EMPLACEMNET AND RETRIEVAL CONCEPTS FOR GERMAN SF/HLW REPOSITORIES IN CLAYSTONE

Philipp Herold[1,2], Michael Jobmann[1]

[1] DBE TECHNOLOGY GmbH, Eschenstraße 55, 31224 Peine, Germany
[2] email: philipp.herold@dbe.de, phone: +49 (0) 5171 43 1613

Within the framework of the R&D project ANSICHT (Safety Assessment Methodology for a German High-level Waste Repository in Clay Formations), DBE TECHNOLOGY GmbH, BGR, and GRS developed an integrated methodological approach on how to demonstrate the safety of a HLW repository in claystone in Germany. One challenging aspect of this approach was the design of a repository concept for the two known potential host rock formations; huge Jurassic claystone layers in the northern part of Germany and thinner but well-known claystone layers in the South, also known as Opalinus Clay. For the northern reference geology, the disposal of unshielded canisters in vertical boreholes was designed as preferred emplacement concept. For the Opalinus Clay, drift disposal of shielded POLLUX® casks was identified as the most suitable emplacement concept. In addition, the ERNESTA study (Development of Technical Concepts for the Retrieval of Waste Containers with Heat-generating Waste and Spent Fuel from Repositories in Salt and Clay Formations) was initiated to investigate in parallel how to fulfil the requirement for retrievability in both concepts. In Germany, retrievability is a design criterion and requirement for licensing stipulated by the "Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste", established in 2010.

I. INTRODUCTION

In 2013, the German Parliament decided to restart the site selection process for a repository for spent fuel and heat-generating high-level radioactive waste and established a new commission, the so-called Commission "Storage of HLW". The objectives of the commission were to define the time frame and the general steps for this process as well as criteria for the selection of a site. Within the new site selection process, three host rocks will be considered: salt, claystone, and crystalline rock. As the preferred disposal option, the Commission recommends the disposal of high-level waste in deep geologic formations with the possibility of retrieving the waste packages (1). In addition to this, the "Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste" (2), established in 2010, stipulate retrievability as a design criterion and requirement for licensing, too.

Within the framework of the R&D project ANSICHT (Safety Assessment Methodology for a German High-level Waste Repository in Clay Formations), DBE TECHNOLOGY GmbH, BGR, and GRS developed an integrated methodological approach on how to demonstrate the safety of a HLW repository in claystone in Germany. Due to the complex geologic conditions, two reference models were developed. The reference model Type NORTH represents huge Jurassic clay formations known from the northern part of Germany. The reference model Type SOUTH represents thinner but well known Opalinus Clay, as known from southern Germany and Switzerland, as well. For both emplacement concepts, repository designs as well as closure and sealing concepts were developed. Additionally, DBE TECHNOLOGY GmbH investigated in parallel how to fulfil the requirements for retrievability. The ERNESTA study (Development of Technical Concepts for the Retrieval of Waste Containers with Heat-generating Waste and Spent Fuel from Repositories in Salt and Clay Formations) was initiated to analyze the boundary conditions during retrieval and to develop technical concepts, including the devices needed for both emplacement concepts. Major technical challenges arose with regard to the handling of the drift liner without negatively influencing long-term safety, at the same time generating comfortable conditions inside the underground facilities with respect to the requirements of radiation protection and ventilation.

II. REFERENCE GEOLOGY AND EMPLACEMENT CONCEPTS

According to the political decision to phase out of nuclear energy, the last German nuclear power plant will shut down in 2022. This allows an estimation of the expected types and amounts of radioactive waste and spent fuel and to calculate the total amount of waste to be disposed of. A potential German repository has to been designed for 8,141 CSB-V/C/B canisters from reprocessing and 34,630 spent fuel assemblies from different types of reactors. Table I gives a detailed overview of the total amounts of waste and the corresponding waste packages needed. Every waste package concept considers a separation of the spent fuel rods from the structural elements (e.g. grid spaces and top nozzle) of all spent fuel assemblies.

