# Engineering for Operation of a Future Belgian Deep Geological Repository for ILW and HLW -12379

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## ABSTRACT

In Belgium, an advanced conceptual design is being elaborated for deep geologic disposal of high level waste (HLW) and for low and intermediate level waste (LILW) not amenable for surface disposal. The concept is based on a shielded steel and concrete container for disposal of HLW, i.e., the Supercontainer. LILW will be disposed of in separately designed concrete caissons. The reference host rock is the Boom Clay, a poorly indurated clay formation in northeastern Belgium. Investigations into the potential host rock are conducted at the HADES underground research laboratory in Mol, Belgium.

In 2009 the Belgian Agency for Management of Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) initiated a four year research project aimed at confirming the fundamental feasibility of building and operating a repository. The goal of the program is to demonstrate at a detailed conceptual level that the proposed geologic disposal system can be safely constructed, operated, and progressively closed. Part of the broader research efforts being conducted includes evaluations optimization of the waste transportation shaft, subsurface transportation system, ventilation system, and evaluation of backfilling and sealing concepts for the repository design. The potential for implementation of a waste retrieval strategy encompassing the first 100 years after emplacement is also considered.

## INTRODUCTION

Several key aspects of the subsurface facility design are being examined and optimized as part of a four year feasibility study being conducted by DBE TECHNOLOGY GmbH of Germany on behalf of the Belgian Agency for Management of Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) [1]. On-going engineering studies are intended to confirm the fundamental feasibility of constructing, operating, and progressively closing a repository in a poorly indurated clay host formation such as the Boom Clay in northeastern Belgium.

Based on the current conceptual design access to the underground facility will be achieved by the installation of three shafts: two shafts function as personnel access and ventilation intake shafts and a large central waste and equipment transportation shaft. The central shaft also functions as a ventilation outlet shaft and construction shaft. The repository itself will be constructed to include a 6 m wide Access Gallery between connecting the shafts. The Access Gallery will be crossed at 90º by nominally 1000 m long Disposal Galleries that dead-end in the host rock. Waste emplacement fields will be constructed to either side of the central waste transportation shaft. The current disposal strategy foresees waste emplacement to be conducted in two phases, separated by several decades. LILW will be emplaced first followed by emplacement of the HLW [2]. The design layout for the Belgian geologic repository is shown in Figure 1 [3].

