Cost estimate for disposal of waste in clay host rock in the Netherlands

Price level 2022

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Review internal draft	Marja Vuorio	31.03.2024
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Consistency check with cost estimate rock salt (from June 2023 until October 2024)		
COVRA final report	Erika Neeft	17.12.2024

Summary

COVRA has a long-term research programme for disposal of radioactive waste. Radioactive waste can be hazardous for thousands of years, especially High Level Waste (HLW). This waste is therefore proposed to be isolated in an underground facility at several hundreds of meters depth. This facility is to be constructed in a geological formation. This formation is at least several tens of million year old. A single disposal facility is envisaged in which also Low and Intermediate Level Waste (LILW) is to be disposed of. The hazard potential of LILW is smaller than HLW by which LILW can be disposed of at a smaller depth than HLW.

The start of emplacement of waste packages in the underground disposal facility is envisaged to be in 2130. This planning provides time to learn from other countries, to carry out research and to accumulate the knowledge to make well-founded decisions. COVRA currently collects waste, processes waste, stores waste packages with solidified waste and takes full title of the waste. COVRA will make not-site specific cost estimates during the next decades in order to assess the contribution of the disposal of waste in the waste fees. That part of the collected financial resources is invested in order to gain sufficient financial provisions to construct, operate and close the Geological Disposal Facility (GDF).

The GDF is assumed to be constructed in poorly indurated clay formations in this report with an age of at least 25 million years. The underground part of the GDF consists of a structure of shafts and tunnels. There are transport tunnels and disposal tunnels in which waste packages are to be emplaced. All tunnels need to be mechanically supported. The lay-out of the construction of tunnels is impacted by the disposal depth since:

1) The necessary distance between disposal tunnels is assumed to be smaller due to the smaller mechanical load at smaller disposal depth by which the length of the transport tunnel is reduced;
2) The thickness of the tunnel liner is assumed to be smaller at smaller disposal depth by which more waste volume can be emplaced per length tunnel by which the total length of the disposal tunnels is reduced or the number of disposal tunnels can be reduced.

The report presents an 'overnight' cost estimate of a disposal concept in these clay formations. All costs have a price level of 2022 assuming the GDF project was completed within a single day. The waste inventory has a high impact on the cost estimate to construct, operate and close the GDF. The base inventory is determined by the past and current operating nuclear installations, waste arising from non-nuclear activities and the waste arising from the operation and closure of the not yet build research reactor Pallas.

If all the different types of waste are disposed of at the same disposal depth i.e. a single level GDF, the estimated costs are 4.8 billion euros with a confidence level of 95% and the best estimate is 3.0 billion euros (price level 2022). The value discounted to 2130 is 2.8 billion euros with a discount rate of 2.3%.

If the different types of waste are disposed of according to their hazard potential, the estimated costs are 4.6 billion euro with a confidence level of 95% and the best estimate is 2.7 billion euros (price level 2022). Conservatively, only the configuration of the disposal tunnels has been allowed to change, not the transport tunnels. The value discounted to 2130 is 2.0 billion euros i.e. much less than the 2.8 billion euro for a single level GDF since the majority of the construction costs are planned after 2130 for a multi-level GDF.

Content

1 Introduction

Although the start of emplacement of waste packages in the underground disposal facility is envisaged to be in 2130 (I&E, 2016; van Gemert et al., 2023), COVRA makes cost estimates for geological disposal of waste every 5 years. COVRA makes not-site specific cost estimates in order to assess the contribution of the disposal of waste in the waste fees. That part of the collected financial resources is invested in order to gain sufficient financial provisions to construct, operate and close the Geological Disposal Facility (GDF).

The proposed technology for the construction of the GDF, the required measures to maintain the GDF, the methodology to emplace waste packages and how the GDF is proposed to be closed determine the costs of the GDF. Only existing technologies are used for the cost estimate and demonstrating examples of these techniques are described in the safety case (Neeft et al., to be published in March 2025). For completeness, some of the figures from this safety case are also put in this cost estimate.

The construction methodology depends on the type of geological formation and depth of the underground disposal facility. This report concerns the emplacement of waste packages in poorly indurated clays. A depth of 500 m was used as a point of departure in CORA for a GDF in Neogene or Paleogene clay formations (the second national research programme into geological disposal of waste) in order to take into account potential glacial erosion in the far future for disposed of vitrified High Level Waste (HLW) (CORA, 2001). It was chosen to dispose of any type of waste at 500 m depth in OPERA only in one type of Paleogene clay i.e. Boom Clay in order to use information and learn from experience in the mature Belgian programme, which has identified the Boom clay as a preferred host rock for its national GDF project (Verhoef and Schröder, 2011). Several clay formations will be present at a single location in the Netherlands e.g. Simmelink et al. (1996). This feature has been used in the optimisation of the disposal facility by making the hazard potential of the waste controlling the disposal depth of the waste (Neeft et al., to be published in March 2025).

2 The waste to be disposed of

The number and dimensions of the waste packages, the weight of the packages and the radiation dose rate of the packages determine how the waste is envisaged to be emplaced and therefore have a high impact on the costs for the GDF. In the second national programme CORA, only vitrified HLW was envisaged to be disposed of in a GDF in clay host rock. Radiation protection during emplacement of the waste packages was foreseen by a not yet existing vehicle and manufacturing of shielding in the underground after emplacement of the canisters with vitrified HLW i.e. CSD-v's (CORA, 2001).

In the third national programme OPERA, it has been chosen only to emplace contact-handled waste in the GDF (Verhoef et al., 2017) in order to optimize the control of the quality of the shielding by manufacturing the shielding above ground. Also in COPERA, only contact-handled is to be disposed of. Low Intermediate Level Waste (LILW) as defined in this report[1] is already contact-handled waste. HLW packages are foreseen to be manufactured in advance of emplacement in a GDF. The dimensions and weight of a package with HLW in order to achieve contact-handled waste are multiple times larger than these dimensions and weights, currently stored as remote handled waste at COVRA's premises (see Table 2-1).

Table 2-1: Expected inventory of wastes for disposal in 2130 for waste scenario 1 (Burggraaff et al., 2022) showing their mass and volume in storage and their mass and volume when packaged for disposal. The diameter of all HLW packages is 2 metres (see Table 3-1).

In storage volume as defined in Burggraaff et al. (2022)[2] including remote-handled waste			Packaged for disposal only contact-handled waste		
Waste category	Volume (m^3)	Number of canisters / containers	Number of packages	Volume (m^3)	Weight per package (tonne)
Spent Research Reactor Fuel (SRRF)	49[3]	244	244	1840	20
Vitrified HLW	86[4]	478	478	3754	22
Compacted hulls & ends (Non heat generating HLW)	90	502	72	452	20
Dismantling waste (LILW)	3814	-	826	3814	Max 20
TE-NORM (LILW)	49360	-	12600	58070	Max 20
Processed LILW	31461	108400	108400	For three 200 litre drums: max 2.25 tonne For one 1000 litre concrete container: max per 3 tonne	

[1] IAEA's definition of HLW requires shielding as well as measures for the generation of heat. Only shielding is necessary for Intermediate Level Waste (ILW). In the Netherlands, a distinction is made between heat-generating HLW and non-heat generating HLW i.e. non-heat generating HLW is ILW by IAEA's definition. Heat generating as well as non-heat generating HLW are stored in the same storage facility at COVRA's premises in which waste packages are only remotely handled.

[2] Rounding off volumes separately may result in a volume of 227 m^3 for HLW as found by Burggraaff et al. 2022.

[3] The volume at storage is assumed be 0.20 m^3 in Burggraaff et al., 2022. The outer dimensions of the container leading to 0.693 m^3 were used in the OPERA Safety Case and also in this cost estimate.

[4] The volume at storage is assumed be 0.18 m^3 in Burggraaff et al., 2022. The outer dimensions of the container leading to 0.195 m^3 were used in the OPERA Safety Case and also in this cost estimate.

3 Lay-outs of the disposal facility

The costs for a single level GDF as well as multiple level GDF are calculated in order to quantify an optimization of the underground disposal facility in which the disposal depth varies as a function of the hazard potential of waste. The hazard potential of HLW is much higher than LILW and therefore LILW can be disposed of at a smaller depth than HLW.

The underground engineering structure consists of tunnels that are connected with the surface through shafts. Three shafts are used, two larger shafts and one smaller separate rescue shaft. This design with a separate rescue shaft is conservative for example in Konrad[5] there is no separate rescue shaft, a small cage is lowered for personnel to leave the underground in case of emergencies. This small cage in Konrad can be lowered from a larger shaft with an internal diameter of 7 m; that shaft also hosts a larger cage for waste packages et cetera.

The planning scheme for the construction, operation and closure of this GDF depends on the construction rate of the tunnels, the emplacement rate of the waste packages and the backfilling rate of the tunnels with disposed of waste. The used rates for the cost estimate, including a short explanation and their references, if available, are shown in Appendix 1.

3.1 Single level GDF

Figure 3-1 shows the structure of tunnels and shafts for a single level GDF in which only tunnels to emplace waste packages (outer diameter of 5 metres) and shafts intersect transport tunnels (outer diameter of 10 metres) i.e. transport tunnels do not intersect each other. Unlike harder rocks, tunnels in poorly indurated clay with the same outer diameter cannot intersect each other. The number and length of the disposal tunnels is also portrayed in Table 3-1.

[5] A disposal facility constructed for LILW in an old German iron mine in which the iron ore is covered by clay rocks.

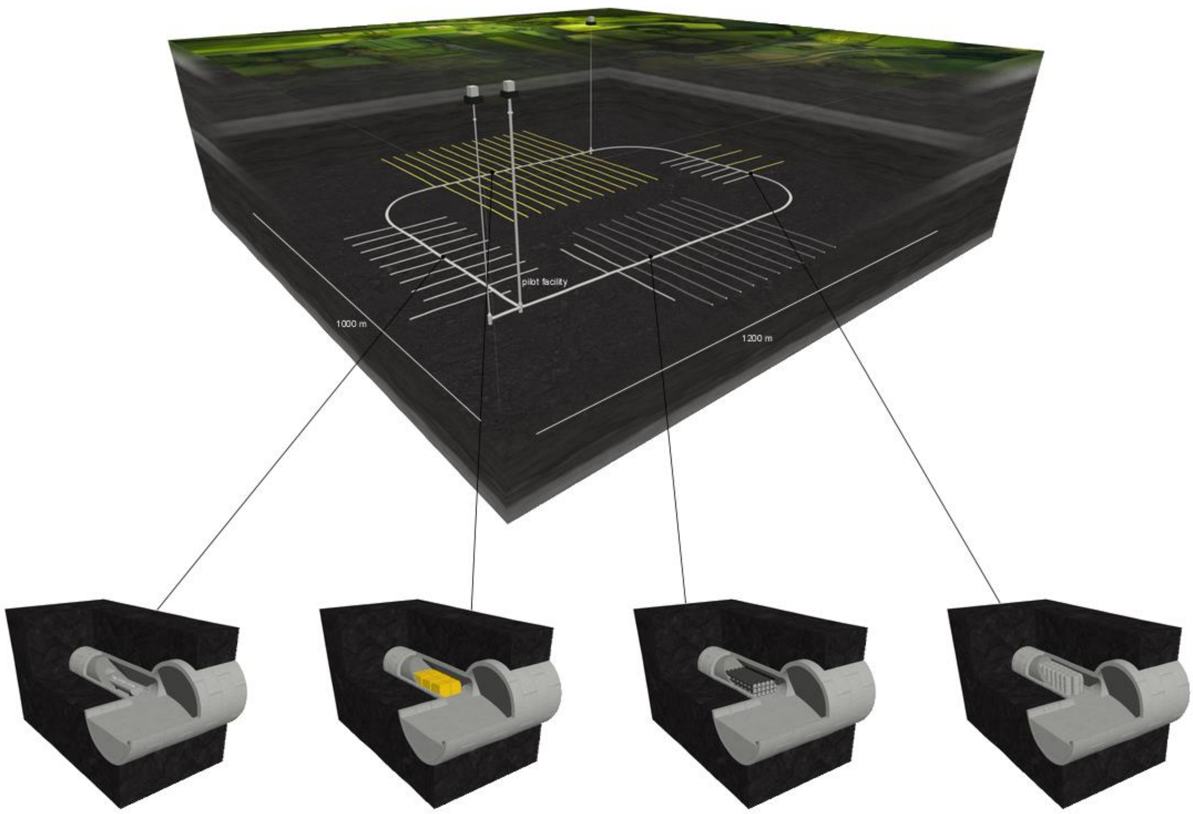


Figure 3-1: Lay-out of a single level GDF in clay host rock with the different types of disposed of waste. Two shafts (internal diameter 6.5 m) for transport of excavated clay, concrete segments, waste packages, cementitious backfill and re-constituted clay. One rescue shaft (internal diameter 2 m) only for personnel has a smaller diameter than these two shafts. Centre to centre distance between disposal tunnels is 50 m at 500 m depth (same as in OPERA).

The construction rate of underground tunnels is limited by hoisting the excavated clay up through the shafts (Li et al., 2023). The hoisting up and down of materials through the shafts is limited by the weight of materials. In the operational phase, the weight is also assumed to be more limiting for hoisting the waste packages down than their size. Most waste packages are small in dimension see for example 200 l drums in Table 3-1; the weight of 36 200 litre drums with an average weight of 0.5 ton is less than 1 HLW package (see Appendix 1). The shafts with an internal diameter of 6.5 m can have a cage with dimensions: 4 m (length) × 4 m (width) × 3 m (height). This cage can hoist 36 200 litre drums down at the same time (see Table 3-1 for the dimensions of the packages). The weight rate for hoisting the 200 litre drums down is more than 9 times smaller than the weight rate for lifting the excavated clay. The assumed volume rate for emplacement of waste is similar to the proposed rate for Konrad in Germany (see Appendix 1).

The excavated clay is to be put in the boxes and transported with vehicles such as fork lift trucks (see Figure 3-2) to the shafts. The transport tunnel is divided in two sections during operation (see Figure 3-2):

- one section with vehicles (forklift trucks and air-cushion devices) to emplace the waste packages;
- one section without emplacement vehicles in order to escape as fast as possible for personnel in case of any emergency.

