands, larger cooling periods are foreseen which may result in a smaller concrete thickness.

Also in Craeye [5] it can be read that the 30 mm thickness of carbon steel is composed of a part to sustain mechanical and thermal stresses, namely 16 mm, and an additional thickness to sustain corrosion, namely 14 mm. Presuming a conservative measured uniform corrosion rate of 2.5 μm per year [5] it can be deduced that contact between water and waste is prevented for the period that the thermal phase lasts. Smaller corrosion rates are expected since alkaline conditions at the overpack surface are calculated to last 80,000 years when the concrete buffer is made with Ordinary Portland Cement [6].

The KONRAD Type II containers have a thickness of steel of at least 3 mm. A similar weight needs to be carried for the steel envelope of the supercontainers during the operational phase. As a start, a thickness of 4 mm is envisaged for this envelope.

Table A-5 Provisional properties of the OPERA supercontainer

Outer container diameter	1.9 m
Outer container length	2.5 m for 1 CSD and 3.0 m for 2 (ECN) containers
Waste container	one CSD-V-canister, one CSD-C-canister, or 2 (ECN) containers
Concrete thickness	0.6-0.7 m
Steel overpack thickness	3 cm
Steel envelope thickness	0.4 cm
Max. dose rate at container surface	≤10 mSv/hr
Weight	Approx. 20 000 kg to maximal 24.000 kg

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OPERA

Meer informatie:

Postadres
Postbus 202
4380 AE
Vlissingen

T 0113-616 666
F 0113-616 650
E info@covra.nl

www.covra.nl