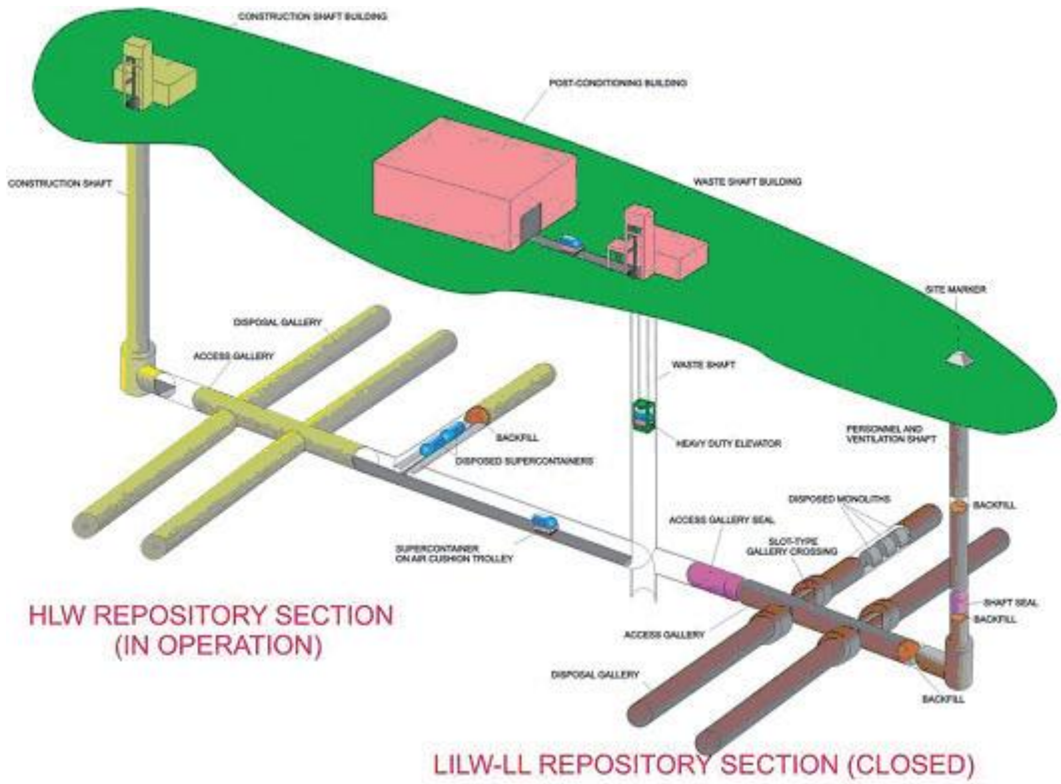


**Fig. 1: Conceptual Design of a Belgian Geologic Repository for Radioactive Waste [3]**

As has been demonstrated by the construction of the HADES facility, underground openings in the Boom Clay require comprehensive ground support. A concrete lining system has been developed to ensure the openings remain stable. However, the lining system and the plasticity of the poorly indurated clay limit the economically feasible size of the underground excavations. Potential stability problems and impacts to the excavation disturbed zone (EDZ) increase significantly with increasing dimensions. Therefore, due to space limitations careful analysis is required when designing and optimizing the underground layout and engineering systems. Key aspects include the design of the shaft, subsurface transport systems, ventilation systems, as well as backfilling and sealing system designs. Additionally, reversibility and retrievability of waste, although not currently a requirement, should be considered.

## ON-GOING ENGINEERING STUDIES

An important aspect of the natural system affecting engineering design considerations are limits imposed on the size of excavations resulting from the high plasticity of the Boom Clay formation and the related thermo-mechanical response of the rock which requires comprehensive ground support measures, consisting of fully enclosed concrete-lined galleries, to be implemented. These measures significantly restrict the available operational space in the repository. Therefore engineering considerations are given to aspects of the design that may require additional evaluation to ensure that they can be feasibly implemented. The aspects studied in detail include the shaft dimensions under consideration of the hoisting requirements for the supercontainer, weighing up to 60 tons, and their handling at the shaft landing station, transportation in both the main access gallery and in emplacement galleries, backfilling and sealing requirements, ventilation requirements, and operational safety aspects.

**Shaft and Hoisting System**

Initial planning in the Belgian concept foresaw the construction of a waste shaft with an inner or usable (open) diameter of 10 m for the horizontal transport of the waste disposal packages to the repository level. Horizontal transportation is preferred as it reduces waste handling operations that would otherwise be required at the repository shaft station. An inner shaft diameter of 10 m also requires a significant wall or liner thickness. A shaft to be sunk through the overlying rock formations would therefore require an excavation diameter of approximately 12 m (i.e., outer shaft diameter). These diameters are significantly larger than those of either of the two shafts currently operated at the HADES facility. A direct transferability of experience from the shaft sinking at HADES is therefore not possible. Additionally, the shaft design ranges at the limit of existing experience with similar shafts constructed in comparable environments.

The time and costs requirements for sinking a large diameter shaft will be significantly greater than those for the original HADES shafts and at the same time the risk of encountering difficult situations that could impact the viability of the shaft, including possible early termination, is increased.

At Gorleben a shaft and hoisting system with similar waste package requirements was designed and key components tested that requires an open shaft diameter of only 7.50 m; a 20% reduction in diameter from the shaft design considered in the Belgian concept, and thus a 40% reduction in excavation volume. As a result a decision was made to investigate options for optimizing the spatial requirements of a waste shaft for a future Belgian repository.