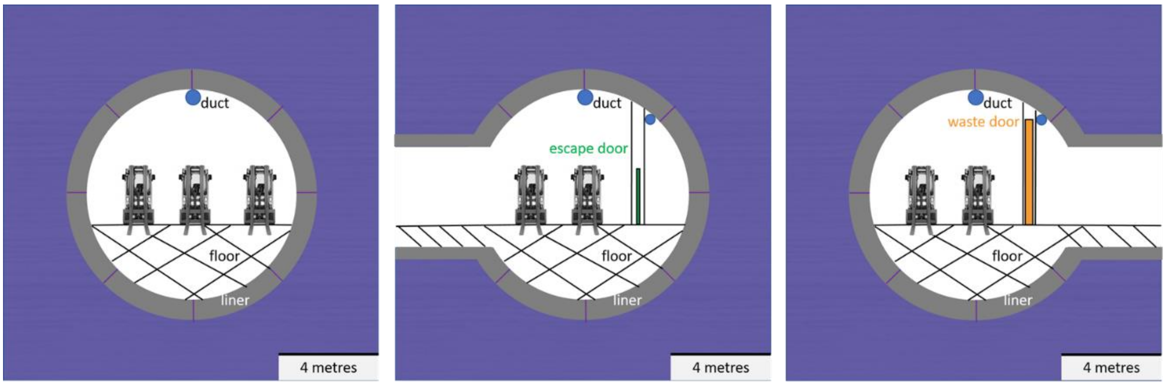


Figure 3-2: Dimensions in transport through the transport tunnel during construction (left) and operation with a fire wall and escape door (middle) and waste door (right). Inner diameter of transport tunnel is 8.4 m.

Table 3-1: Number and dimensions packages and disposal tunnels for a single level GDF and in italics and brackets different from a multiple level GDF. Weight of the packaged waste is available in Appendix 1.

		Packages for disposal			Disposal tunnels		
Waste category		Height (m)	Diameter (m) or Width (m) × Length (m)	N packages	N	$Ø_{out}/Ø_{in}$ (m)	Length (m)
Spent research reactor fuel (HLW)		2.4	2.0	244	6	5.0 / 4.0	100
Vitrified HLW		2.5	2.0	478	12	5.0 / 4.0	100
Compacted hulls & ends (HLW)		2.0	2.0	72	1	5.0 / 4.0	150
Dismantling waste (LILW)		1.7	1.6 × 1.7	826	4	5.0 / 4.0 *(5.0 / 4.6)*	185 *(175)*
TE-NORM (LILW)		1.7	1.6 × 1.7	12600	27	5.0 / 4.0	400
Processed LILW	200 l	0.88	0.59	100000	21 *(20)*	5.0 / 4.0 *(5.0 / 4.6)*	250 *(200)*
	1000 l	1.25	1.00	8400	7 3 *(8)*	5.0 / 4.0 5.0 / 4.0 *(5.0 / 4.6)*	150 200 *(200)*

N=Number

3.2 Multi-level GDF

Several Paleogene clay formations will be present at a single location in the Netherlands e.g. Simmelink et al. (1996). In foreign counties e.g. Sweden, Finland, Spain, Czech and Hungary, processed LILW and dismantling waste in Table 2-1 are being disposed of in surface or near surface facilities. Dismantling waste and the processed LILW (200 litre drums) contain mainly short-lived radionuclides and are therefore proposed to be disposed of at a smaller disposal depth than HLW (see Figure 3-3). Waste is proposed to be disposed of at the smallest disposal depth of 100 m. TE-NORM is depleted uranium and has only long-lived radionuclides but its activity is low and therefore proposed to be disposed of at a depth between HLW and short-lived LILW i.e. 200 m. The 1000 litre processes containers have such a high activity that the major volume of the waste package is shielding material. The HLW needs even more shielding material and is proposed to be disposed of at a depth of 500 m i.e. similar to the single level GDF. The number and length of the disposal tunnels at smaller disposal depths is also portrayed in brackets in Table 3-1.

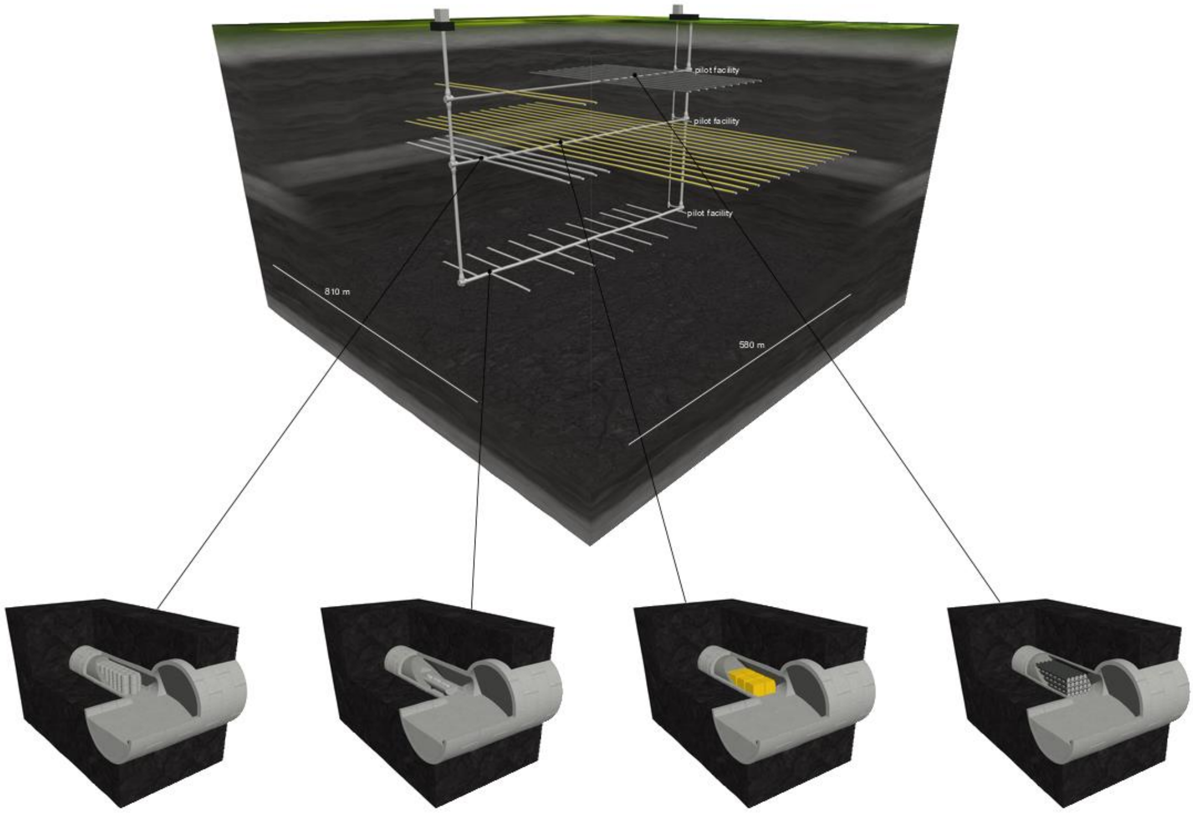


Figure 3-3: Lay-out of a multiple level GDF in clay host rock with the different types of disposed of waste. Two shafts (internal diameter 6.5 m) for transport of excavated clay, concrete segments, waste packages, cementitious backfill and re-constituted clay. One rescue shaft (internal diameter 2 m) only for personnel has a smaller diameter than these two shafts. Centre to centre distance between disposal tunnels is 20 m at 100 m depth, 30 m at 200 m depth and 50 m at 500 m depth.

4 Cost estimates of the geological disposal facilities

4.1 Costs for a single level GDF

In OPERA, the average costs for the disposal facility were estimated to be 2.05 billion euros with a price level of 2017, discounted to 2130 (Verhoef et al., 2017) using a constant yearly discount rate of 2.3%. Without discount, the average costs of the GDF was estimated to be 2.61 billion euros with a price level of 2017. These average costs would be 2.9 billion euros with a price level of 2022 using a constant yearly inflation rate of 2%. The margin was chosen to be 50% (see section 4.5 Sources of information). The reviewers of the cost estimate performed in OPERA advised COVRA to perform the future cost estimates probabilistically (Bruinsma and Tempels, 2017). Probabilistic cost calculations are also made by WMOs that already construct GDFs such as SKB (IAEA, 2020). The number of simulations of cost estimates shown in this report is 10.000. With a price level of 2022, the total costs for a disposal facility with three shafts within a single clay formation and excluding VAT have estimated to be (see also Figure 4-1):

- 3.0 billion euros is the best estimate / 3.4 billion euro with a probability to exceed 50%;
- 4.8 billion euro with a probability to exceed of 5%.

The average costs for disposal of 3.0 billion euro as currently calculated for a price level 2022 is larger than the 2.9 billion euro for the inflation corrected to 2022 cost estimate made in 2017. There is therefore hardly a reduction in costs despite a significant reduction in disposal volume for non-heat-generating HLW (CSD-c). There are several reasons for this lack in reduction. The most important one is that the concept as proposed in OPERA may not be feasible in terms of:

- Removal of the excavated clay to the surface through an inclined ramp. This removal through an inclined ramp is not possible by which transport by shaft is needed. Removal through the shafts requires longer periods for construction;
- Transport tunnels were crossing transport tunnels in the lay-out shown in the OPERA Safety case. Such crossings can currently not be constructed by which the length of the transport tunnel is increased due to curved sections without disposal tunnels;
- Also the envisaged crossings in OPERA between transport tunnels and disposal tunnels are currently not possible to construct since the ratio between the transport tunnel and disposal tunnel should be at least 2. This ratio in OPERA was 1.3 i.e. the outer diameter of the transport tunnel was 6.2 metres while the outer diameter for tunnels to dispose of LILW was 4.8 metres. Currently the diameter of the transport tunnel is 10 metres and an increasing size of the diameter of the tunnel requires more material by which the costs are higher;
- The manoeuvring space to emplace waste package with a vehicle was too small in OPERA with an inner diameter of 3.7 metres. The minimum in diameter of 4 metres used in this report is constrained by the fork lift truck that is proposed to emplace waste packages (Neeft et al., to be published in March 2025).

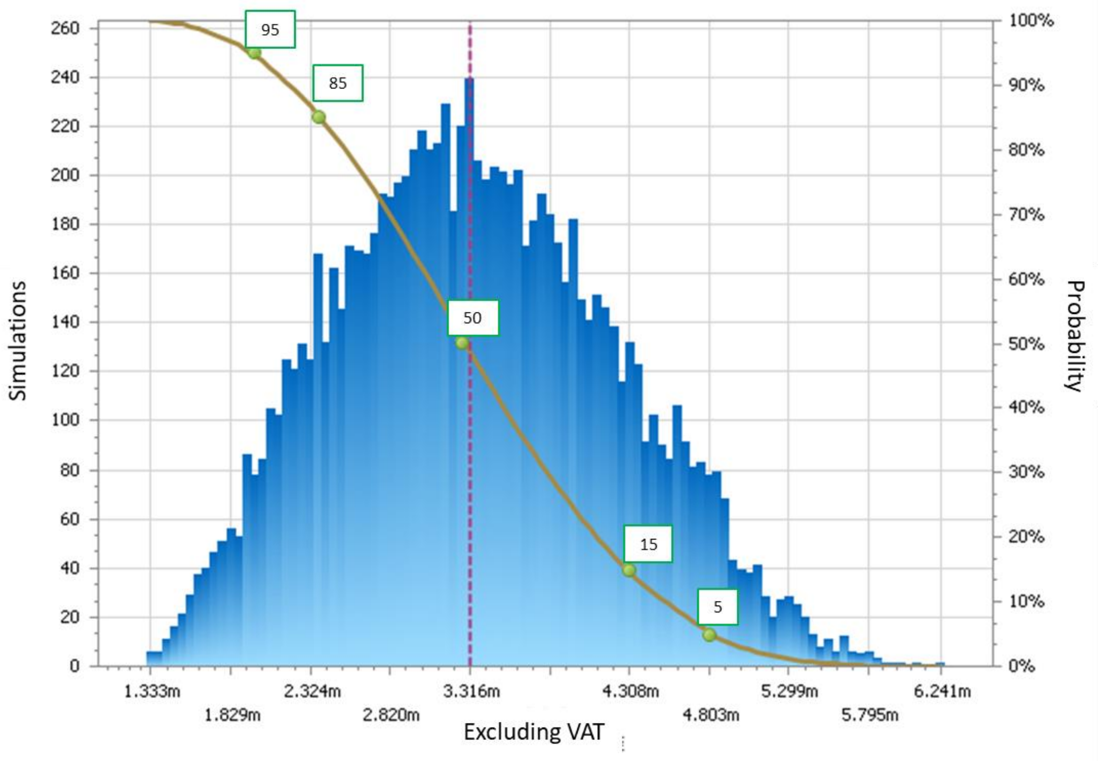


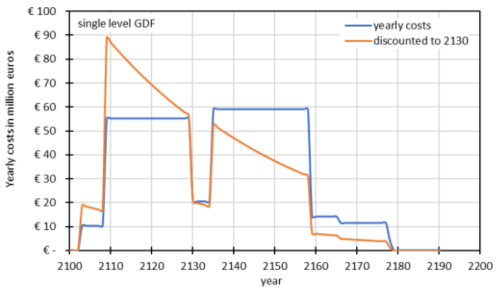
Figure 4-1: Total costs price level 2022 for a single level GDF excluding VAT, variation coefficient 26%.

There are four different levels for margins defined by the Electric Power Research Institute (EPRI) (IAEA, 2020):

1) Simplified planning (conceptual screening): 30-50%
2) Preliminary planning (feasibility study): 15-30%
3) Detailed planning (budgeting stage): 10-20%
4) Final or near-final planning (tendering stage): 5-10%

The variation coefficient of 26% fits the preliminary planning (feasibility study). The variation in waste inventory is not included (Burggraaff et al., 2022) but is a big uncertainty in cost estimates. In the Belgian cost estimate for example, the variation in number of packages with heat generating HLW is 50% (see Appendix 4). Such a high variation propagates in the variation of the number of required disposal tunnels, their length and the length of the transport tunnel. Uncertainties have been set to achieve a variation suitable for a feasibility study.

The price of the single level GDF discounted to 2130 has been determined by assuming an average yearly costs in several stages of the GDF and the discount rate in OPERA of 2.3% i.e. an escalation rate was neglected. The cost estimate discounted to 2130 becomes 2.8 billion euros with this approach. The discount rate as well as the year to which the costs are discounted determine the discounted value of the cost estimate and can start a debate on the necessary costs (IAEA, 2020).



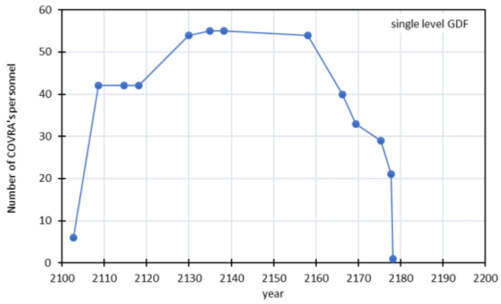


Figure 4-2: Cost estimate for a single level GDF discounted to 2130 with a discount rate of 2.3% (left) and number of COVRA's personnel working fulltime to the control of the GDF and containment and emplacement of waste (right).

4.2 Costs for a multiple level GDF

Several clay formations will be present at a single location in the Netherlands that may all be suitable for the different types of waste. This feature has been used in the optimisation of the disposal facility by making the hazard potential of the waste controlling the disposal depth of the waste. With a price level of 2022, the total costs for a disposal facility with three shafts with disposed of waste at different depths and excluding VAT have estimated to be (see Figure 4-3):

- 2.7 billion euros is the best estimate / 3.0 billion euro with a probability to exceed 50%;
- 4.6 billion euro with a probability to exceed of 5%.