TABLE I. Total amount of HLW and SF and amount of waste packages for each emplacement concept (FA = Fuel assemblies, * - BSK, ** - POLLUX®-3, *** - MOSAIK®, **** - POLLUX®-9) (5, 10)

Type	Amount	Borehole	Drift
Spent Fuel			
PWR UO_2 MOX	 12,450 FA 1,530 FA	6,990*	4,600**
BWR UO_2 MOX	 14,350 FA 1,250 FA	2,600*	1,734**
WWER	5,050 FA	1,010*	674**
Structural elements		874*	2,620***
High Level Waste (from reprocessing)			
CSD-V	3,729 casks	1,245*	1,245**
CSD-B	308 casks	103*	35****
CSD-C	4,104 casks	1,368*	456****

II.A. Geologic model and emplacement concept Type North

The geologic model Type NORTH is one of two generic reference models and is based on known geologic formations. Type NORTH represents the geology as expected in the eastern part of the so-called Lower Saxony Basin in northern Germany. This area and the formations were already characterized as potential host rocks by (3) in 2007.

The reference model includes different geologic levels, starting at the "Zechstein" (German term for Permian formations, mostly evaporated sediments). For geological disposal only the upper 1,000 m of the model are relevant, see Fig 1. This area is characterized by huge marine sediment formations from the Jurassic. The so-called "Barremium" and "Hauterivieum" layers are proposed as potential host rock. The layers lie between 400 and 950 m below surface. Inside this huge formation, the repository will be located at 770 m below surface. Barremium consists of partly bituminous claystones rich in clay. The density lies around 2,300 kg/m³ with a total porosity of 21 % and a hydraulic conductivity of 10^{-12} m/s. Hauterivium is characterized by claystone and clay marl in alternating strata. The density is a bit higher (approximately 2,400 kg/m³), with a total porosity of 28 % and a permeability of 10^{-12} m/s. (4)

The top of the Jurassic formations lies approximately 100 m below surface. They are covered by lose Quaternary sediments. These sediments include aquifers. One aquifer with higher salinity is located in the so-called Hilssandstein (sandstone layer) between 250 m and 290 m below surface. (4)

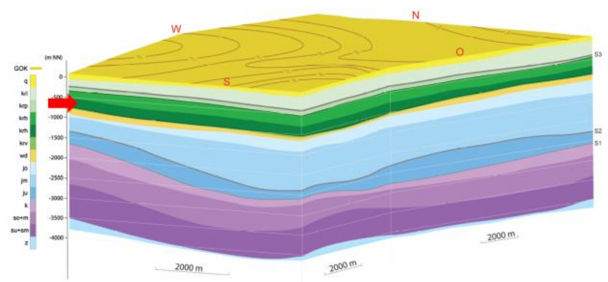

Fig. 1. 3D model of the generic geology of Type North, potential host rock in green (red arrow) (4)

The repository facility is connected to the surface by two shafts located in the center of the mine openings, see Fig. 2. Additional infrastructure drifts are located next to the shafts, e.g. for maintenance and support. Inside the repository, SF and HLW are separated in two different sections. The smaller HLW section consists of twelve emplacement fields. The larger SF section consists of 32 emplacement fields. Every field comprises nine emplacement drifts with an inner cross-section of 40 m². The waste canisters are emplaced in short vertical boreholes inside these drifts. The boreholes are arranged in a hexagonal system. Depending on the borehole location, the emplacement drifts comprise 12 or 13 boreholes. Every emplacement field is framed by two access drifts and connected to three main drifts; one main drift for mining operations, one for waste package transport, and one for air exhaust. The overall footprint of the mine layout is approximately 6.2 km². All drifts are equipped with a concrete liner. Thickness, type of concrete, and type of installation as well as additionally needed support structures (e.g. roof bolting) are not defined, yet. The final design depends on the local conditions as well as the functions and lifetime of every drift. The liner will always remain inside the drifts.

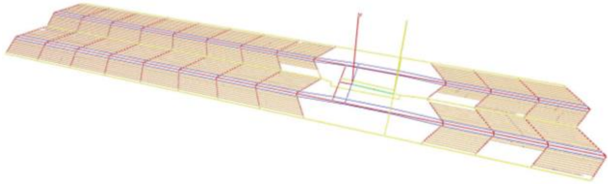

Fig. 2. Generic model of the repository layout (4)