In a first step the design of the Gorleben hoisting system was modified to comply with the Belgian disposal requirements. This included consideration of the slightly larger spatial requirements of the envisaged waste package. The Supercontainer in the case of the ONDRAF/NIRAS system has a maximum length of 6.25 m and a diameter of 2.15 m while the POLLUX container for the Gorleben system has a length of 5.52 m and a diameter of 1.56 m. Both containers have maximum weights in the range of 60 to 65 tonnes.

By adapting the main features of the Gorleben hoisting system to the requirements of the Belgian repository concept it is possible to reduce the usable diameter of the shaft by 20% from about 10 m to 7.8 m. This was accomplished by diagonally orienting the hoist guide rails with respect to the cage, optimizing the counter weight dimensions, and reconfiguring the auxiliary hoisting system as a single rope system. The results of the shaft optimization are shown in comparison to the original design concept in Figure 1.

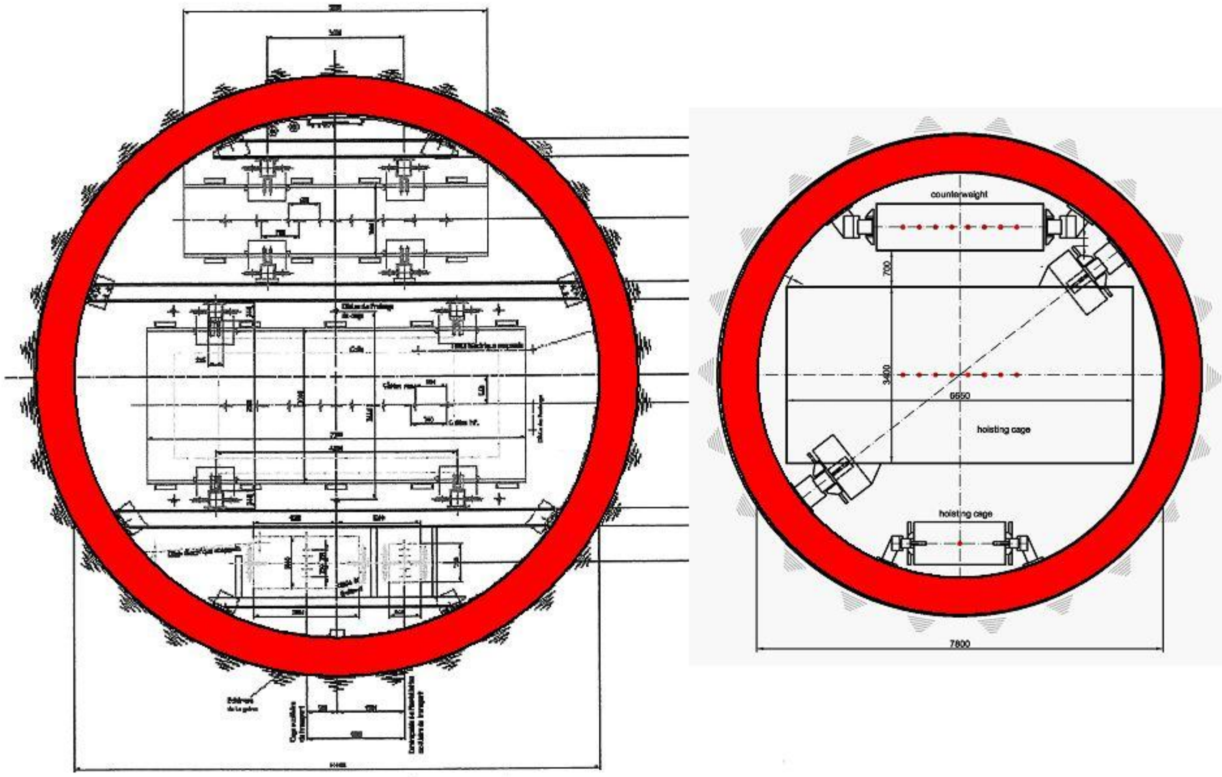


**Fig. 2: Comparison of the original Belgian shaft design concept with the optimized shaft design.**

**Subsurface transport of waste containers**

A separate study evaluates the transport of Supercontainers in the subsurface facilities. The study examines the two transport solutions included in the 2005 concept (i.e., the preferred air cushion and alternate rail-bound systems).