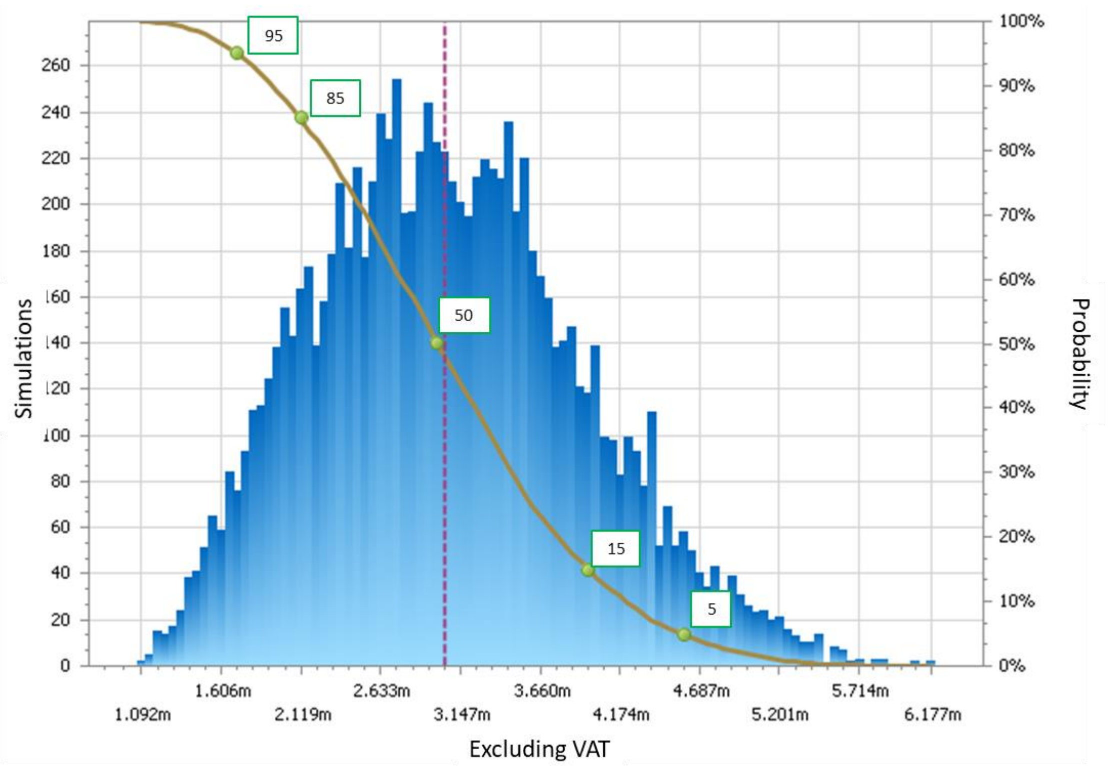


Figure 4-3: Total costs price level 2022 for a disposal facility with three different disposal depths excluding VAT ,variation coefficient is 28%.

The main reason for these lower costs compared to single level GDF is that a larger disposal volume per length of the disposal tunnel is possible due to a smaller assumed required thickness of the concrete liner at a smaller disposal depth and most construction costs are made after 2130. Also the length of transport tunnels can be smaller due to a smaller assumed distance between disposal tunnels at a smaller disposal depth. The cost estimate discounted to 2130 becomes 2.0 billion euro. The main reason is that the majority of the construction costs are scheduled after 2130.

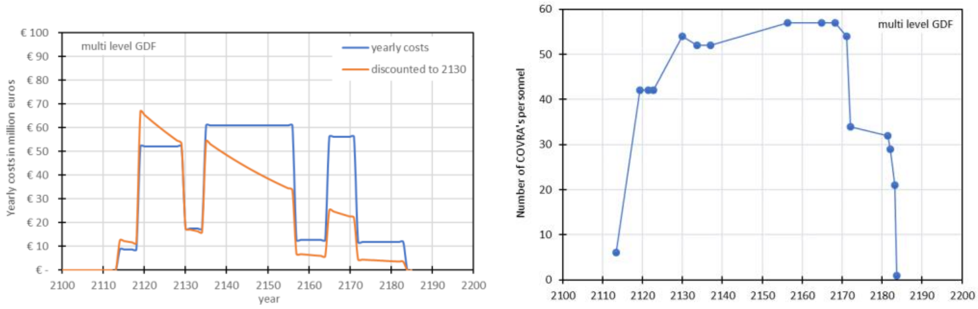


Figure 4-4: Cost estimate for a multi-level GDF discounted to 2130 with a discount rate of 2.3% (left) and number of COVRA's personnel working fulltime to the control of the GDF and containment and emplacement of waste (right).

4.3 For what will the cost estimate be used?

An underground facility to receive waste should be operational in 2130 (I&E, 2016). The cost estimate for realization of this facility is used at the moment that COVRA takes full title of the waste i.e. during collection of the waste. The contribution of costs for the disposal of waste in an underground disposal facility are included in COVRA's waste fees since COVRA is obliged to make a provision for the disposal facility. The contribution of disposal of waste in COVRA's waste fees will be adjusted with the current cost estimations.

4.4 Which method is used to determine the cost estimate?

The SSK calculation methodology is used to make the cost estimate. SSK is the Dutch acronym Standaard Systematiek Kostenramingen (SSK) rekenmodel in which the cost estimate is standardized through a system. In this system, the costs need to be subdivided in subjects with the activities. Each subject should have an overview of the following four categories construction costs (bouwkosten in Dutch), engineering costs (engineeringskosten in Dutch), real estate costs (vastgoedkosten in Dutch) and other costs (overige bijkomende kosten in Dutch). Each of these categories have both investment costs (investeringskosten in Dutch) and maintenance costs (instandhoudingskosten in Dutch). This method is frequently used by the government as well as business in the Netherlands and advised after an audit of the cost estimate that was made in 2014 (Bruinsma and Tempels, 2017). The use of this method allows a better assessment of the uncertainties in the cost estimate. Table 4-1 shows the activities in the subjects:

- *Surface* for above ground activities related to construction and maintenance of or within surface facilities;
- *Underground* for activities related to construction and maintenance of or within the underground facility;
- *Operation* for activities related to the handling of waste;

- *Closure* for activities that ultimately lead to a so-called green zone.

Table 4-1: Division in subjects used in the cost estimate (in time see Figure 4-6 and Figure 4-7)

	Surface	*Underground*	*Operation*	*Closure*
Period of pre-construction GDF	Land purchase	Drilling and research		
	Management & communication COVRA (%)			
	Archaeological activities (%)			
	Construction of surface facilities			
Period of construction, operation and closure of GDF	Management, (engineering*), communication, maintenance, security and administration COVRA	Research, (engineering*) and maintenance COVRA.	Radiological, labour and environmental protection, inspection COVRA	Backfilling disposal tunnels with porous cementitious backfill**
		Construction of shafts		
		Construction of transport tunnel(s) with reinforced concrete	Packaging of depleted uranium	Backfilling transport tunnel with re-constituted clay i.e. sealing disposal tunnels
	Housing costs (electricity, heat and cleaning)	Construction of disposal tunnels with unreinforced concrete	Packaging of HLW to generate contact-handled waste	Backfilling shafts with excavated sand and clay
	Insurance		Emplacement of waste packages	Dismantling surface facilities
			Observation	Dumping debris

*only during the construction of facilities a percentage of the construction costs, **this activity is in the disposal phase / operation phase in the cost estimate for rock salt.

The benefit of the SSK calculation methodology is that it is facilitated through an Excel sheet with macros that can be downloaded for example at the website of the technology platform for transport, infrastructure and public space (CROW). It is widely used for infrastructural works and it is becoming a standard. Its widely use allows easy comparison with other infrastructural works.

The disadvantage is that the limit in the construction period is 15 years. The Excel sheet can be used to calculate the overnight costs but an ordinary Excel sheet was used for the planning's in Figure 4-6 and Figure 4-7.

Currently, COVRA collects, processes and stores the processed waste. Labour radiological protection minimizes the personnel to:

- become contaminated with radionuclides from the waste;
- be exposed to radiation by decay of these radionuclides in the waste.

The risk for contamination is most high during collection and processing of the waste into solidified waste in which the outer surfaces of the waste packages are clean. The contamination risk is small for all activities related disposal of this processed, solidified waste. Radiological protection for disposal of waste therefore focusses to minimize the exposure to radiation by the personnel during handling of the waste. A couple of operational safety assessments have been made before the emplacement of the waste packages in the GDF starts.

Any public radiological exposure should be minimized to those that visit the pilot facility and other tunnels in the GDF during the operation of the GDF. This public exposure is limited to some radiation from waste packages but also from the tunnel liners due to presence of traces of radioactive potassium, uranium and thorium in concrete segments. COVRA's personnel (director, chiefs, radiological protection officers, geotechnical engineer or geologist) guide the visitors in the GDF[6]. Figure 4-5 shows COVRA's organisation chart for the different subjects in Table 4-1. Figure 4-6 and Figure 4-7 show the planning of these subjects for a single level GDF[7] and a multiple level GDF.

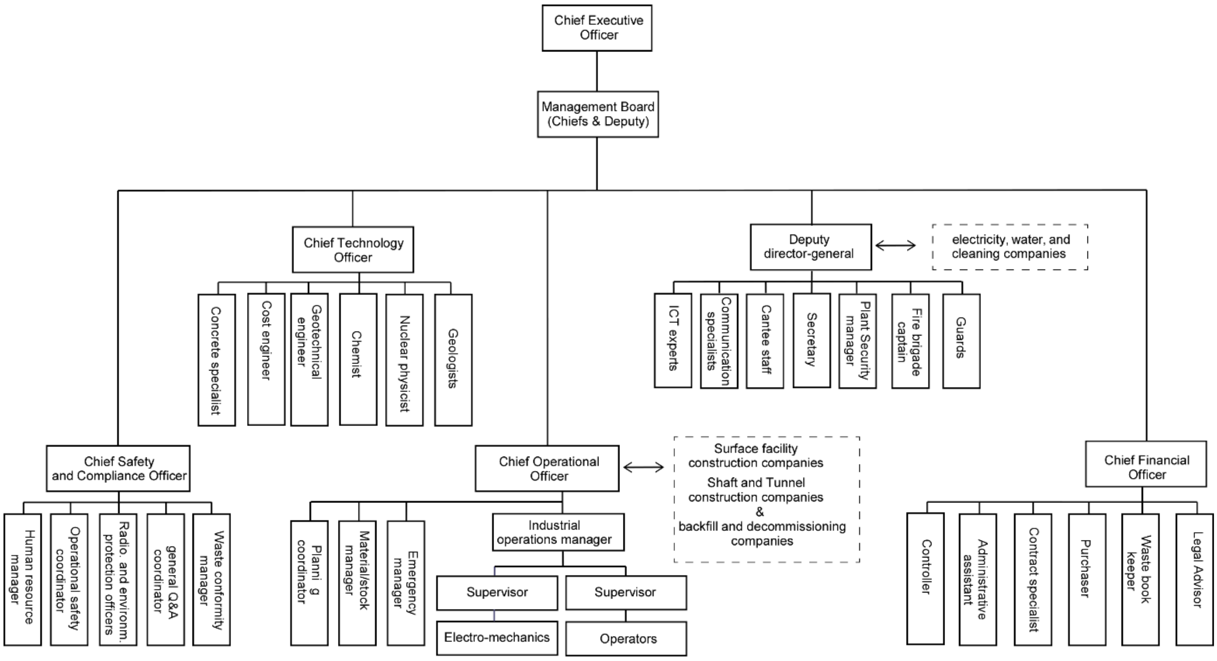


Figure 4-5: COVRA's organisation chart for the control of the GDF, the waste packaging and emplacement of waste packages in the GDF.

[6] Any other public radiological exposure form the disposed of waste in the far future is after closure of the GDF. This public exposure in the far future is determined in a post-closure safety assessment e.g. Neeft et al. (to be published) and this public exposure is negligible compared to the background radiation. This negligible exposure is from long-lived radionuclides that are non-sorbed by the clay host rock and (clay pore water affected) concrete. The performance of a multibarrier system with the natural barriers (clay host rock(s) and surrounding rock formations) and engineered barriers (backfill, waste package and waste form) is assessed on the long-term. Such a post-closure safety assessment was already made in the pre-construction phase but remains to be updated until the GDF has been closed for example due to deviation of the properties of the components in the multibarrier system.

[7] Appendix 3 shows the planning with a focus on the activities in the GDF

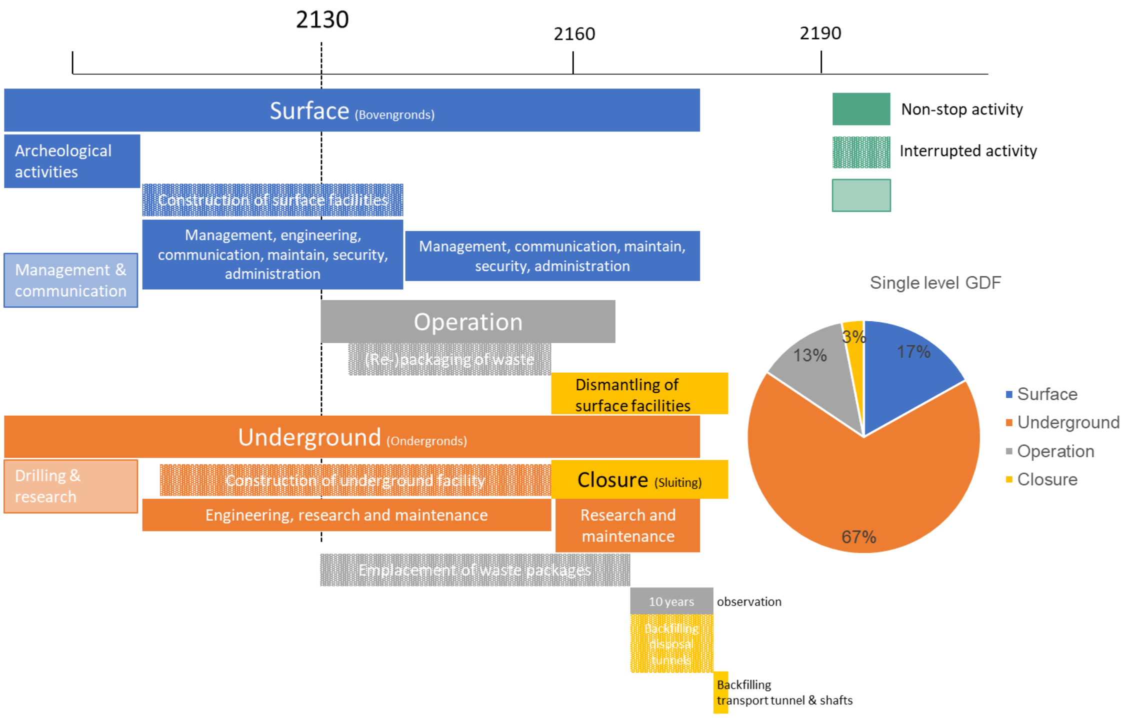


Figure 4-6: Division in subjects used in the cost estimate and the planning for a single level GDF with the waste scenario of base + Pallas (Burggraaff et al., 2022).