Every emplacement borehole is 27 m deep and designed to take up three canisters type BSK. Fig. 3 illustrates the different components of an emplacement borehole. The contour of every borehole is lined with an outer steel liner. The main function of the liner is the stabilization of the borehole wall and the creation of a defined cylindrical shape. The thickness of the liner depends on the local geo-mechanical conditions. Inside the outer liner, a buffer made of pre-compacted clay rings will be installed. The main function of the buffer is the delay of fluid flow from or to the canisters in order to slow down metal corrosion. In the center of the buffer a second liner, the inner liner is installed. The inner liner has to be gas- and water-tight to retard fluid inflow and corrosion inside. The inner liner has to resist the mechanical loads from host rock and buffer to allow retrieval, if necessary. Inside the liner, the three canisters are located. The spacing between the canisters is guaranteed by sand backfill. The canister concept is based on the so-called BSK 3 design. BSK stands for the German "Brennstabkokille" (Spent Fuel Canister). The BSK 3 canister is designed for the final disposal of irradiated fuel. Every canister can contain rods from up to three PWR fuel assemblies, a corresponding amount of BWR or WWER fuel rods, or three HLW canisters.

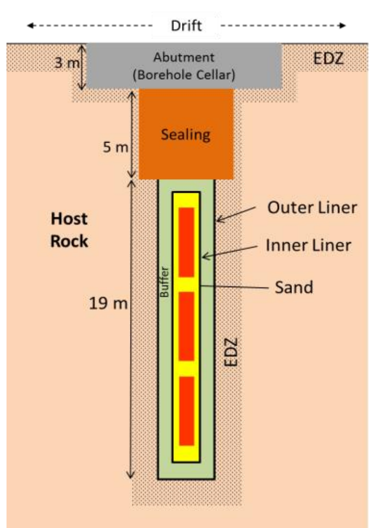

Fig. 3. Schematic design of an already filled and sealed emplacement borehole, BSK in red (5)

The repository is designed for a maximum temperature of 150°C. Inside the borehole, the interface of the inner liner and the clay buffer represents the design-relevant element. At this location the temperature is not to exceed 150°C.

The transport and emplacement equipment for BSK canisters was successfully tested by DBE TECHNOLOGY GmbH in 2009 (6), see Fig. 4. Initially, the disposal concept and the emplacement technique were developed for salt formations. Due to the use of the same canisters, a transfer of the technique to other host rocks seems to be possible.

The emplacement process starts at the surface with the placement of a BSK canister into a transfer cask. The loaded transfer cask is tilted from vertical into horizontal position and placed onto a transport cart. The loaded transport cart is driven into the hoisting cage and subsequently transported through the shaft down to the repository level. Inside the drifts, an electrically driven mining locomotive moves the transport cart to one of the active disposal drifts and the disposal borehole where the emplacement device is already positioned.

The flap frames of the emplacement device pick up the transfer cask and raise it off the transport cart, still in a horizontal position. Subsequently, the transport cart is hauled away. The emplacement device then tilts the transfer cask into a vertical position, lowers and docks it onto the borehole lock, which covers the borehole. Once a transfer cask has been docked onto the borehole lock, its slider is mechanically locked to that of the transfer cask so that sliding doors of the lock and the transfer cask can be operated simultaneously by the drive of the borehole lock.

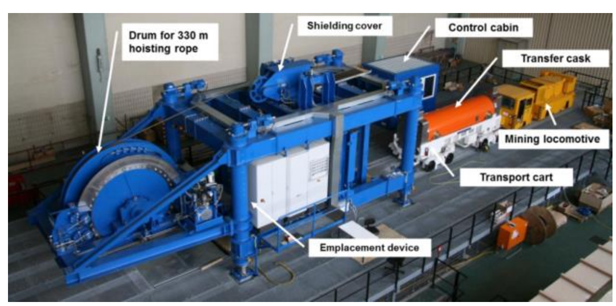

Fig. 4. Test facility for borehole disposal of spent fuel canisters (6)

After the transfer cask has been tilted into a vertical position, the shielding cover (which is part of the hoisting installation in the load portal above the raised transfer cask) is lowered and locked onto the top of the transfer cask. This shielding cover contains pulleys and ducts to guide the hoisting cables. After the lock slider at the top of the transfer cask has been opened, the canister grab, which is retracted inside the shielding cover, is lowered into the transfer cask where it takes hold of the BSK canister and lifts it off the transfer cask bottom so that the lower lock slider, which is mechanically connected to the borehole lock slider, can be opened.

When both lock sliders have been opened, the hoisting installation lowers the BSK 3 canister into the borehole to its final position. The canister grab opens and is retracted out of the borehole. Undocking and return to the surface of the empty transfer cask is done in reverse order. Backfilling is realised with a special backfilling canister that is operated by the emplacement device in the same way.