In underground excavations such as mines and waste repositories floor movements caused by stresses in the surrounding host rock can cause deformation of the excavation floor and walls. In a repository these deformational processes would likely be enhanced by increased temperatures in the formation resulting from the emplaced waste. In the Belgian concept deformational impacts may be further exasperated by the high-plastic response of the preferred host rock; a poorly indurated clay. After completion of a State-of-the-Art study [4] on existing air cushion systems and their operational requirements, particularly with respect to floor evenness and smoothness, DBE TECHNOLOGY advised ONDRAF/NIRAS to develop an alternative transportation system. The system currently being evaluated is an optimized hybrid rail-wheel system.

Specific to the Belgian concept the use of a traditional railed system may not be acceptable as such a system would introduce additional steel into the emplacement galleries. Because of the reducing environment in the Belgian repository design it is desirable to minimize the quantity of steel used in the repository. To this end a hybrid system combining features from both wheel and rail based systems is being evaluated for implementation in the Belgian concept. The hybrid transportation system would utilize a reverse profile or grooved track in the access gallery and the profile of the concrete waste pedestal guide-way in the disposal galleries as shown in Figure 2. Instead of traditional rail wheels, a waste transport cart and electric battery-powered locomotive with castor-type wheels would be used to for waste transportation in both the access and disposal galleries.