The construction of the surface facilities includes all other costs such as the site investigation. The design and construction of the disposal facility excluding the surface facilities amounts 67%. In OPERA, this amount was 70% for design and construction including the surface facilities. The reason for the larger contribution to the construction costs are the higher engineering costs (30% currently used for the construction of tunnels etc in the underground compared to 10% in OPERA, see section 4.7.2) and the inclusion of unnamed risk reserve, see section 4.7.3. The pie chart shows that the contribution of the constructions of the underground facilities for a multilevel GDF is 65% (see Figure 4-7) which is smaller than the 67% in Figure 4-6. The reason for this reduction is due to a smaller disposal depth for LILW. This smaller disposal depth allows:

1) a reduction in thickness of the tunnel liner by which the waste volume that can be disposed of per disposal tunnel length is increased;
2) a reduction in spacing between disposal tunnels by which the length of the transport tunnel is reduced.

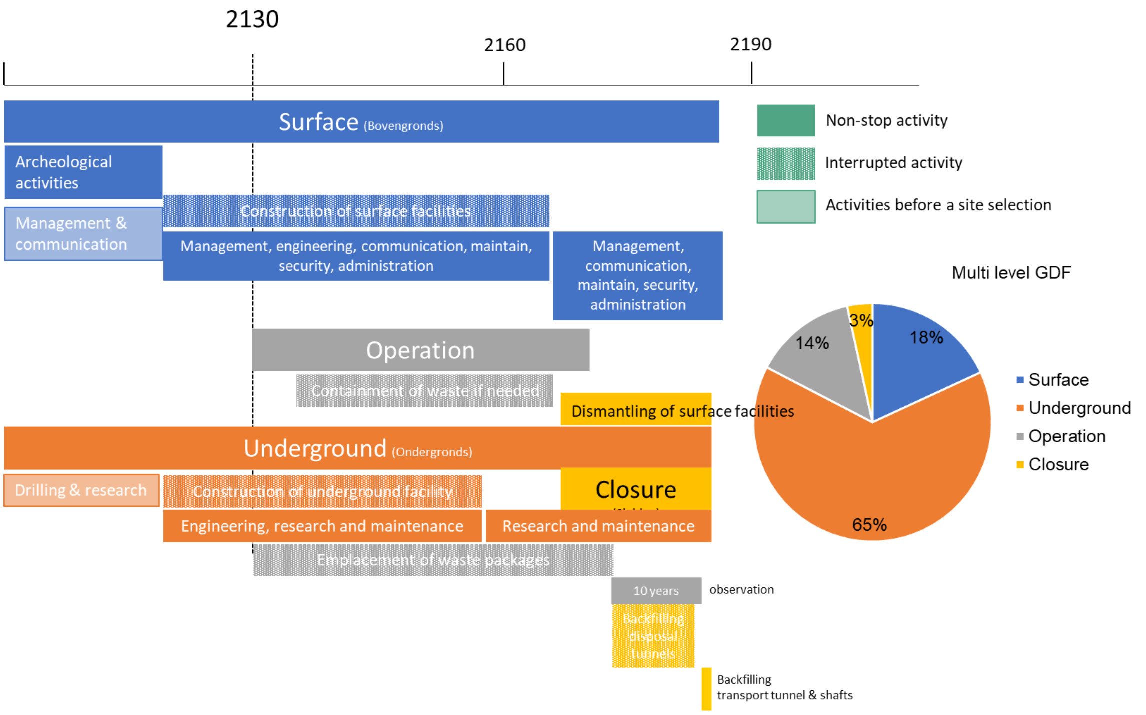


Figure 4-7: Division in subjects used in the cost estimate and the planning for a multi level GDF with the waste scenario of base + Pallas (Burggraaff et al., 2022).

4.5 Sources of information

The previous cost estimate was based on Belgian prices and COVRA's costs for personnel. The audit made of the previous cost estimate also advised to make own substantiation of important cost items and to use unit base data from Dutch sources instead of relying solely on Belgian prices. A ranking was made in the sources in order to accommodate this advice. The sources from which the costs of manufacturing of components have been extracted are preferably costs determined by the Dutch Association of Cost Engineers (DACE). Almost every year, DACE publishes a price booklet with the uncertainty for each cost item. The year 2022 was an extreme year in terms of inflation by which there is no Price booklet with the publication year 2022. DACE (2023) was used for the current cost estimate after an audit of a previous version of the current cost estimate in which DACE (2021) was used with an inappropriate indexation for 2022 (Tempels et al., 2023).

Costs as prepared by DACE are without discounts. Discounts are common especially if large quantities are used. COVRA's experience is that the costs as indicated in the Price booklet are beyond the maximum of the submitted quotations. Other key figures for cost items were obtained from the Dutch website for underground infrastructure Centrum Ondergronds Bouwen (COB). If the component could not be found in the Price Booklet (DACE, 2023), the website of Centrum Ondergronds Bouwen (COB) was consulted. If the component could also not be found at COB, other websites were consulted and screen shots have been made for traceability. If no open accessible source was available, costs available at COVRA from purchase in the past and these companies that supplied earlier to COVRA had been contacted in 2022 in order to obtain the costs in 2022. Ultimately, the information as supplied by the Belgian WMO ONDRAF/NIRAS (O/N) in 2014 was indexed for 2022 and uncertainty of 50% was assumed since this uncertainty was used in OPERA.

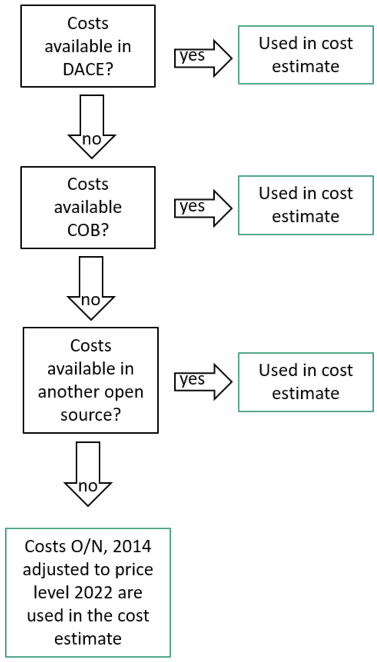


Figure 4-8: Ranking in preferences of sources used for costs in the current cost estimate.

Only the DACE source has a price level of appropriate for 2022 i.e. January 2023. An inflation rate of 2% is used to adjust these costs from other sources. Table 4-2 shows that this assumption may be conservative since the index in 2021 determined by this inflation rate is higher than the real index defined by DACE. The year 2022 is however also a year in which significant changes occurred in the index due to the high increase in energy prices.

Table 4-2: Indices to determine price level 2022

Year	(DACE, 2021)		Index assumption 2% inflation rate
	Index wages per worked hour (metal-electric)	Index machines	
2015	100	100	100
2016	102	101	102
2017	104	101	104
2018	106	102	106
2019	108	104	108
2020	107	106	110
2021	107	106	113

Table 4-3 shows the five scales in personnel costs that have been used for the current cost estimate. The COVRA's personnel costs from 2014 have been indexed for 2022, except for the Director due to the availability of a public source (COVRA, 2022) that deviated from the personnel costs used in 2014.

Table 4-3: COVRA's personnel costs used for the cost estimate (price level 2022)

Scale	Yearly costs	Functions in Figure 4-5	
1	233.000	Chief Executive Officer (CEO)	(COVRA, 2022)
2	106.000	Deputy director-general Contract specialist Radiological and environmental protection officer Plant Security Manager Nuclear physicist Geotechnical engineer Geologist Cost engineer	Chiefs other than CEO Emergency manager Waste conformity manager QA coordinator Industrial operations manager HR manager Operational Safety coordinator Controller Legal advisor ICT expert
3	80.000	Supervisor Chemist Fire brigade captain	Communication specialist Concrete specialist
4	60.000	Operator Administrative assistant	Electro-mechanic Material stock manager Planning coordinator
5	55.000	Guard Canteen staff	Secretary Waste book keeper Purchaser

4.6 Pre-construction costs

The real estate costs are the costs for the acquisition of the surface area and making this area ready to realize the facility (CROW, 2018). COVRA envisages a process in which several volunteering regions are investigated. CROW suggest to categorize the geotechnical research and environmental research under engineering costs (CROW, 2018). These costs resemble the costs for the site selection and are therefore discussed in paragraph 4.7.2.

Land needs to be purchased if the GDF is not sited at COVRA's premises. An area of 500 m × 500 m is considered to be more than sufficient for the surface facilities including, parking lot and access to the underground facility[8]. A twice as large area is included as a maximum is order to prevent human intrusion. The costs for land is controlled in the Netherlands and the *Nota grondprijzen 2022* proposes an amount of 25 euro per m^2 for non-commercial provisions i.e. 6.25 million euros for land purchase and 25 million euros as an upper limit. Any underground constructional work in the Netherlands cannot be performed without an archaeological assessment. The archaeological costs are estimated to be a function of the purchased surface area at which actual constructional work is planned i.e. 12 euro per purchased m^2 i.e. 3 million euros (3.000 k€) for 25 ha.

4.7 Costs determined with a percentage of a category of costs

4.7.1 Insurance costs

The insurance costs of the constructed facility are included in the category other costs. These costs have been assumed to be a percentage of the construction costs for the cost estimate with a price level of 2014 made in OPERA. To our current knowledge, there is not a single company that is willing to provide insurance to a nuclear facility. The insurance

[8] The coverage of surface area being equal or larger than the disposal area in the underground may depend on the disposal depth since future activities are envisaged to be more near the surface.

companies have made an international collective: Atoompool. COVRA pays 550.000 euro for 2023. This amount has been used in the cost estimate for each year.

4.7.2 Engineering costs

Engineering costs are the costs for the thinking about the to-be-used techniques and associated disciplines for the organisational, environmental, juridical and economic aspects. These costs can be made in the preparational phase as well as when the realization phase (CROW, 2018). Like in OPERA, a percentage in the construction cost is used. This percentage was 10% in OPERA. In this cost estimate, a distinction is made between facilities at the surface and underground facilities for the assumed percentage in engineering costs:

- 15% for surface facilities;
- 30% for underground facilities.

These percentages are the same as those used for cost estimate for a GDF in rock salt. The Dutch Network and Knowledge Centre for Cost Engineering and Value Management however proposes (DACE, 2021):

- a minimum of 7% and maximum in 15% for new office and industrial buildings;
- a minimum of 12% and maximum in 25% for tunnels.

The maximum of 15% has been used for the surface facilities in this cost estimate. The minima and maxima for tunnels have been derived from more near surface underground constructions than anticipated for the GDF and therefore a higher maximum of 30% is used in this cost estimate. In addition, there are also engineering costs for COVRA's personnel to control the GDF. The costs for geotechnical research and environmental research have also been categorized as engineering costs (CROW, 2018). These costs resemble the research needed to select a site for the disposal facility. The costs for the site selection was earlier estimated to be 100 million euros and has been adjusted to 50 million euros in 2019 (COVRA, 2020). These costs would in 2022 be 53 million euros when assuming an inflation rate of 2%.

4.7.3 Unnamed risk reserve

The construction of the geological disposal facility is a complex project. Experts advice to take into account a percentage of the cost estimate between 20% and 25% (Tempels et al., 2023) for the cost estimate with the minima proposed by DACE (2021) There is already a higher engineering costs percentage in the current cost estimate than the 10% used in OPERA (see section 4.7.2). Inclusion of 20% to 25% is therefore doubling up but included in the cost estimate for the subjects Surface, Underground and Closure. The emplacement of waste packages is already conservative compared to Konrad in which one operator emplaces one heavy waste package in a disposal tunnel while operators work at least with another operator i.e. a minimum of 2, in the current cost estimate.

4.7.4 To be determined

Key figures have been used as input for the cost estimate. Especially for the surface facilities, furnishing needs to be included as well. Experts advice to take into account a percentage of the cost estimate of 2.5% since the significant cost items were already included in the cost estimate they had reviewed (Tempels et al., 2023).

4.8 Construction costs

The construction costs are the costs to physically realize the facility. These costs are often the costs associated with the final contracts for realization of the facility and maintenance of the facility. These costs can be a sum of the needed person-hours, material-hours, material costs rental hours and subcontractors' costs. Depending on the phase of the facility, these costs consist of a detailed substantiation with a unit times a price or more global key figures (CROW, 2018). These costs have been subdivided in a section Surface and Underground in Figure 4-6.

4.8.1 Surface facilities

The costs for the surface facilities has been distinguished between industrial, laboratory and office buildings. The costs in the DACE Price Booklet are available per m^2 based on the price level of January 2023 (DACE, 2023) and these costs:

- include contractor's surcharges. Contractor's surcharges are general costs on site, general costs and profit and risk. These costs include the additional fee or charge by the contractor to the initial price of the good or service;
- exclude design and engineering costs and value added taxes.

Only single floor buildings are assumed. Costs as prepared by DACE are without discounts. Discounts are common e.g. if large quantities are used. COVRA's experience is that the costs as indicated in the Price booklet is beyond the maximum of the submitted quotations.

The representative office building per m^2 (DACE, 2023) has been chosen for the visitor and office centre. The costs for such a building of 2000 m^2 is envisaged to cost about 5 million euros.

Features within surface facilities such as toilets, fire doors and fire extinguisher systems and outside surface facilities such as pile foundations, parking lots, sewage system, and gardening are explicitly included in the cost estimate. The roads have a negligible contribution in the costs.

The industrial buildings per m^2 (DACE, 2023) has also been chosen for the factories and laboratory. The factories for manufacturing cementitious materials including controlled hardening and sieving and rinsing of excavated soil have each an area of 10000 m^2. The facility for waste inspection and security and hot cell have each an area of 2000 m^2. The costs for a hot cell for packing HLW and ILW is assumed to be 10 times as costly as an expensive industrial building i.e. 55 million euros. This estimation is more than the costs for the latest extension of the HABOG of 32 million euros (COVRA, 2020) since the extending the facility with an additional part of the processing of waste is considered more difficult and costly than extending storage space.

4.8.2 Underground facilities

The shafts costs € 55.000 per meter (€ 50.000 material and € 5.000 labour) used and both lay-outs have shafts with a length of 500 meters i.e. a single shaft with an inner diameter of 6.5 metres costs 165 million euros. These costs are determined by multiplying the labour and material costs from the personnel shaft with an inner diameter of about 2 metres. There are not so many public available sources with a cost estimate for a GDF available in sufficient detail in order to compare the cost items. An exception is a EURAD deliverable in which such details have been provided by Croatia, Hungary, Czech and Slovenia. The construction costs of shafts can also be expressed per m^3. The costs used in Croatia with a price level of 2018 were 274 euro per m^3 in hard rock (Carbol et al., 2022). Even corrected for inflation, the costs for the shafts used in the current estimate is more than 4 times higher but the hard rock requires less support than the poorly indurated clays and sand formations.