After emplacement and backfilling of the borehole, the upper part of the inner liner is removed and closed by a welded cap. The inner liner is then covered by additional buffer elements. The EDZ at the top of the borehole is removed over a length of 5 m, and a sealing element made of bentonite is installed. The bentonite, made of a binary mixture of pellets and powder, will be compacted in situ. This represents a well-known technique from shaft sealing (7). The borehole cellar, needed for disposal, will be filled with concrete, see also Fig.3.

When all boreholes in one emplacement drift are filled and sealed, the drift will be backfilled. Currently, the backfill material is designed as a mixture of excavation material and clay rich in smectite. The final composition depends on the properties of the host rock and pore water at the repository site. The main functions of the backfill are the reduction of fluid flow and mechanical support to minimize rock convergence. It is required that the backfill has permeability comparable to the undisturbed host rock. The access drifts and main drifts will be backfilled with the same material.

Each emplacement field will be sealed at the end of the access drifts by small seals made of bentonite sealing elements supported by two concrete abutments. Next to the infrastructural area, all main drifts will be sealed by bentonite-based drift seals. Finally, the shafts are sealed by a combination of different sealing elements made of asphalt and bentonite sealing elements, see Fig. 5. The main shaft seal lies below 600 m. It is known that in northern Germany, glaciogenic channels from former ice ages reach down to 500 m below surface, and it is expected that during future ice ages such channels could form again. An additional sealing module (asphalt and bentonite) separates the Quaternary aquifers from the Hilssandstone layer. It is expected that this seal will erode over time. The functional period of all seals is limited to the transient phase of thermo-hydro-mechanical processes inside the repository. After this phase, it is expected that the backfill compaction is finished and that the backfill can provide the long-term sealing function. Currently, the exact functional period is not known in detail. It is expected that these processes are finished after several thousand years.

Fig. 5. Shaft sealing concept for reference geology Type NORTH (5)

II.B. Geological model and emplacement concept Type South

The reference geology Type SOUTH represents a potential geology of southern Germany. The geology is strongly influenced by the alpine orogenesis and it is characterized by a complex structure. The model includes the stratigraphically units of Triassic at the bottom, Jurassic, divided into lower, mid, and upper, followed by Tertiary and Quaternary layers at the surface, see Fig. 6. The overburden includes huge aquifers and karst formations. (8)

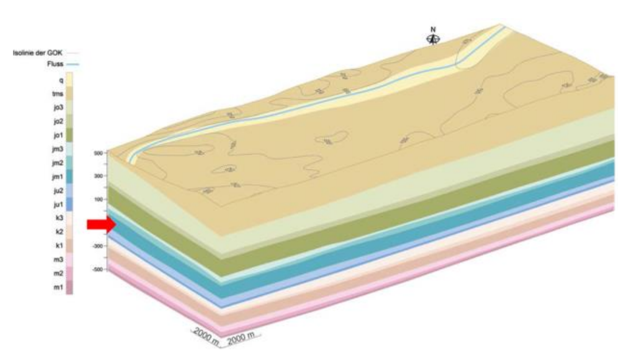

Fig. 6. 3D model of the generic geology of Type SOUTH, potential host rock (red arrow) (8)

The so-called Opalinus clay from the mid Jurassic is defined as potential host rock formation (Fig. 6, red arrow). The rock is characterized by highly compacted and homogenous claystone. Based on (8), the saturated bulk density is 2,450 kg/m³, total porosity is 18.3 % and the hydraulic conductivity is approximately 10^{-13} m/s. The clay layer has a thickness of 100 m to 120 m and is located approximately between 620 m and 730 m below the surface. The repository is located more or less in the center of the Opalinus clay, 680 m below surface.

The repository layout is comparable to that of Type NORTH. Two shafts connect the surface to the underground. The repository is divided into two main sections. In each section, several emplacement fields are located, covered by access drifts and connected to three main drifts. Only the emplacement concept inside the drifts is different from that of Type NORTH. Within Type SOUTH, self-shielded POLLUX® casks will be emplaced directly inside the drifts, see Fig.7. The casks are designed to hold the fuel rods from three PWR spent fuel assemblies, too. Overall, 48 SF emplacement fields and 14 HLW emplacement fields result in a footprint of approximately 7.8 km². The larger footprint is a result of the disposal concept. All waste packages are disposed of in the same plane.