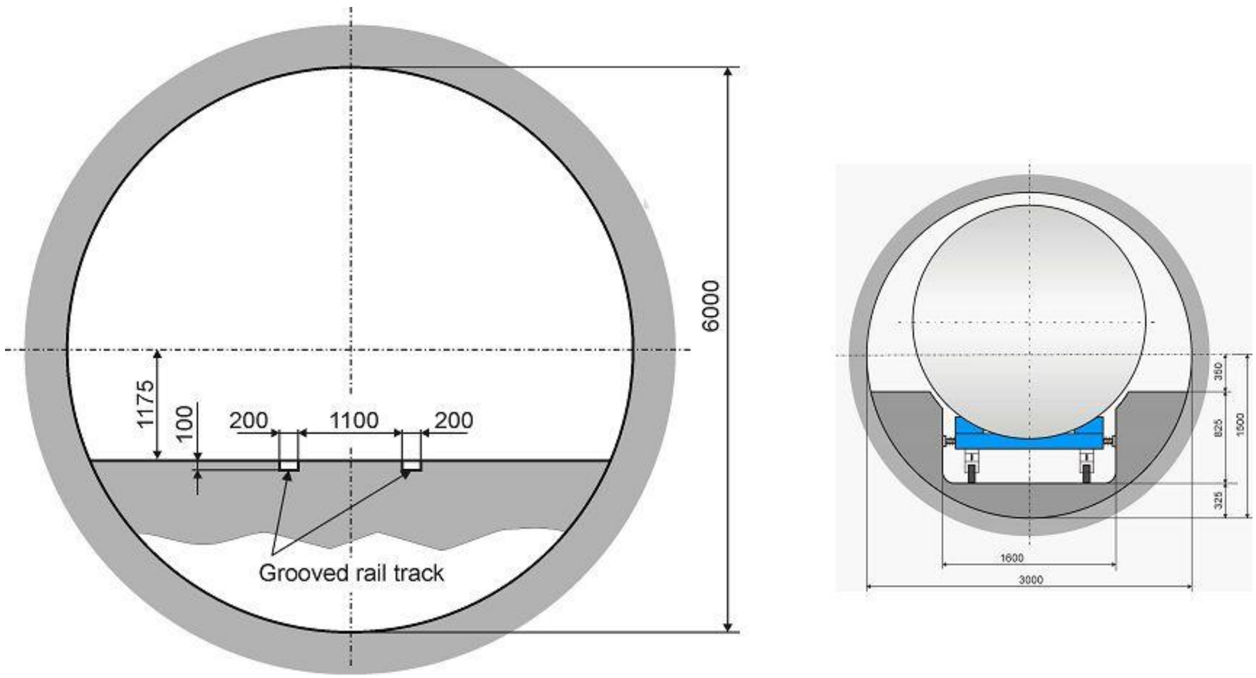


**Fig. 3: Subsurface transportation system utilizes grooved rail tracks in the access gallery and the concrete waste pedestal guide-way in the disposal galleries.**

In the Belgian repository concept the disposal galleries branch off perpendicularly to both sides of a central access gallery. This layout in conjunction with space limitations imposed by the geomechanical characteristics of the host formation limits the available space at the intersection of the galleries. Therefore, a curved turnout design is not practicable. Instead turntables will be used at the gallery intersections to transition waste shipments from the access to the disposal galleries. Once disposal galleries have been filled the rails used in the access gallery can be removed in a retreating fashion and completed portions of the repository can be fully backfilled.

The subsurface transportation concept is largely based on the tested and proved underground transport concept designed for a potential future German repository in a salt dome such as the Gorleben one, and on the fully licensed repository being constructed at Konrad. The main adaptations in regard to the Belgian requirements were: the use of turntables, which in turn have been tested at the Konrad repository and the transportation guiding systems used by both the waste transport cart and the locomotive allowing avoidance of rails inside disposal galleries. A locomotive similar to that proposed for the implementation in a future Belgian repository has been procured and tested as part of a prototyping effort associated with the Gorleben project.

## Ventilation

The Belgian repository concept provides for a two-tier repository layout to accommodate both ILW and HLW in two separate emplacement areas utilizing a common central waste transportation shaft. The emplacement areas for each waste type are located to either side of the waste shaft connected by an access gallery running the length of the entire repository. Smaller service shafts are located at either end of the access gallery. The disposal galleries for both repository emplacement areas extend up to 1000 m perpendicular to the access gallery into the formation where they dead end. Studies currently are underway to design an appropriate ventilation system to ensure worker safety, remove hazardous gases, and provide acceptable climatic conditions.

The ventilation concept being studied anticipates that ventilation air will flow into the repository through the respective service shafts, while main fans at the waste shaft on the surface will extract exhaust air through the waste shaft and discharge it through a diffusor to the outside environment. The disposal galleries are ventilated using dedicated ductwork installed along the entire gallery length. Fresh air enters into the disposal galleries through the gallery access and is removed via suction from the end of the gallery via the ventilation duct by using an auxiliary fan installed in the exhaust shaft. As Supercontainers are emplaced and the disposal galleries subsequently backfilled in a retreating fashion, the ventilation ducts are shortened accordingly. A schematic layout of the ventilation system is shown in Figure 3.