The construction of the disposal tunnels of 151 euro per m^3 in the Croatian cost estimate. Hard rock that does not require a tunnel supported structure. There are many bored tunnels constructed in the Netherland in unconsolidated formations from which also cost information is available as published by Centrum Ondergronds Bouwen. Usually only the total costs are available i.e. no distinction is made between for example archaeological, engineering, personnel and material costs but a key figure of 100.000 euro per meter seems a reasonable assumption according to the data in Table 4-4.

Table 4-4: Available costs from cored tunnels in the Netherlands

Example	Length (m)	(External) diameter (m)	Total sum (Million euro)	Building period	Cost per meter (kiloeuro)	Costs per meter (price level 2022)
Tweede Heinoordtunnel	1600	8.3	133	1995-1999	71	121
Westerschelde tunnel	6600×2	11.3	750	1997-2003	57	93
Groene Hart tunnel	7160	15	435	2001-2004	61	92
Sluiskil tunnel	1330×2	11	210	2011-2015	79	98

The Tweede Heinoordtunnel was the first bored tunnel in the Netherlands by which many features needed to be investigated. This tunnel is the most expensive tunnel per meter if transferred to a price level of 2022 assuming 2% inflation rate. The other tunnels are between 90 and 100 k€. The costs per meter of the Westerschelde and Sluiskil tunnel include the crossings every 250 metres in order to have sufficient escape routes for these public road tunnels. The Groene Hart tunnel does have such crossings in which two tunnels intersect. These costs include the contractor’s surcharges and crossings. This amount is much more than solely material costs per meter that have been estimated to be 15 k€ (price level 2022) for disposal tunnels with a tunnel diameter about half of the tunnels in Table 4-4, excluding casting the floor, personnel costs, assembly and disassembly of the TBM, and crossing. If all these costs are included and averaged over a length of a gallery of 100 meter then about 50 k€ per meter is the result. This result is a convincing similarity. As a first approximation, it has been assumed that the floor with drainage features is very costly and is about 25% of the price per meter. Consequently, 75 k€ per meter may be assumed for the boring and installation of the reinforced concrete liner as a support for the transport tunnel including contractor’s surcharges and excluding casting the floor if the thickness of the concrete segments would be the same. The thickness of the concrete segments is 0.45 meter for the traffic tunnels (Neeft et al., to be published in March 2025) and about 0.8 meter for the transport tunnels at 500 metres (ANDRA, 2016). For simplicity, such a thickness is assumed for all disposal depths. About 50% more reinforced concrete is needed per meter tunnel. A value of 150 k€ per meter could therefore be assumed for the boring and installation of the reinforced concrete liner as a support for the transport tunnel including contractor’s surcharges and excluding casting the floor. The review of the cost estimate however proposed 125 k€ per metre since installation costs such as lightning and fire protection are explicitly included (Tempels et al., 2023) and this cost indicator is therefore used in the cost estimate.

In the OPERA cost estimate, steel crossings between the transport tunnel and disposal tunnels were explicitly included. The transport tunnel and disposal tunnel were both proposed to be manufactured from unreinforced concrete. In the current disposal concept, it is uncertain whether such steel crossings are needed since a reinforced concrete liner is proposed as a transport tunnel. The number of crossings have therefore been taken with a large range in uncertainty.

Cooling can be more important than ventilation, even during the construction. Some numbers have been provided by ITA at the IAEA Technical meeting of 12 September 2023. For a host rock temperature of 45°C (Gotthard tunnel), the cooling requirements needed 59.2 MW electric power while the ventilation requirements were 4.5 MW. As it concerns harder rocks than the poorly indurated clays considered here, the ventilation requirements for the construction of this tunnel in Switzerland were much higher due to the higher amounts of dust that are generated during excavation. For the cost estimate, the ventilation costs are already included in the construction costs of 125 k€ per metre.

4.8.3 Maintenance of the surface facilities and underground facility

The maintenance is mainly envisaged to be necessary for the surface facilities with all manufacturing and processing equipment for packaging solidified waste. The maintenance of the facilities is included in the personnel costs with 2 electro-mechanical engineers. The materials costs would be 12.000 euro per year for each surface facility i.e. an average of the maintenance of the costs used by the Belgian WMO indexed for price level 2022. This value is much smaller than the maintenance costs of surface facilities at COVRA's premises i.e. 676.000 for 5 facilities (COVRA, 2022) becomes on average 135.200 euros per year for each surface facility. The value of 135.200 euro per year was chosen in the current cost estimate. The material costs for the maintenance of a shaft has been estimated to be 47.000 euro per year using these Belgian numbers indexed for 2022. Vehicles are replaced every decade.

The mechanical support in the underground facility in the form of a concrete liner requires virtually no maintenance. In not-supported tunnelling structures, creep of the host rock remains. This creep (convergence) is too fast for poorly indurated clay by which supported tunnel structures have been chosen as a design from the start. For indurated clay, however, although there is much less creep compared to poorly indurated clay, the French agency recently shifted its design from shotcrete and anchor supported structures into (reinforced) concrete supported tunnel structures to dispose of ILW (ANDRA, 2016) in order to minimize the maintenance in the operational phase of the GDF. Also the (reinforced) concrete supported structures in the Konrad disposal facility are designed to be maintenance free for the operational period of 40 years.

This absence in maintenance also hold for current engineered analogues in concrete supported structures such as traffic tunnels. There is virtually no maintenance to the manufactured concrete in the Westerschelde tunnel except near the exit at the tunnel due to tensional forces induced by seasonal influences (Sonke, 2023). This type of tensional forces would also be present if the GDF had an inclined ramp. The current GDF does not have an inclined ramp but only shafts and this type of damage is therefore not expected.

The maintenance in traffic tunnels consists mainly of cleaning the walls, traffic lines and traffic signs, checking lights and repair of damage; once a year traffic tunnels may be closed to check the electrical system, the emergency system and inspection of the asphalt of the road (Westerscheldetunnel, 2022). Conservatively, ordinary and emergency lightning and fire extinguishers are envisaged to be installed for the full tunnel length in the underground facility[9]. The maintenance and inspection is assumed to be included in the activities by electro-mechanical engineers.

4.9 Operational costs

The considered operational costs are the costs for the housing, emplacement of waste packages and (re-)packaging of processed waste. The emplacement of waste packages and packaging of waste is envisaged by COVRA's operators. The (re-)packaging of the waste is foreseen during the construction of parts of the underground facility.

4.9.1 Housing costs

The costs for the use of gas(heating), water, light (electricity), cleaning, insurance of facilities and terrain as well as environmental tax and real estate tax are grouped under housing costs. The housing costs at COVRA's premises were 961.000 per year (COVRA, 2022). Insurance of the facilities have been described in section 4.7.1 and these costs are excluded in the housing costs since a separate section post for these insurance costs is included in COVRA's yearly report.

Conservatively, 961 k€ per year has been assumed for housing costs. Cooling is more important than heating for a GDF, especially at larger depth (see section 4.8.2). For example in the Underground Research Facility (URF) in Belgium at about 200 m depth, there is no cooling since the temperature of 16°C is sufficient for working. There are no ducts in this URF, between the two shafts there is a slight overpressure inducing a flow of wind that is not felt i.e. the wind speed is smaller than 5 km per hour. This is sufficient ventilation for the length of the URF. Ducts are included in the GDF since the disposal tunnels with a larger length of tunnels are considered than the URF. The diameter of these ducts are 1.0 m in the transport tunnel and 0.4 m in the disposal tunnels. Another feature for which ventilation is important is dust. Unlike harder rocks such as granitic rock, rock salt and indurated clay, there is hardly any generation of dust during construction in poorly indurated clay. After construction of (parts of the GDF), during normal operation, there can only be dust coming from the air outside that is flowing into the GDF. Electricity costs have therefore been excluded in OPERA because these costs are negligible. The costs for electricity for ventilation during emplacement of the waste packages are included in the housing costs in the current cost estimate. These housing costs include the electricity costs for:

- the HABOG in which the air output is about 35,000 m^3 per hour if waste is only stored and 50,000 to 60,000 m^3 per hour during activities such as welding off stainless steel canisters;
- the waste processing facility with air output of 46,000 m^3 per hour if the waste is not processed into solidified waste products;

[9] For example, the vehicles and the personnel carry lights and the fire extinguishers in the Konrad disposal facility i.e. there is only installation of lights and extinguishers near the shafts and some crossings in the underground.

- COVRA's office, meeting rooms, canteen and movie theatre with an air output less than 20,000 m^3 per hour.

The sum of these outputs is about twenty times more than the output needed for the GDF during the emplacement of waste packages in a disposal tunnel.

4.9.2 Packaging of waste

The 200 litres drums, 1000 litre containers and dismantling waste are suitably processed for emplacement in the GDF. Depleted uranium and HLW have been processed into stable solidified waste products and are currently safely stored. In the current estimate, depleted uranium and HLW are further packaged for easier emplacement in the GDF and for a more robust post-closure safety. The required personnel per package is shown in Table 4-5.

Table 4-5: Assumptions for the additional containment of waste

Waste disposal package	Assumptions per package			Additional in cost estimate
	Time [days]	Number of persons	Source	
200 litre drum	Already sufficiently packaged for disposal			No
1000 litre concrete container				
Konrad (dismantling waste)				
Konrad (depleted uranium)	0.25	4 (3 operators & 1 supervisor)	(Oudenaren and Browning, 2023)	Yes
2 meter in diameter concrete container (CSD-v)	2.75 (2.25+0.5)	3 (2 operators & 1 supervisor)	COVRA's personnel	Yes
2 meter in diameter concrete container (SRRF)	5 (2.75+2.25)	3 (2 operators & 1 supervisor)		Yes
2 meter in diameter concrete container (CSD-c)	0.5	3 (2 operators & 1 supervisor)		Yes

HLW is currently stored in a dedicated surface facility and remotely handled with attributes that provide sufficient shielding. CSD-v and CSD-c are already processed in France. The additional packaging of these types of HLW is required in order to make contact-handled waste. Currently, the welding off at COVRA's premises SRRF takes about 2.25 days of three operators i.e. 54 person-hours. The dimensions for welding are for SRRF about twice as large as the overpack for CSD-v. The pouring of a concrete cube in concrete container in which (overpacked) HLW is positioned in order to eliminate void volume is considered to cost less time i.e. 0.5 days. This pouring of concrete takes for HLW 1.5 person days (0.5 day × 3 persons) which is more than the 1 person day (0.25 day × 4 persons) for depleted uranium. Although the pouring volume for HLW is much less than depleted uranium, the placing of packages is considered to be more time consuming for HLW due to remote handling for shielding as well as weight. Remote handling for depleted uranium is only necessary for the weight. The manufacturing of the 12,600 Konrad containers with depleted uranium takes about 9 years with 4 persons (Oudenaren and Browning, 2023).

With 1720 hours per year i.e. 215 working days per year: the potential packages that can be made each year with CSD-v is 78, with CSD-c 430 and SSRF 43 with 3 persons. The manufacturing of the HLW inventory in Table 2-1 and packages as listed in Table 3-1 takes 12 years[10].

[10] The packaging periods depends for simplicity only on the availability of personnel e.g. the HLW packaging period would be reduced to 6 years with 6 persons instead of 3 persons.

4.9.3 Emplacement of waste packages

In OPERA, waste packages were to be emplaced with a 'transport cart' for HLW as well as LILW. Viable systems for moving and emplacing large waste containers in the underground needed to be developed (Verhoef et al., 2017). In COPERA, the equipment for the transportation of waste is further distinguished in weight of the packages with waste and only existing techniques are proposed (Neeft et al., to be published in March 2025). The transport devices used in the cost estimate are forklift trucks and air-cushion vehicles. COVRA's personnel has successfully worked with these two devices.

The transport of the waste packages from the surface towards the underground is only through shafts. On the surface, an electric forklift truck that can carry 20 ton can be used in order to optimize the emplacement of (several) waste packages in the shaft. This forklift truck is envisaged to be able to carry 36 200 litre drums or 8 1000 litre concrete containers. The costs for an electric truck are estimated to be 180'000 euro.

The 200 litre drums and 1000 litre concrete containers drums have been demonstrated to be emplaced using a smaller forklift truck than used at the surface. Unlike the electric forklift truck that can carry 20 ton, these smaller trucks fit in the disposal tunnels and can therefore emplace the drums and concrete containers. Each small forklift truck costs 45'000 euro. Each shift of 36 200 litre drums or 8 1000 litre containers can be emptied by 2 operators in about half a day. Using a similar period for loading the truck and having 8 operators makes the foreseen emplacement period be 3.5 years for the 100.000 200 litre drums and slightly less than 1.5 years for the 8400 1000 litre drums.

The other waste packages are envisaged to be emplaced with air cushion vehicles. The floor needs to be very smooth in order to use these vehicles. The application of epoxy liquid and its hardening is frequently used for the generation of industrial floors for example in COVRA processing facility. This floor was sufficiently smooth for the use of air cushion vehicles. The generation of floated concrete is more expensive than the manufacturing of an epoxy covering but floated concrete limits the introduction of new materials in the disposal facility. The manufacturing of floated concrete was therefore used in the cost estimate (part of construction).

Each electric forklift truck can carry one Konrad container. Two Konrad containers are put in the shaft for each shift. These two Konrad containers are emplaced through an air cushion vehicle by 2 operators in about half a day which makes the total emplacement period 1 day by assuming also half a day for loading. Again with 8 operators, the emplacement period is therefore foreseen slightly more than 0.5 year for the Konrad containers with dismantling waste and almost 8 years for the Konrad containers with TE-NORM (depleted uranium).

The emplacement speed of HLW packages is envisaged to be half the emplacement speed of the Konrad containers i.e.1 HLW disposal containers per day for 2 operators. Again with 8 operators, all 794 HLW packages can be emplaced in the disposal facility within one year.

4.10 Closure costs

The closure costs are determined activities taken place at the surface and in the underground facility. The underground facility will be backfilled with:

- pouring foamed (cellular) concrete for the disposal tunnels;

- compaction and backfilling of excavated clay mixed with some cement for the transport tunnel;
- excavated clay for the parts of the shafts that cross clay formations;
- excavated sand for the parts of the shafts that cross sandy formations.

The costs for cellular concrete is available with the densities 600, 900 and 1200 kg/m^3 (DACE, 2021, 2023). These costs increase with increasing density. The costs for the envisaged backfill with a density of 1600 kg /m^3 is extrapolated from these values resulting into a minimum of 218 euro per m^3 and maximum of 381 euro per m^3 (price level 2022) i.e. on average 300 euro per m^3.

A price for the isostatic compression of clay blocks and emplacement of these blocks has not been found. The costs for backfilling and compacting have therefore also been taken from DACE (2023) and amounts on average 11 euro per m^3.