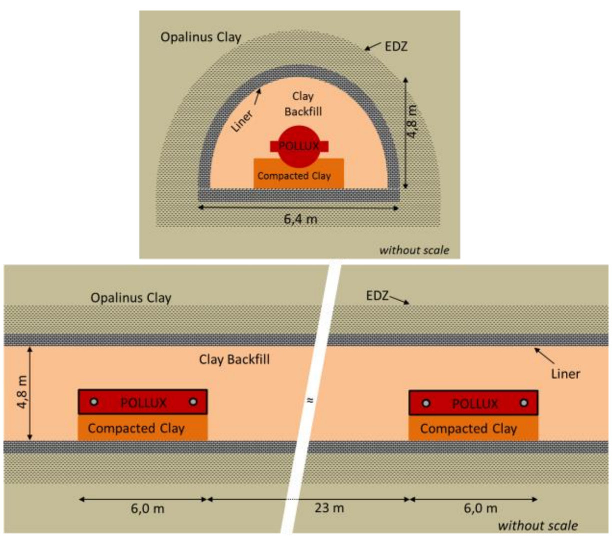

Fig. 7. Illustration of emplaced waste packages in front view (on top) and side view (below) (10)

In the SF section, every emplacement drift contains 16 or 17 POLLUX® casks, based on the hexagonal emplacement design. All POLLUX® casks are placed on a socket made of pre-compacted clay blocks. According to the design calculation results, the spacing between two casks is 23 m in lateral direction. The spacing between the emplacement drifts is 20 m. For operational reasons a minimal cross-section of 24 m² is needed to handle the casks.

The emplacement technique is currently still a very rough conceptual design. The rail-bound transport and emplacement devices for larger POLLUX®-10 casks have already been successfully tested for the drift disposal concept in salt formations (11), see Fig.8. It is currently planned to adapt this general design to the needs of drift disposal in clay.

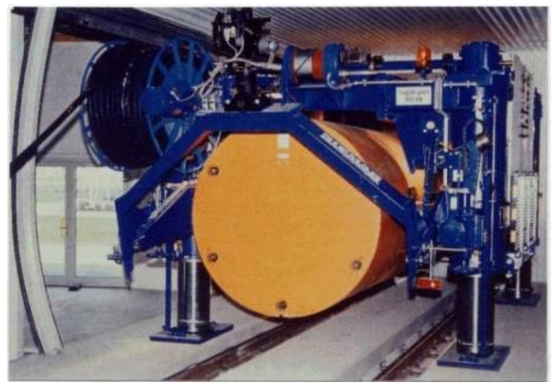

Fig. 8. Test facility for drift disposal of spent fuel canisters (POLLUX®-10) (11)

Each cask is covered with backfill immediately after emplacement. The backfill material is defined as a swellable clay material. To reach a high final bulk density inside the backfilled drifts it is planned to install granular backfill (pellets) that consists of a binary mixture of excavation material and swellable clay/bentonite. The sealing concept is similar to that of Type NORTH. Small drift seals called migration barriers, large drift seals, and shaft seals are to close the underground openings and retard fluid flow.

Unlike the small drift seal of Type NORTH, the migration barriers are supplemented by an additional asphalt sealing element, see Fig.9. The asphalt is located next to the emplacement drifts to provide an instantaneous sealing function against fluid flow out of the emplacement fields. Likewise, the main drift seals are supplemented with an asphalt seal. These asphalt seals are located next to the shafts to provide an instantaneous sealing function against fluid inflow in case of a shaft seal failure. The functional period of all asphalt elements is limited to the saturation period of the bentonite elements, which is expected to last several decades. This modified sealing concept is seen as advancement and is expected to be applied at Type NORTH as well.

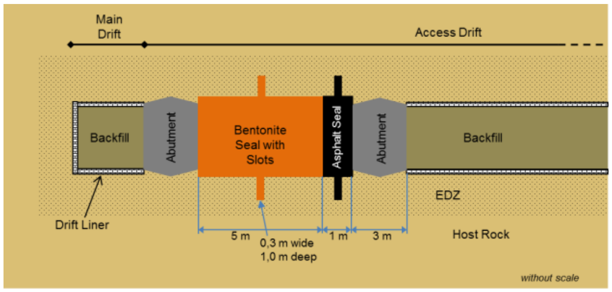

Fig. 9. Migration barrier (10)

The design of the shaft seal is adapted to the expected geology. The functional period of the seals is limited to the time until the backfill compaction and saturation are finished so that the backfill can provide the long-term sealing function.