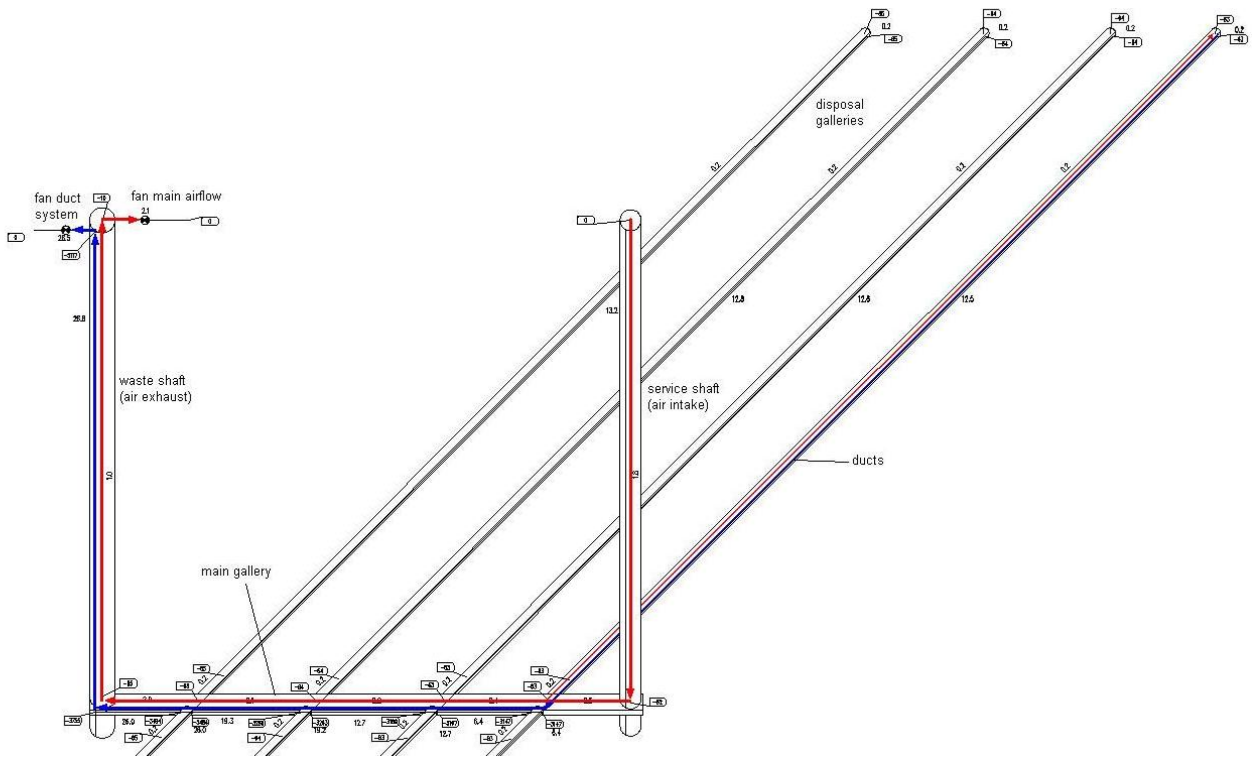


**Fig. 4: Schematic layout of the ventilation system (not to scale).**

The repository climate is characterized primarily as a function of the air's velocity, humidity and temperature. The use of electric powered vehicles as opposed to diesel and the relatively small number of workers (three to eight) required in the subsurface substantially reduce the requirements on the ventilation system.

The determination of the final system requirements must consider the various factors needed to ensure worker safety. An individual worker requires about 2 $m^3$/min of fresh air with a minimum air circulation velocity of 0.2 m/sec. At the foreseen depth of a potential repository at 230 m below ground surface the ambient formation temperature is a relatively minor concern as opposed to the temperature resulting from the disposal of heat generating wastes. The ventilation system must provide sufficient fresh air to maintain the temperature in the repository at or below the legally prescribed limit for worker safety. By increasing the ventilation rate and volume it is possible to dissipate the heat production from the waste and prevent excessively high temperatures. The primary limiting factor is the diameter of the ventilations ducts which combined with the ventilation velocity establishes an upper limit on the thermal management of the galleries.

Additional considerations in the design of the final ventilation system include removal of $CO_2$ from worker exhalation, removal of any gases generated from the disposed waste, and removal of any formation gases. The release of gases from the waste should be avoided where possible; however, where not possible the ventilation system must be adequate to ensure that levels remain below acceptable limits.

The main challenge in the Belgian concept is designing a ventilation system that can be installed in the limited space available in the subsurface, particularly in the disposal galleries. Therefore, the available space must be used as effectively as possible. For HLW disposal galleries the ideal locations for the installation of the ventilation duct work would be immediately above the concrete pedestal to either the left or right of the final position of the waste containers. Locating the ducts here should provide adequate volume to ventilate the galleries while not interfering with emplacement activities. For ILW disposal galleries the ventilation requirements are anticipated to be significantly less during emplacement. The ILW is non-heat generating and should be adequately sealed to minimize the release of gases during emplacement. The final design of the ventilation system will be optimized with the final disposal strategy.