Backfilling with foamed concrete is assumed to envisage with a speed of 50 m^3 per day (DACE, 2021) i.e. at a significant smaller speed than previously assumed in OPERA of 100 m^3 per hour (Verhoef et al., 2014). The backfilling with compacted clay is assumed to be limited to the supply of clay through the shafts that is assumed to be equal to the removal rate of clay through the shafts. The removal rate is 314 m^3 per day (see Appendix 1). The backfilling rate of the shafts with sand and clay has been taken equal to this excavation rate: 300 m^3 per day.

A 10 year observation period after the emplacement of HLW is foreseen in which the shafts, transport tunnels and disposal tunnels with HLW have been kept open. The ‘observation’ period for LILW was already more than 20 years since the disposal tunnels with LILW were not backfilled. This backfilling for tunnels with disposed of LILW therefore starts at the same time as the observation period for HLW.

The surface facilities will be dismantled and the debris will be dumped except perhaps for the visitor centre and office. The demolish of concrete structures is also listed in DACE (2023) and amounts on average 258 euro per m^3. The dumping costs are available per ton in DACE (2023) and have been transferred into m^3 by assuming a density of 3000 kg/m^3. These costs are on average 46 euro per m^3.

References

ANDRA, (2016). Safety Options Report - Operating part (DOS-Expl) - Volume II Descirption of waste packages, the facility and its environment, CG-TE-D-NTE-AMOA-SR1-0000-15-0060, international.andra.fr.

Arnold, P., Vardon, P.J., Hicks, M.A., Fokkens, J., and Fokker, P.A., (2015). A numerical and reliability-based investigation into the technical feasibility of a Dutch radioactive waste repository in Boom Clay, OPERA-PU-TUD311, www.covra.nl.

Bruinsma, B., and Tempels, E., (2017). Review Kostenbegroting Nucleaire eindberging.

Burggraaff, E., Welbergen, J., and Verhoef, E.V., (2022). Nationale radioactief afval inventarisatie, www.covra.nl, p. 27.

Carbol, P., Faltejsek, J., Mele, I., Železnik, N., Ormai, P., Nős, B., Mikšová, J., and Fuzik, K., (2022). Guidance on Cost Assessment and Financing Schemes of Radioactive Waste Management Programmes D12.4 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593., http://www.ejp-eurad.eu/.

CORA, (2001). Terugneembare berging, een begaanbaar pad? Eindrapport CORA, Ministry of Economic Affairs, The Hague.

COVRA, (2020). Jaarrapport 2019, www.covra.nl.

COVRA, (2022). Jaarrapport 2021, www.covra.nl.

COVRA, (2024). Masterplan 2050, www.covra.nl.

CROW, 2018, Chapter 3: Standaardsystemantiek voor kostenramingen - SSK -2018

DACE, (2021). DACE Cost and value - Price Booklet, Dutch Association of Cost Engineers (DACE) Bouwkosten.nl BV.

DACE, (2023). DACE Cost and value - Price booklet, Dutch Association of Cost Engineers (DACE) Bouwkosten BV.

Erkens, (2024). Motie van het lid Erkens.

EU, (2020). Methdologies of cost assessment for radioactive waste and spet fuel management of the practives adopted in the EU, ENER/D2/2017-60.

I&E, (2016). The national programme for the management of radioactive waste and spent fuel, Ministry of Infrastructure and the Environment (I&E), The Hague, Netherlands, Parliamentary papers, session year 2015-2016, 25422, no. 149.

IAEA, (2020). Costing methods and funding schemes for radioactive waste disposal programmes, No. NW-T-1.25.

Li, X., Neerdael, B., Raymaekers, D., and Sillen, X., (2023). The construction of the HADES underground research laboratory and its role in the development of the Belgian concept of a deep geological repository, Geological Society Special Publication Geological Disposal of Radioactive Waste in Deep Clay Formations: 40 years of RD&D in the Belgian URL HADES, v. 536.

Neeft, E.A.C., Vuorio, M.R., Bartol, J., Verhoef, E.V., McCombie, C., and Chapman, N.A., (to be published in March 2025). COPERA Clay 2024 A Conditional Safety case and Feasibility Study, www.covra.nl.

Oudenaren, G.I.L., and Browning, K.M., (2023). Cost estimation for processing and disposal of (TE)NORM, NRG Note 2.6008.20/254194.

Simmelink, H.J., Heidema, A.H., Hoogendoorn, A., and Pagnier, H.J.M., (1996). Kartering slecht-doorlatende laagpakketten van tertiaire formations, NITG TNO GB 2514 CORA 15, www.covra.nl.

Sonke, E., (2023). Schade Oostbuis Westerscheldetunnel, ARCADIS.

Tempels, E., de Nijs, S.E., and Rooijakkers, J., (2023). Review kostenbegroting - Nucleaire eindberging COVRA.

van Gemert, J., Luck, G., Mason, K., Paleari, F., Smit, S., and Vandendries, R., (2023). Draft Memorandum on Scope and Level of Detail - National Progamme on Radioactive Waste (NPRA).

Verhoef, E.V., de Bruin, A.M.G., Wiegers, R.B., Neeft, E.A.C., and Deissmann, G., (2014). Cementitious materials in OPERA disposal concept, OPERA-PG-COV020, www.covra.nl.
Verhoef, E.V., Neeft, E.A.C., Bartol, J., Vuorio, M.R., Scholten, C., Buitenhuis, A., van der Veen, G., Chapman, N.A., and McCombie, C., 2020, Long-term research programme for geological disposal of radioactive waste, Overall research programme and work programme for 2020-2025: COVRA document, p. 59.
Verhoef, E.V., Neeft, E.A.C., Chapman, N.A., and McCombie, C., 2017, OPERA Safety case: www.covra.nl.
Verhoef, E.V., and Schröder, T.J., (2011). Research Plan, OPERA-PG-COV004, www.covra.nl.
Westerscheldetunnel, (2022). https://www.westerscheldetunnel.nl.

Appendix 1: Used rates for schedule of the GDF

The number of hours per year used for the planning is 1720 per year. The number of hours per day is 8 by which the number of working days is 215 days. The 3 shafts (two shafts with an inner diameter of 6.5 m and one with an inner diameter of 2 m) until a depth of 500 m are constructed in 6 years.

Phase of GDF	Solid materials through shafts	Weight rate [ton per day]	Volume rate [m^3 per day]	Explanation	Reference
Construction	Excavated clay (transport tunnel; outer Ø 10.0 m)	628	314	2 m per day, removal excavated clay through shaft is constraining the construction rate*	(Li et al., 2023) for construction rate (ANDRA, 2016) for dimensions concrete liner at 500 m depth
	Reinforced concrete segments (transport tunnel; inner Ø 8.4 m)	115	46		
	Excavated clay (disposal tunnel; outer Ø 5.0 m)	106	53	3 m per day	
	Unreinforced concrete segments (disposal tunnel; inner Ø 4.0 m for 500 m depth)	50	21	Thickness segments determined from equations and properties used in OPERA	(Arnold et al., 2015)
Operation**	200 litre drums	72	29	144 drums per day by 8 operators; Average weight of each drum is 0.5 ton.	
	1000 litre concrete containers	96	32	32 concrete containers per day by 8 operators. Average weight of each container is 3 ton.	
	Konrad containers	160	37	8 Konrad containers per day by 8 operators. Max weight per Konrad container is 20 ton.	
	HLW package for CSD-v	68	31	4 HLW packages per day by 8 operators. HLW package for SRRF & CSD-c is 20 ton HLW package for CSD-v is 22 ton	
	HLW package for CSD-c	50	25		
	HLW package for SRRF	60	30		
Closure	Porous cementitious backfill (disposal tunnel)	80	50	Common practice	(DACE, 2021)
	Re-constituted clay (transport tunnel)	210	300	Similar to excavated clay	
	Sand and clay backfilling (shafts)	600	300	Similar to excavated clay	

*a ramp would may increase the construction rate of the tunnel to more than 10 m per day but a ramp is currently not demonstrated in the unconsolidated formations on top of the clay host rock at disposal depth and therefore not considered in this cost estimate.

**The volume rate is similar to the rate proposed by Konrad: 303,000 m^3 LILW (www.bge.de/en/konrad) is to be disposed of in 40 years leaving an average of 35 m^3 per day using the same amount of working hours. The internal diameter of the shaft of 7 m for lowering the packages with waste is similar to the 6.5 m internal diameter used in the current lay-out. The current range for LILW ranges between 29 m^3 per day and 37 m^3 per day. In OPERA, fifty 200 litre drums per day were to be transported resulting into 10 m^3 per day i.e. much lower than assumed for Konrad and currently used. Forklift trucks can carry three 200 litre drums at the same time (Neeft et al., to be published in March 2025) so a multiple of three 200 litre drums is appropriate.

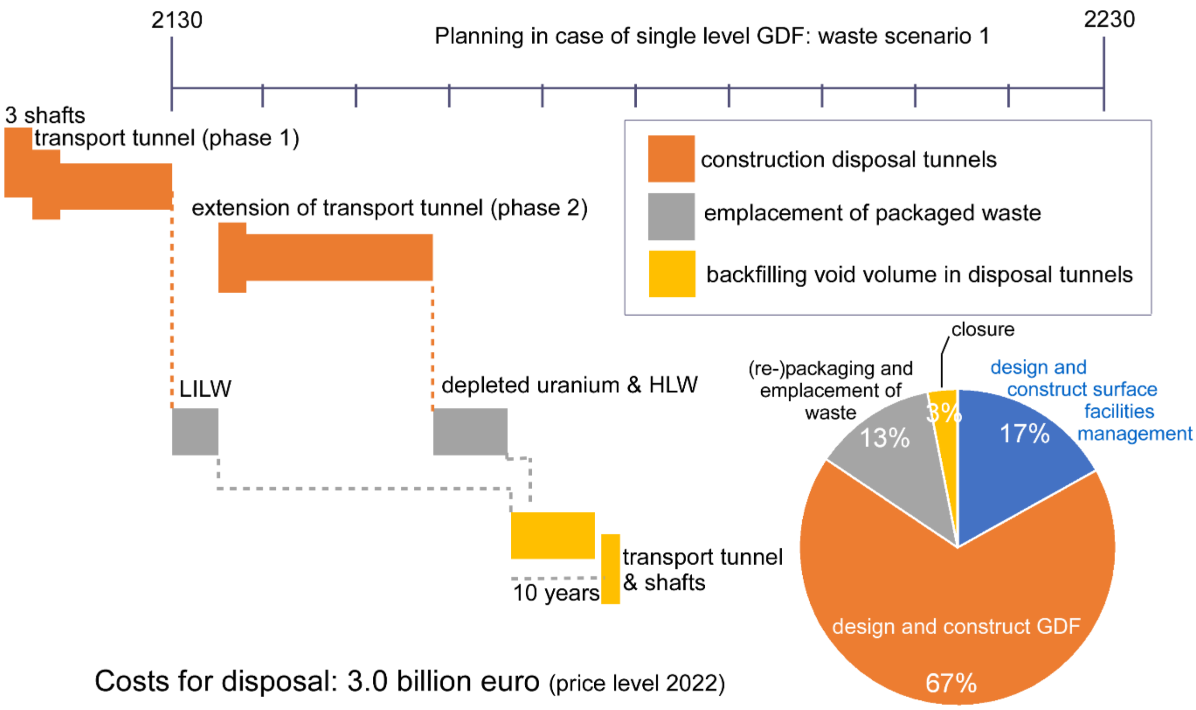
Appendix 2: Used prices for the cost estimate