III. RETRIEVABILITY AND RETRIEVAL

During the last decades, HLW and SF disposal in Germany focused on salt formations. But about 15 years ago, a discussion about disposal in alternative host rocks started. In 2013, at the end of a controversial political debate, the German Bundestag passed a law to restart the site selection process. As a consequence, the parliament decided to establish a commission that has to re-evaluate the general strategy, develop criteria for site selection, and develop a road map for the site selection and disposal process. The commission delivered its final report in June 2016 and recommends as preferred disposal option the disposal of high-level waste in deep geologic formations with the possibility to retrieve the waste packages. It is now planned to transfer these recommendation into law (1).

Furthermore, the "Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste" (2) established in 2010 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety require retrievability, too. The safety requirements have to be applied to the design, further exploration, construction, emplacement operations and decommissioning of a repository. They replace the former safety criteria from 1983. Compliance with the safety requirements has to be demonstrated and for the first time, retrievability of the emplaced waste packages was stipulated as design criterion. In detail, retrievability is defined as *"...the planned technical option for removing emplaced radioactive waste containers from the repository mine."* (2)

Retrievability must be possible during the operational period. The end of the operational phase is marked by the sealing of the shafts. As long as there is a direct connection to the surface, retrievability must be guaranteed. Recovery is limited to a period of 500 years after final closure of the repository, see Fig.10.

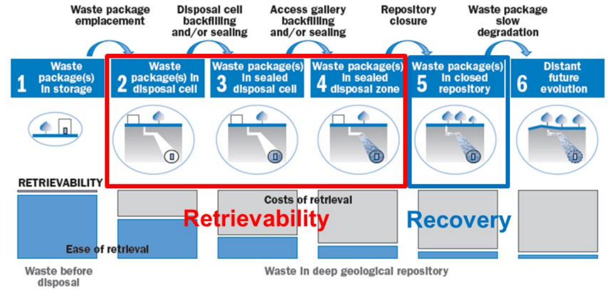

Fig. 10. Retrievability Scale based on (12) compared with German understanding/definition of Retrievability and Recovery given by (2)

Additional demands that influence repository design and retrievability are given by the limitation of the number of open emplacement zones. These should be kept to a minimum, be promptly loaded, then backfilled and reliably sealed from the mine building. Considering the long operational period of 30 to 40 years, this means that the three main processes – emplacement, backfilling, and sealing – take place in parallel and have to be considered by the design of retrieval concepts. It is also pointed out that measures taken to secure the options of retrieval must not impair the passive safety barriers and thus long-term safety (2).

The commission (1) gives similar recommendations. Retrieval of all waste packages already emplaced must be possible without negative impact on safety. But one big difference is given in the definition of the repository lifetime and operational period. The commission defines emplacement including backfilling of the emplacement areas as one stage. After that, an as yet undefined period of observation is planned before final closure of the repository. During this time, access to all main drifts has to be possible. There is no stepwise sealing parallel to emplacement. Sealing is defined as a new stage and includes the main drifts and shafts. However, this approach has not been fixed in a law. It remains to be seen whether this will happen or not.

Based on the demands given by the safety requirements, DBE TECHNOLOGY GmbH proposes a so-called "Re-Mining" strategy as most suitable approach for the implementation of retrievability. This strategy allows the operation of the repository as designed. The individual emplacement areas are backfilled and sealed parallel to the ongoing disposal progress. In addition, modifications to ease retrieval or to improve conditions during retrieval are possible. If a decision for retrieval is made, the seals already constructed and the backfilled drifts will be re-excavated. The excavation creates a new access to the waste packages and allows their exposure. Removal of the waste packages will be realized with modified emplacement equipment. Finally, the waste packages will be transferred from the passive safety system of the repository back into human care.

The implementation of this strategy into existing emplacement concepts is connected with different assumptions:

- The considerations related to retrievability are limited to underground operations.
- Retrieval starts after emplacement of all waste packages and backfilling and sealing of all drifts. This covers the full operating period [and observation or supervision period as defined by (1)].
- To ease retrieval, removal of all internals before backfilling is required.
- A decision to release drifts from the controlled area or not is made before backfilling and sealing. This question is currently still open.
- And finally, a minimization of mine openings is a requirement to protect containment/host rock/long-term safety. During retrieval, this will not be relevant and additional drifts can be excavated if needed.