**Backfilling and Sealing in the Belgian Concept**

Backfill is an essential part of the Belgian geological repository concept. As a backfill material the ONDRAF/NIRAS concepts employs concrete mortar to isolate the waste from the accessible environment. The use of concrete mortar backfill is intended to prevent drift collapse, limit the presence of free oxygen, reduce void space, and limit corrosion of the outer liner of the supercontainer by promoting a high alkaline environment as the backfilled galleries naturally resaturate. The concrete backfill will also function to inhibit inadvertent human intrusion. Should the decision be made to dispose of SNF the elimination of void space by backfill also functions to further reduce the likelihood of the unlikely supercriticality scenario, by eliminating voids where soluble fissile materials could potentially collect in sufficient concentrations of concern (ONDRAF/NIRAS 2005, Section 10.2).

Gallery and shaft seals serve to further isolate the repository from the accessible environment and to compartmentalize waste within the repository, limiting the effects from a potential waste package failure on the remaining emplacement area, were such a failure to occur. Under the current concept seals would be installed after disposal activities have been completed in a gallery. Sealing would consist of removing the concrete liners over an as yet to-be-determined length of tunnel followed by installation of bentonite plugs. The bentonite plugs would be installed a small distance into the surrounding formation to achieve a tight seal. The access gallery and shafts would be similarly sealed after disposal operations have been completed.

The current concept appears feasible from an implementation and safety aspect and would likely ensure the long term isolation of waste from the accessible environment.

**Consideration of Waste Retrievability**

In Belgium there is no statutory requirement for retrievability. However, it is current policy to avoid taking actions that would rule out or unduly difficult waste retrieval. The Belgian concept supports the notion that retrievability provisions, if implemented, must not be adverse to the long-term safety goals of a repository [5]. Therefore the current goal of ONDRAF/NIRAS is to examine retrievability options and potential impacts to the current repository design concept, should a future implementation decision be made. For purposes of this evaluation, ONDRAF/NIRAS assumes retrievability for a period of 100 years after emplacement.

Retrievability in the Belgian repository concept can be achieved by either maintaining reversibility in the repository facility pending a future closure decision, or through partial closure of the repository where the backfill and sealing systems are designed and sequenced in a manner that does not preclude waste retrieval. Consistent with the Belgian concept, implementation of retrievability irrespective of how it may be implemented should not negatively impact repository performance and safety. Therefore, consideration is being given to identifying means by which retrievability could be implemented while ensuring adequate protection to humans and the environment.

In order to implement a reversible design option, backfilling and final sealing of the disposal galleries, the access gallery, and the shafts would be delayed until such a time that retrievability is no longer desired. Under expected repository conditions, maintaining a reversible repository would likely realize a retrievable design, although additional analysis would be required to evaluate the ability to maintain waste accessibility and to assess potential impacts on the barrier function of the host formation, as well as potential impacts to operational safety. Additionally, unexpected conditions may arise which could jeopardize the performance of the repository. For example flooding of the repository could result in significant damage to waste containers and repository facilities, eventually leading to unacceptable radionuclide releases to the accessible environment. Seismic events, although rather unlikely in the part of Belgium being studied, could also cause significant damage to the gallery lining system leading to its potential collapse and thereby obstruction of any potential retrieval efforts.

An alternative approach currently favored by ONDRAF/NIRAS would be to partially close the repository facility. Partial closure of the repository could be achieved by limiting backfilling to the disposal galleries. Installation of seals would ideally be delayed until after a decision to fully close the repository is made. Partial closure has the benefit that both operational and long term safety considerations remain consistent with the current design concept. Implementation of retrieval from a closed or partially closed repository requires development and implementation of new equipment.