	Eenheidsprijzen investeringskosten:			
90.11	Building ground facility; F1001 (DACE, 2023) Industrial building for manufactory (	m2	€	1,400.00
90.12	Building ground facility; F1001 (DACE, 2023) Industrial building for sieving excav	m2	€	3,245.00
90.13	Building ground facility; F1001 (DACE. 2023) Industrial building for w aste inspec	m2	€	1,400.00
90.14	Building ground facility; F1001 (DACE, 2021 & HABOG,2003) (Extension of) Indu	m2	€	24,153.60
72.11	Building User facility; F1007 (DACE, 2023) Representative office building on indu	m2	€	2,382.50
17.11	Pile foundations; prefabricated concrete piles F4009 (DACE, 2023)	m	€	117.50
90.81	Site selection (COVRA, 2020) Jaarrapport 2019 included as a parcentage in pre	keer	€	53,000,000.00
90.83	Buying land (Notaprijzen, 2022)	m2	€	25.00
90.84	Archeological costs (VU hbs archeologie, 2022) included as a percentage in Bo	m2	€	11.00
97.11	Building parking Place, F2004 (DACE, 2023)	keer	€	18,200.00
74.11	Sanitary,F 1008 (DACE, 2023) Additional office building	keer	€	26,050.00
97.12	Sew age system (O/N, 2014)	keer	€	1,115,000.00
97.13	connection of sites to utilities and sew age	keer	€	1,630,000.00
94.11	Building fence (bars), F6004 Fencing, gates and barriers (DACE, 2023)	m	€	184.00
98.11	Gardening soil, F6005 (DACE, 2023) Garden w ork	m2	€	22.80
98.12	Landscaping F6005 (DACE, 2023)	m2	€	15.00
19.21	Material costs personnel shaft (O/N, 2014)	m	€	50,000.00
19.22	Labour costs construction personnel shaft (extracted from required time to cons	m	€	5,000.00
19.23	Material costs equipment and material shaft	m	€	150,000.00
19.24	Labour costs builidng equipment and material shaft (extracted from required time	m	€	15,000.00
72.51	Shaft hoisting system (O/N, 2014)	keer	€	5,400,000.00
16.39	Chamber crossing shafts w ith transport tunnel; 2 times crossing transport tunne	keer	€	4,200,000.00
19.51	Open Face Tunnel Boring Machine (10 meter; tw ice O/N, 2014 5 meter)	keer	€	12,000,000.00
19.5X	Assembly of OF-TBM (10 meter, O/N, 2014)	keer	€	1,400,000.00
19.5X	Disassembly of OF-TBM (10 meter, O/N, 2014)	keer	€	500,000.00
16.54	Total (labour material etc.) costs building tunnel w ith reinforced concrete liner (!	m	€	125,000.00
19.52	Assembly and Disassembly of OF-TBM (10 meter, O/N, 2014)	keer	€	1,900,000.00
0.56	Concrete (manufacturing of buffer > 40 MPa, Humbeeck et al., 2017) (O/N, 2014	m3	€	470.00
19.72	Electric truck w ith open container e.g. 10 ft (Rabobank, 2022)	keer	€	300,000.00
65.11	Dry fire extinguisher line, F1008 (DACE, 2023) Office buildings, additional	m	€	184.00
22.11	Fire w all (cellular concrete), F1002 (DACE, 2023) Production buildings, additiona	m2	€	137.00
22.12	Fire door (piece), F1002 (DACE, 2023) Production buildings, additional	keer	€	5,105.00
64.11	Communication telephonic exchange F 1008 (DACE, 2023) Office buildings, addi	keer	€	644.00
57.11	Fan main system (O/N, 2014)	keer	€	36,000.00
57.12	Fan auxiliary system (O/N, 2014)	keer	€	18,000.00
57.13	Main duct (diameter: 1 meter) (O/N, 2014; DACE, 2021 four times less than O/N)	m	€	235.50
57.14	Duct disposal tunnel (diameter, 0.4 m) (O/N, 2014)	m	€	147.63
63.11	Emergency lightening F5004 (DACE, 2023) Lighthening installations	m2	€	5.50
63.12	Lightening 500 lux F5004 (DACE, 2023) Lightening installations	m2	€	58.00
22.13	Waste door is assumed to be four times fire door	keer	€	20,420.00
19.73	Conveyor belt (removal of excavated soil) 1800 meter w idth A3002 (DACE, 202	keer	€	2,718,000.00
19.7X	Assembly conveyor belt (assumption 30%)	keer	€	271,800.00
19.7X	Disassembly conveyor belt (assumption one-third of assembly)	keer	€	100,000.00
19.74	Assembly and Dissaembly conveyor belt	keer	€	350,000.00
19.61	Open Face tunnel Boring Machine (5 meter, O/N, 2014)	keer	€	6,000,000.00
19.6X	Assembly of OF-TBM (5 m, O/N, 2014)	keer	€	700,000.00
19.6X	Disassembly of OF-TBM (5 m, O/N, 2014)	keer	€	250,000.00
19.6X	Material costs unreinforced high strength (C80/95) concrete liner (inner diamete	m	€	13,500.00
19.6X	Material costs concrete liner unreinforced high strength (C80/95) (inner diamete	m	€	15,000.00
19.66	Labour costs concrete liner (5 meter outer diameter, extracted from required tim	m	€	6,000.00
16.38	Crossing (5 meter outer diameter) w ith personnel shaft	keer	€	2,100,000.00
16.69	Crossing (5 meter outer diameter) w ith transport (outer diameter 10 meter)	keer	€	2,100,000.00
43.11	Floated concrete (gevlinderd beton) floor finish air cushion w w w .betonvloereni	m2	€	128.00
16.67	Total (labour, material etc.) costs building tunnel w ith unreinforced high strength	m	€	19,500.00
16.68	Total (labour, material etc.) costs building tunnel w ith unreinforced high strength	m	€	21,000.00
19.62	Assembly and Dissassembly of OF-TBM (5 meter diameter, O/N, 2014)	keer	€	950,000.00
19.81	Open Face TBM (2.5 meter, O/N, 2014)	keer	€	3,000,000.00
19.82	Assembly and Dissassembly of OF-TBM (2.5 meter diameter, O/N, 2014)	keer	€	425,000.00
16.83	Labour costs building tunnel w ith unreinforced high strength concrete (2 meter i	m	€	8,000.00
0.15	Packaging depleted uranium (Oudenaren & Brow ning, 2023) for 12600 Konrad c	keer	€	269,823,861.98
0.11	Vorige kosternschattingen Processing solid compressible w aste (COVRA, 2022	m3	€	9,585.00
0.12	Vorige kostenschattingen Containment solid LLW (aanname 50% COVRA, 2022; (	m3	€	5,490.84
0.21	Vorige kostenschattingen Processing solid HLW assumption 50 times COVRA w	m3	€	479,250.00
0.22	Vorige kostenschattingen Containment solid HLW assumption 75 times containm	m3	€	359,437.50
0.51	Overpack (O/N, 2014)	keer	€	6,100.00
0.52	Steel frame, F4016 (DACE, 2023) Main supporting constructions	m2	€	290.00
19.91	Electric forklift truck 5 ton (solidhub, capaciteti 2.5 ton vermenigvuldigt)	keer	€	45,000.00
19.92	Electric forklift truck 20 ton (solidhub, capaciteti 2.5 ton vermenigvuldigt)	keer	€	180,000.00
19.93	Air cushion 24 ton for transport Konrad and HLW-container (Aerofilm, 2023)	keer	€	10,566.00
49.11	Cellular concrete 1600 kg/m3 assumption linear , cubical > 10 MPa F4006 (DACE	m3	€	299.59
49.12	Backfilling and compacting, exclusive delivery soil F4002 (DACE, 2023) Excavati	m3	€	10.50
49.13	Backfilling manually F4002 Excavations and backfilling (DACE, 2023)	m3	€	34.00
94.21	Demolish concrete structures F3010 (DACE, 2023) Demolish by hand and w recl	m3	€	257.50
94.22	Dumping costs - coarse debris (3000 kg/m3) F3011 Dumping costs	m3	€	15.33
0.55	LiNO3 (corrosion inhibitor)-concrete (2 times concrete O/N, 2014)	m3	€	940.00

	Eenheidsprijzen instandhoudingskosten:			
67,1X	personnel costs scale 4 for electro-mechanic; maintenance surface facilities ge	keer	€	60,000.00
84,1X	personnel costs for scale 5 for guard, canteen staff, secretary, waste book kee	keer	€	55,000.00
72.53	Housings costs including cleaning (COVRA Jaarrapport 2021)	keer	€	961,000.00
72,1X	personnel costs for scale 3 supervisor, chemist, communication and concrete s	keer	€	80,000.00
72.13	personnel costs for scale 1 for Chief Executive Officer / director (COVRA Jaarr	keer	€	233,000.00
72,1X	personnel costs for scale 2 for ICT-expert, legal advisor, controller, labour expe	keer	€	96,000.00
		keer		
		keer		
		keer		
		keer		
		keer		
72.51	Material costs for maintenance office and communication (COVRA, 2021)	keer	€	102,838.00
72.52	vorige kostenschattingen Legal and accountant advice (COVRA, 2021)	keer	€	103,397.00
67.5X	Material costs for maintenance surface facilities (O/N, 2014)	keer	€	12,000.00
67.61	Material costs for maintenance shafts (O/N, 2014)	keer	€	47,000.00
67.51	Maintenance of a surface facilitty (COVRA,2022)	keer	€	135,200.00
72.54	Insurance costs (atoompool, 31.07.2023)	keer	€	550,000.00
		keer		
		keer		
72.21	COVRA's personnel costs scale 2 Emergency manager (08.10.2024)	keer	€	106,000.00
72.22	COVRA's personnel costs scale 4 Material /stock manager (08.10.2024)	keer	€	60,000.00
72.23	COVRA's personnel costs scale 4 Planning coordinator (08.10.2024)	keer	€	60,000.00
72.24	COVRA;s personnel costs scale 2 Waste Conformity Manager (08.10.2024)	keer	€	106,000.00
72.25	COVRA;s personnel costs scale 2 QA coordinator (08.10.2024)	keer	€	106,000.00
		keer		
72.29	COVRA's personnel costs scale 2 Industrial Operations Manager (08.10.2024)	keer	€	106,000.00
72.31	COVRA;s personnel costs scale 2 (08.10.2024) Chief Financial Officer (16.09.2	keer	€	106,000.00
72.32	COVRA's personnel costs scale 2 Chief Safety and Compliance Officer (05.10.2	keer	€	106,000.00
72.33	COVRA'personnel costs scale 2 Deputy director general (08.10.2024) (16.09.20	keer	€	106,000.00
72.99	COVRA's personnel costs scale 2 Chief Technology Officer (08.10.2024) (16.0	keer	€	106,000.00
72.34	COVRA's personnel costs scale 2 Chief Operational Officer (08.10.2024) (16.09	keer	€	106,000.00
72.35	COVRA's personnel costs scale 2 (16.09.2024) controller	keer	€	106,000.00
72.36	COVRA's personnel costs scale 2 (16.09.2024) Legal advisor	keer	€	106,000.00
72.37	COVRA's personnel costs scale 5 (16.09.2024) Waste book keeper	keer	€	106,000.00
72.38	COVRA's personnel costs scale 5 (16.09.2024) Purchaser	keer	€	55,000.00
72.39	COVRA's personnel costs scale 3 (19.09.2024) Supervisor (emplacement & pac	keer	€	80,000.00
72.41	COVRA's personnel costs scale 4 (16.09.2024) Operator (Packaging HLW; depl	keer	€	60,000.00
72.82	COVRA;s personnel costs scale 2 (19.09.2024) Geologist	keer	€	106,000.00
72.43	COVRA's personnel costs scale 2 (16.09.2024) Nuclear physicist	keer	€	106,000.00
72.44	COVRA's personnel costs scale 3 (16.09.2024) concrete specialist extra 1	keer	€	106,000.00
72.45	COVRA's personnel costs scale 2 (16.09.2024) radiological and environmental p	keer	€	106,000.00
72.46	COVRA's personnel costs scale 3 (16.09.2024) concrete specialist	keer	€	80,000.00
72.47	COVRA's personnel costs scale 2 Operational Safety Coordinator (08.10.2024)	keer	€	106,000.00
72.48	COVRA's personnel costs scale 2 (16.09.2024) HR manager	keer	€	106,000.00
72.49	COVRA's personnel costs scale 2 (16.09.2024) cost engineer	keer	€	106,000.00
72.75	COVRA's personnel costs scale 2 (16.09.2024) geotechnical engineer	keer	€	106,000.00
72.65	COVRA's personnel costs scale 4 (16.09.2024) Electro-mechanic surface	keer	€	60,000.00
72.71	COVRA's personnel costs scale 2 (16.09.2024) ICT expert	keer	€	106,000.00
72.61	COVRA's personnel costs scale 5 (16.09.2024) Canteen staff	keer	€	55,000.00
72.55	COVRA's personnel costs sale 5 (16.09.2024) Secretary	keer	€	55,000.00
72.56	COVRA's personnel costs scale 3 (16.09.2024) Communication specialist	keer	€	80,000.00
72.57	COVRA's personnel costs scale 5 (16.09.2024) Guard	keer	€	55,000.00
72.58	COVRA's personnel costs scale 2 (16.09.2024) Communication specialist extra	keer	€	80,000.00
72.62	COVRA's personnel costs scale 5 (16.09.2024) Canteen staff extra	keer	€	55,000.00
72.66	COVRA's personnel costs scale 4 (16.09.2024) Electro-mechanic surface extra	keer	€	60,000.00
		keer		
72.68	COVRA's personnel costs scale 4 (16.09.2024) Electromechanic (operation)	keer	€	60,000.00
72.72	COVRA's personnel costs scale 2 (16.09.2024) ICT expert extra 1	keer	€	106,000.00
72.69	COVRA's personnel costs scale 4 (16.09.2024) Electro-mechanic GDF	keer	€	60,000.00
72.81	COVRA's personnel costs scale 3 (16.09.2024) chemist	keer	€	80,000.00
72.83	COVRA's personnel costs scale 2 (16.09.2024) Geologist extra 1	keer	€	106,000.00
72.85	COVRA's personnel costs scale 4 (16.09.2024) Operator (emplacement)	keer	€	60,000.00
72.86	COVRA's personnel costs scale 4 (16.09.2024) Operator phase 2	keer	€	60,000.00
72.87	COVRA's personnel costs scale 3 (19.09.2024) Supervisor (packaging HLW; de	keer	€	80,000.00
72.88	COVRA's personnel costs sale 4 (16.09.2024) Operator phase 3	keer	€	60,000.00
72.91	COVRA's personnel costs scale 3 (08.10.2024) fire brigade captain	keer	€	80,000.00
72.92	COVRA's personnel costs scale 2 (08.10.2024) Plant Security Manager	keer	€	106,000.00
72.93	COVRA's personnel costs scale 4 (08.10.2024) Administrative assistant	keer	€	60,000.00
72.94	COVRA's personnel costs scale 2 (08.10.2024) Contract Specialist	keer	€	106,000.00
72.95	COVRA's personnel costs scale 3 (16.09.2024) Supervisor (electromechanics)	keer	€	80,000.00

Appendix 3: Focus subjects in the GDF

Figure 4-6 shows division in subjects used in the cost estimate and the planning for a single level GDF with the waste scenario of base + Pallas. The image in the OPERA Safety case (2017) focussed on the construction of the GDF, the emplacement of waste packages in the GDF (operation) and backfilling the left void volume (closure). The figure below is a sub-set of Figure 4-6 with only these three activities.



Appendix 4: Comparison with the Belgian cost estimate

A cost estimate for the Belgian waste inventory has also been made with a price level of 2022. The data that have been used in the Dutch cost estimate results into a similar order of costs per waste package as can be found for the Belgian cost estimate.

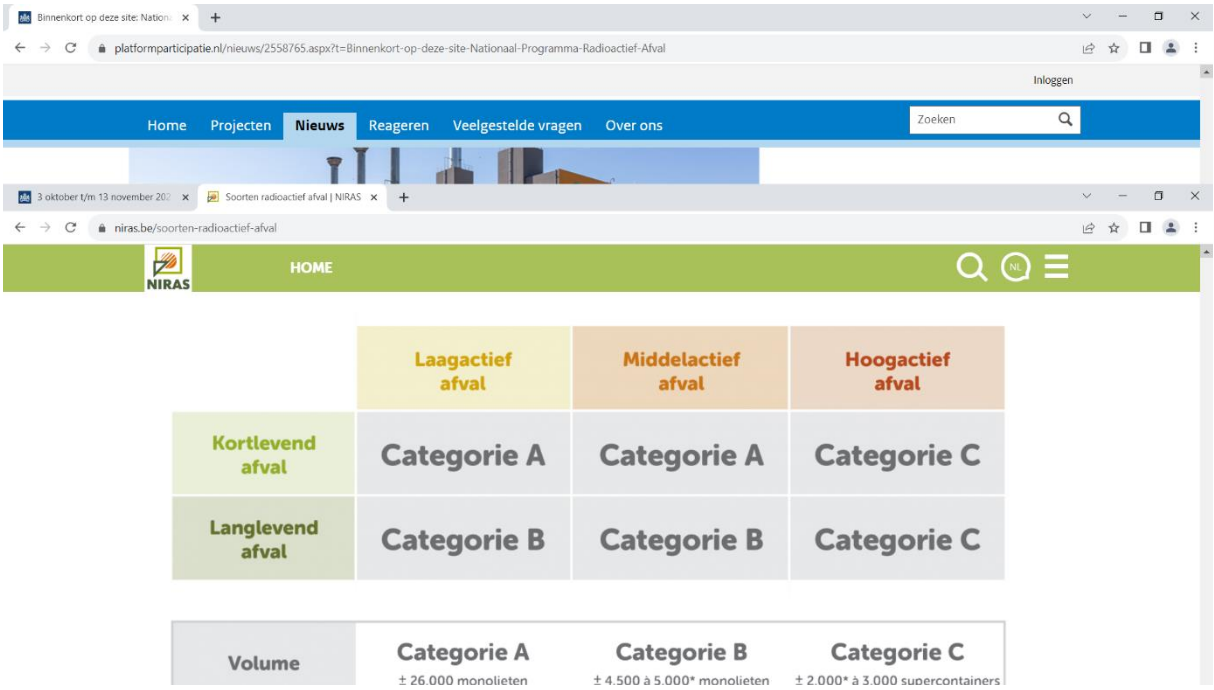
Differences between types of waste

Belgium is considering two types of facilities for disposal of waste. A surface facility for low level waste and short lived waste in Dessel. This is so-called category A waste. A geological disposal facility is foreseen for the waste categories B and C.