Based on the general retrieval strategy and the assumptions listed above, DBE TECHNOLOGY GmbH developed technical retrieval concepts for both emplacement concepts; i.e., vertical borehole disposal (Type NORTH) and horizontal drift disposal (Type SOUTH) in clay formations.

III.A. Retrieval at Type North

If a decision for retrieval is made, all drifts already backfilled have to be re-excavated again. Basically, this comprises the removal of the drift backfill material. Removing the main drift seals next to the infrastructure area is not necessary. It is possible to excavate new drifts parallel to them. The small drift seals located inside the access drifts have to be removed to reach the emplacement fields. At the location of the seals, a new concrete liner has to be installed.

Re-excavation comprises the removal of the backfill and a restauration of the liner. It is possible to use conventional equipment from mining and tunneling, similar to the excavation during repository construction. Inside the emplacement drifts, the concrete abutment, the bentonite seal and the top of the buffer at every borehole have to be removed. The inner liner is opened again and the already removed upper part is reinstalled. Finally the borehole lock is remounted at the bottom of the borehole cellar, see Fig.11.

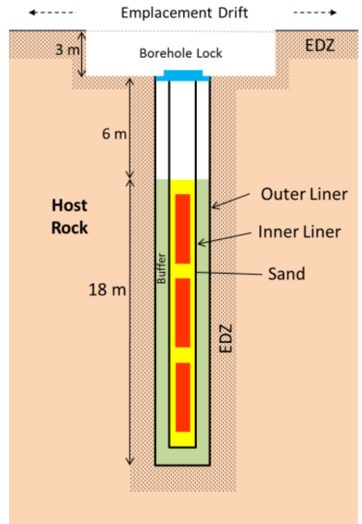

Fig. 11. Schematical design of the re-opened borehole (13)

Retrieval of the waste canisters from the vertical borehole is practically a reversal of the emplacement process. This process was already unintentionally tested during the demonstration tests in 2009 (5). The test facility was equipped with one dummy canister and a 10 m artificial borehole (steel tube). The dummy was removed by the emplacement device after every emplacement test. Overall, 1,000 emplacement and retrieval processes were performed. The remaining technical challenge is the backfill removal. Because of gravity, backfilling is quite easy. The reversal, however, is more complex. DBE TECHNOLOGY GmbH developed a new suction device to handle the backfill removal. The device has the same outer dimensions as the BSK canister. This allows handling of the device with the transfer cask and emplacement device. This way, the borehole is always separated from the remaining facility and provides a good shielding of the canisters. The device's main components are a storage area, a fan, and an electric drive, see Fig.12. Energy is supplied via an additional cable.

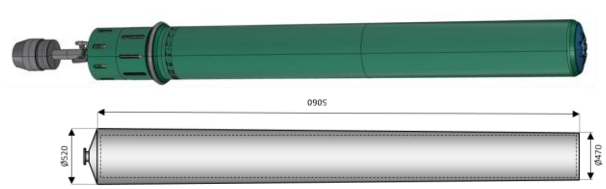

Fig. 12. BSK-R canister (below) and new suction device (top) (13)

The heat input of the emplaced waste and spent fuel increases the rock temperature over time. Based on the scenario chosen (retrieval after emplacement of all waste packages at the latest), rock temperatures up to 57°C are expected inside the emplacement drifts directly above the emplacement boreholes. Temperatures in the access and main drifts will not be higher than 50°C. These conditions call for an additional cooling effort. First simulations showed that the preferred ventilation concept and the additional cooling measures allow compliance with the temperature requirements given by German mining authorities.

During retrieval, the emplacement drifts will be part of the controlled area again. A steady radiological monitoring program including exploration drilling before excavation will monitor the radiological conditions during excavation and opening of the boreholes. All excavations are ventilated by a blowing duct system, including cooling system. If a better separation of the airflow is needed, sucking ventilation is also possible but leads to an increased cooling effort. In the same way, opening of the boreholes can be realized in a temporary enclosure with separate ventilation.