It appears likely that closure of only the disposal galleries would provide adequate safety to protect the waste from both expected and unexpected repository conditions pending final repository closure. Assuming the shafts are maintained open, additional flood protection precautions should be implemented to protect these accesses. Backfilling of the disposal galleries would provide mechanical support to the lining system and provide a chemical and thermal environment consistent with the current design concept. However, because of the relatively limited space remaining in the galleries after waste emplacement, mechanical excavation of Supercontainers would be difficult to implement without potentially causing significant damage to either the tunnel liner or the waste container. One potential solution for removing backfill, while at the same time limiting potential damage to Supercontainers and tunnel lining systems, could be through use of hydro-jet excavation methods. For hydro-jet excavation the composition of the backfill is a key factor. Minimal requirements on the backfill would include:

- Maintenance of the alkaline near-field environment for consistency with the current Belgian repository concept.
- Sufficient viscosity to allow pumping over the length of a disposal gallery (i.e., 1000 m), yet adequate for installation immediately after emplacement of a small number of supercontainers
- Completely filling of annular gaps/voids within the disposal galleries.
- Allow emplacement of aged waste at temperatures of up to 85°C.
- Have a low compressive strength of 1 to 2 MPa (the compressive strength of the Boom Clay is approximately 2 MPa) to allow removal without damaging either the disposal drift liner or the Supercontainer, yet with sufficient strength to fulfill the structural support function.

Studies on retrievability are ongoing and additional analysis is being performed. In general should a retrievability requirement be included in the Belgian concept at a future date its implementation is likely a function of level-of-difficulty and not a question of possibility, related to the level of closure of the facility, i.e., have the disposal galleries been backfilled, have seals been installed closing off disposal galleries, has the access gallery been backfilled, have seals been installed closing off the access gallery, has the shaft been backfilled and sealed. However, a final assessment regarding the feasibility of implementing retrievability in the Belgian repository concept is not yet available.

## SUMMARY

In the framework of a four year research program aimed at confirming the fundamental feasibility of building and operating a repository in poorly indurated clay design studies have been underway to optimize the waste transportation shaft, subsurface transportation system, and ventilation system. Additionally backfilling and sealing concepts proposed for the potential repository have been reviewed in conjunction with impacts related to the potential future inclusion of a retrievability requirement in governing regulations.

The main engineering challenges in the Belgian repository concept are size limitations on the underground facilities imposed by the mechanical behavior of the candidate host rock type (i.e., poorly indurated clay) and the resulting ground support requirements. Underground excavations in the Boom Clay require a significant level of ground support to ensure the openings remain stable. A concrete lining system has been developed to address this engineering requirement. As a result strict size limits are imposed on both the diameter of the tunnels and the dimensions of the shaft stations resulting in unique design challenges requiring maximal optimization of the available space.

Ongoing studies indicate that a significant (20%) reduction in shaft diameter can be achieved by diagonally orienting the hoist guide rails with respect to the cage, optimizing the counter weight dimensions, and reconfiguring the auxiliary hoisting system as a single rope system. Reliable subsurface transportation of waste packages can be achieved through a hybrid rail/wheel system powered by a battery operated electric locomotive. Key components of the system, including the battery-powered locomotive and a turntable used for transitioning waste shipments from the access gallery into disposal galleries without the need for constructing turnouts, have been successfully demonstrated at the Gorleben exploratory facility and the Konrad repository in Germany, respectively. By optimizing the available space in the disposal galleries and limiting the introduction of hazardous gases by using electric powered systems combined with the relatively small number of workers envisioned in the Belgian repository concept adequate ventilation can be achieved to ensure safe operational conditions. The proposed sealing and backfill systems in the Belgian repository concept should provide adequate safeguards as currently planned. Should a future retrievability requirement be imposed on the design it appears likely that a partial backfilling strategy could be employed. The key component in ensuring retrievability in the design would be the selection of a backfill that combines the safety functions required in the current design concept with a material strength amenable to removal by hydro-jet excavation techniques.

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