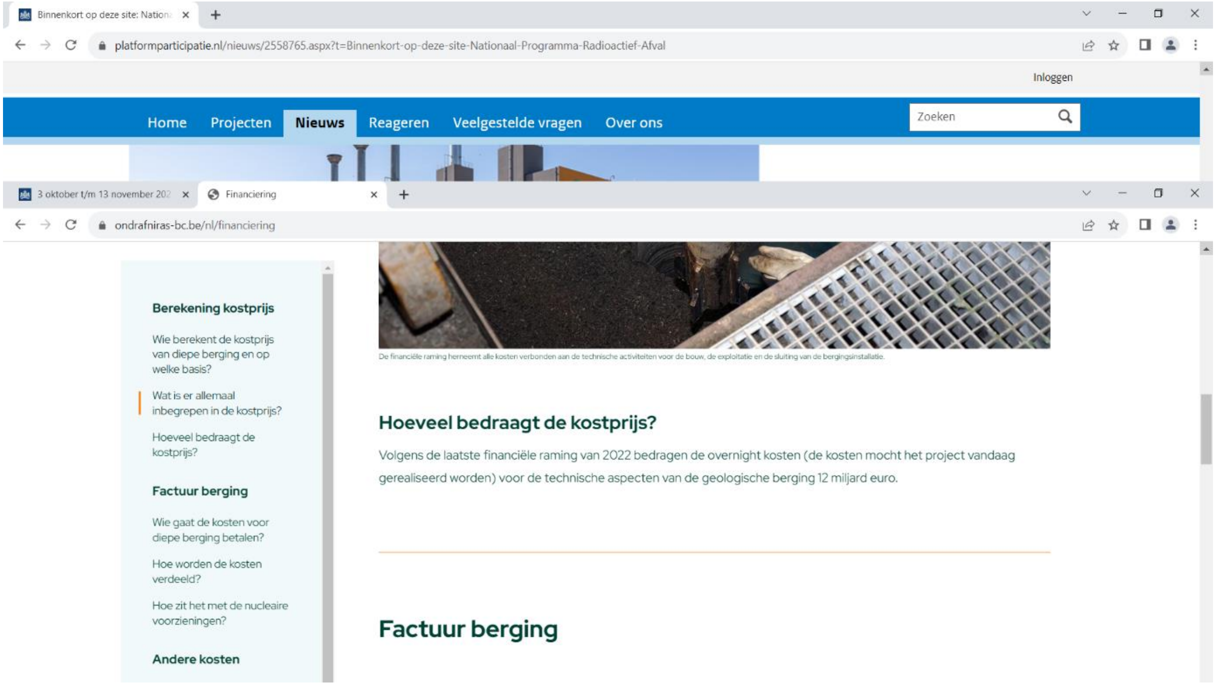
	Belgium			Netherlands	
	HLW	ILW	LLW	HLW	LILW
Contact dose rate (mSv/hour)	More than 2000	More than 5 Less than 2000	Less than dan 5	More than 10	Less than 10
	Category C	Category A - short-lived Category B - long-lived	Category A		

Packaged amounts and costs

The amounts of the different types of waste are published on the website of ONDRAF/NIRAS.



The costs for the disposal facility is also published on the website of ONDRAF/NIRAS.



The number and dimensions of the waste packages, the weight of the packages and the radiation dose rate of the packages have a high impact on the costs for the construction and operation of the Geological Disposal Facility (GDF). The methodology to compare cost estimates is to indicate the costs per volume of waste (EU, 2020). A cost assessment indicator HLW(Dutch) package is made per package instead of volume with the above two screenshots. The table below shows that the derivation per Dutch HLW package.

	Belgium			Netherlands (waste scenario: basis + Pallas)	
	HLW (Belgian)	ILW		HLW (Dutch)	
Contact dose rate (mSv/hour)	More than 2000	More than 5 Less than 2000		More than 10	
	Category C	Category B			
Number	2000 to 3000 supercontainers, for example 2 CSD-v per supercontainer	4500 to 5000 monoliths		478 - CSD-v (supercontainer); 1 CSD-v per container 244- SRRF (supercontainer) 72 - CSD-c ('monoliths')	
Prijslevel (2022)	12 billion euro				
Assumption	6 billion euro	6 billion euro			
Per HLW disposal package	2 million to 3 million euro per 2 CSD-v	1.2 million to 1.3 million euro per monolith			
Key figure	1 million to 1.5 million euro per CSD-v			1 million to 1.5 million euro per CSD-v would make with the Dutch inventory: 0.49 billion euro to 0.72 billion euro in the cost estimate	CSD-v
				1 million to 1.5 million euro per SRRF would make with the Dutch inventory: 0.24 billion to 0.37 billion euro in cost estimate	SRRF
				1.2 million to 1.3 million euro per 'monolith' would make with the Dutch inventory: 0.086 billion euro to 0.096 billion euro in cost estimate	CSD-c
Total in cost estimate HLW (Dutch) with 'Belgian' numbers				0.81 billion euro to 1.2 billion euro	

HLW(Dutch) makes a distinction between heat-generating HLW (CSD-v & SRRF) and non-heat generating HLW (CSD-c).

In COVRA’s waste fees, two third of the costs are for disposal of HLW and one-third for LILW. With the Belgian data and this assumption in the waste fees, the total costs for disposal would be 1.2 billion euro until 1.8 billion euro. Using the 5% and 95% confidence levels for a multiple GDF, it would be 1.8 billion euro until 4.2 billion euro.

Consequently, the Dutch cost estimate is more than the cost estimate with the ‘Belgian’ data. Of course, assumptions such as engineering costs being 30% instead of 10% have a high impact on the total costs. Also the large volume of LLW suggested currently to be geologically disposed of in the Netherlands is contributing a lot to the cost estimate.

Appendix 5: Cost estimate with waste inventory from Masterplan

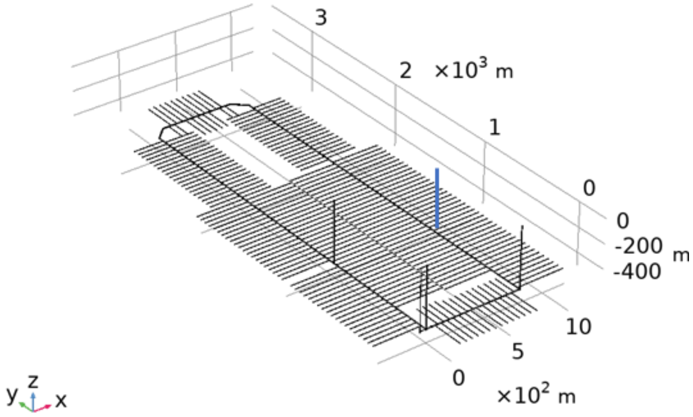
The publication of safety cases are aligned with the review cycles of the national programme on radioactive waste (NPRA) set by the Ministry of Infrastructure and Water Management every 10 years. This cost estimate is published together with COPERA CLAY 2024 (Neeft et al., to be published in March 2025). In 2023, this Ministry initiated a public consultation about the scope of the NPRA (van Gemert et al., 2023). Several scenarios addressing the generation of radioactive waste from potential future nuclear plants were identified and a Strategic Environmental Assessment for these plants was defined (van Gemert et al., 2023). On 28 February 2024, the Dutch parliament voted to include 4 large nuclear power plants in these scenarios instead of 2 (Erkens, 2024). The nuclear landscape will certainly change drastically in 2035 if all proposed nuclear plants are realized, and the volume and the characteristics of waste will change, especially if the spent fuel from the nuclear power plants is not reprocessed. COVRA is investigating the impact of these scenarios for the extension of surface facilities at their premises. The following table shows the amount of packages waste with the base scenario that includes two addition nuclear power plants and that LILW is processed with a plasma furnace instead of with cementitious materials (COVRA, 2024).

Waste category	Type of Package	Waste base scenario Masterplan (COVRA, 2024)	Waste scenario 1 (Burggraaff et al., 2022)
Spent Research Reactor Fuel (SRRF)	Supercontainer (concrete container + steel overpack)	250	244
Vitrified HLW	Supercontainer (concrete container + steel overpack)	8,000	478
Compacted hulls & ends (Non heat generating HLW)	Concrete container	1429 determined by 10,000/7	72 determined by 502/7
Dismantling waste (LILW)	Konrad container	4,130	826
TE-NORM (LILW)	Konrad container	70,000	12,600
Processed LILW	1000 l concrete container	12,000	8,400
	200 l drum	105,000	100,000

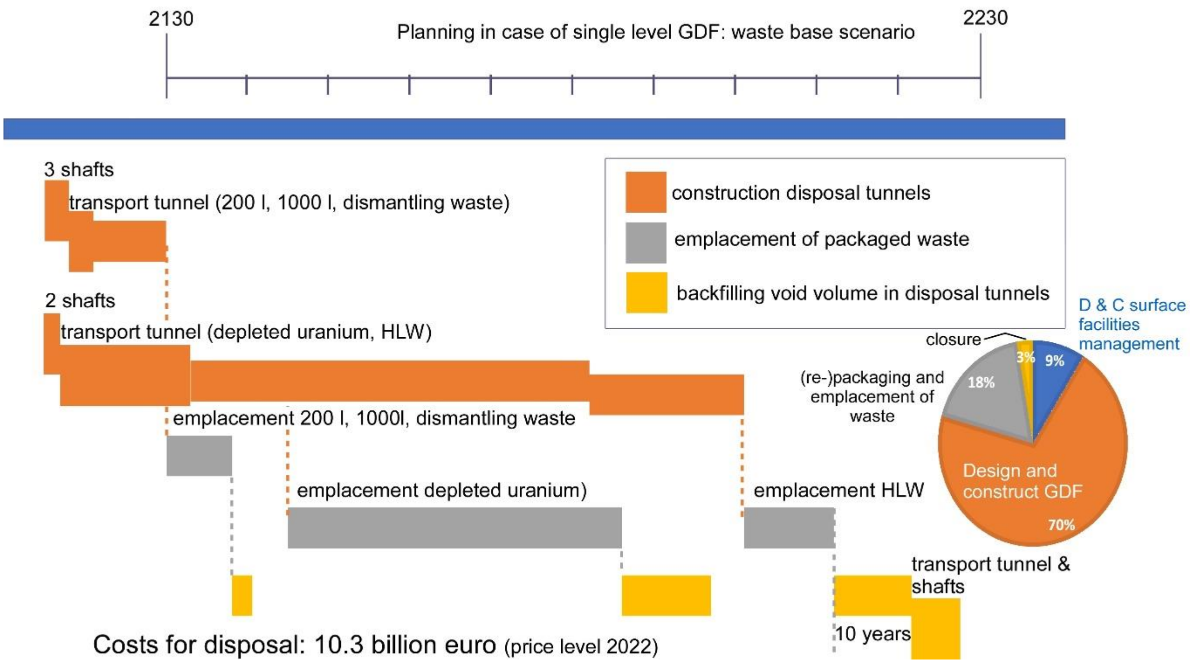
HLW disposal packages (supercontainer) are currently foreseen to have a carbon steel overpack in which the solidified waste in the stain steel canister is put. This overpack is put in a concrete container. The use of depleted uranium as aggregates in cementitious materials as hypothesized in COVRA's research programme for disposal packages for HLW (Verhoef et al., 2020) would eliminate a large proportion of the volume of waste to be disposed of. What needs to be known are:

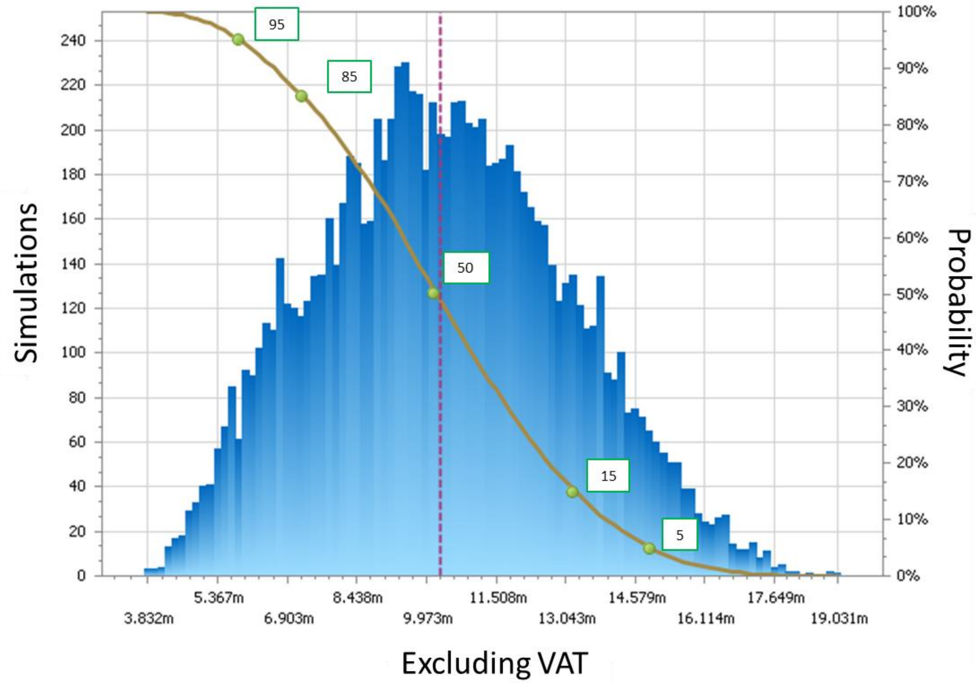
- Technical details such as the strength and permeability of the depleted uranium granules;
- Political acceptance: the use of depleted uranium granules as aggregates in concrete makes the retrievability of depleted uranium as granules more difficult.

The volume of the floor in the GDF already approaches the volume of depleted uranium to disposed of in waste scenario 1 made in the framework of NPRA (Burggraaff et al., 2022). The cost estimate would reduce significantly if it is politically accepted to use waste for the manufacturing of components in the GDF and technical details are known. For now, both type of uses of depleted uranium to optimize the costs for the construction and operation of a GDF in poorly indurated clay are not included. The following figure shows the lay-out of the disposal facility.



The same rates for the construction of the transport tunnel, emplacement of waste packages and backfilling of open void volumes are used (see Appendix 1) for the cost estimate. The construction of the disposal tunnels has been doubled from 3 metres per working day to 6 metres per working day in order to have a similar amount of volume of concrete segments from the surface to the underground as used for the construction of the transport tunnel. The following two figures show the planning and the total costs price level 2022 for a single level GDF excluding VAT, variation coefficient 26%.





Simulations
Probability
Excluding VAT
95
85
50
15
5
240
220
200
180
160
140
120
100
80
60
40
20
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3.832m
5.367m
6.903m
8.438m
9.973m
11.508m
13.043m
14.579m
16.114m
17.649m
19.031m