III.A. Retrieval at Type South

The re-excavation of the already backfilled and sealed main drifts and access drifts correspond to the conceptual design of type NORTH. The re-excavation of the emplacement drift and the exposure of the POLLUX® casks pose a much higher technical challenge. The emplacement drifts of borehole disposal are nearly twice as big as those of drift disposal and the waste packages are located inside. Every POLLUX® cask has to be completely exposed before removal. An increase of the drift diameter is connected to very strict limitations. The current repository design is optimized to a densest packaging of the POLLUX® casks. In the case of drift disposal, the geo-mechanical conditions (width of the drifts and thickness of the pillars) are more important than the thermal restrictions to determine repository design. An increased diameter of the drift requires increasing the pillars, increasing the support structures (liner), increasing the emplacement fields and consequently results in a larger foot print. This is not acceptable. Therefore, the retrieval concept developed considers the use of small and partly remote-controlled equipment to allow excavation close to the waste packages and within the old cross-section.

The concept proposed results in higher temperatures inside the underground facilities. Depending on the retrieval scenario chosen, temperatures close to the design temperatures are expected at some locations, see Fig. 13. Finally, the backfill removal and re-excavation are connected to a much higher cooling effort, the need for cooling breaks and a limitation of daily excavation rates. The thermal input also results in higher mechanical stresses and could require a renewal or at least a restoration of the drift liner.

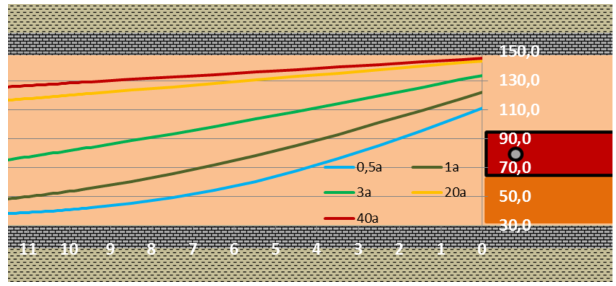

Fig. 13. Expected temperature increase inside the backfilled emplacement drifts over time (14)

To reduce work activities and radiation exposure of the personnel, rails will not be reinstalled inside the retrieval drift. The emplacement device has to be modified for retrieval. An automotive drive is needed. In addition, it is expected that after an undefined disposal time, the use of the trunnions will not be possible. Therefore, a new bearing structure has to be designed. In a first feasibility study, a new modified emplacement device for the retrieval of POLLUX®-10 casks was designed, see Fig. 14. The new device takes up the cask directly at the lateral surface and is able to lift the cask from a socket.

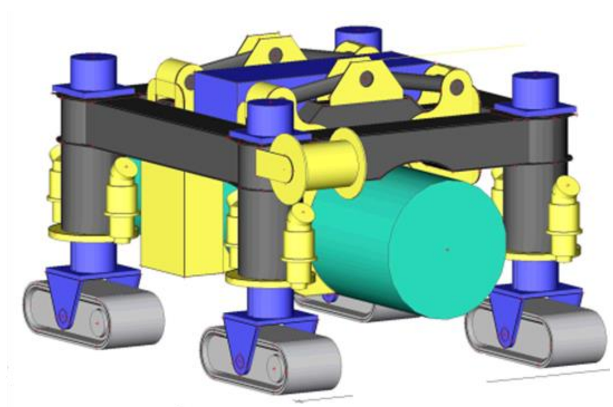

Fig. 14. Modified emplacement device for waste retrieval (14)

The device will transfer the casks to the access drifts and pass them to the rail-bound transport cart. The known and already tested horizontal and vertical transport equipment will transfer the cask back to the surface.

IV. CONCLUSIONS

Within the ANSICHT project, DBE TECHNOLOGY GmbH developed new emplacement concepts and repository designs for both German reference geologies in claystone formations. The concept of vertical borehole disposal applies to huge clay formations, as expected in the north, and the horizontal drift disposal concept applies to Opalinus clay in the south. In addition, the ERNESTA project analyzed the effects of retrievability on both concepts and developed technical concepts for retrieval.

With regard to the new site selection process and the current safety requirements, both projects provide important input for ongoing investigations and further safety assessments.

ACKNOWLEDGMENTS

This paper summarizes the results of the studies "Development of Technical Concepts for the Retrieval of Waste Containers with Heat-generating Waste and Spent Fuel from Repositories in Salt and Clay Formations" (ERNESTA) and "Safety Assessment Methodology for a German High-level Waste Repository in Clay Formations" (ANSICHT). The authors would like to thanks the Project Management Agency Karlsruhe (PTKA) of the Karlsruhe Institute of Technology (KIT) for funding these projects on behalf of the German Federal Ministry for Economic Affairs and Energy (BMWi).

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