# Technical Approach for Retrieving Heat-Generating Waste from Repositories in Salt Formations – 16240

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## ABSTRACT

During the last decades, the management of SNF and HLW in Germany focused on deep geological disposal inside salt formations. The geological barrier of the rock salt is to safely isolate the waste over a period of one million years. In recent years, retrievability has moved into the focus of an ongoing public discussion about waste management strategies. The discussion is driven by socio-ethical, economical, safety and technical aspects. As DBE TECHNOLOGY GmbH has expertise in repository safety and technology, the development of technical concepts for retrieving SNF and HLW canisters was launched in an R&D project. This paper summarizes the latest results concerning the implementation of retrievability into existing emplacement concepts for rock salt in Germany and gives an overview of how retrieval could be realized safely and in a technically reliable manner.

## INTRODUCTION

In 2010, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety issued the new “Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste” [1]. These requirements replace the former Safety Criteria from 1983. The safety requirements apply to SNF and HLW repositories in Germany and all organisations *"… involved in the construction, operation, licensing and supervision of this final repository"* [1]. Within these safety requirements, retrievability has become a design criterion and licensing prerequisite. All new repository concepts have to ensure that the retrieval of the emplaced waste packages is possible. This includes the demonstration of technical feasibility. The necessity to demonstrate retrieval prior to licensing justifies the current considerations concerning retrievability and retrieval.

In Germany, retrievability *"… is the planned technical option for removing emplaced radioactive waste containers from the repository mine"* [1]. This has to be possible *"…during the operating phase up until sealing of the shafts…"* [1]. The safety requirements also stipulate a minimization of mine openings as well as backfilling and sealing of the openings as soon as possible. For a period of 500 years after closure, recovery has to be guaranteed by *"…handleability of the waste containers…"* [1]. To clarify the understanding of retrievability and recovery Figure 1 illustrates the two definitions based on the "Retrievability-Scale" drafted by NEA [2].

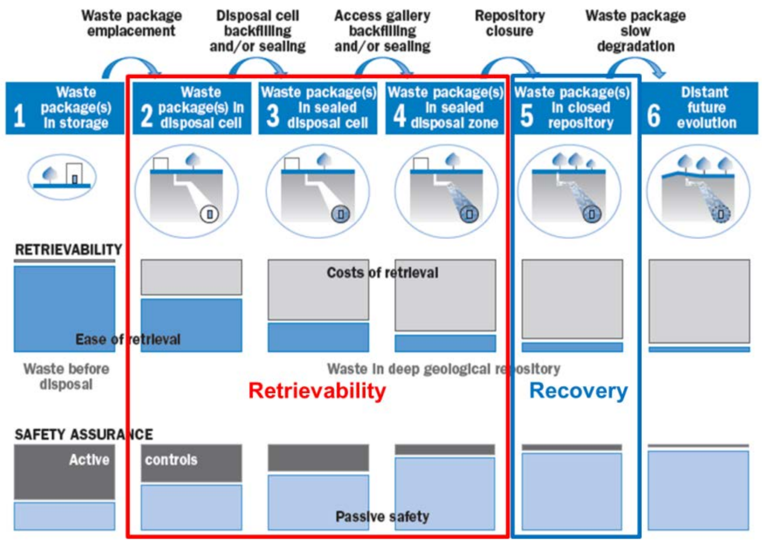


Fig. 1: Classification of German definitions to retrievability and recovery based on [2]

Taking into account the design standards included in the German Safety Requirements, DBE TECHNOLOGY GmbH considers the so-called "Re-Mining" strategy as the most suitable for the retrieval of waste containers [4]. The emplacement of the waste containers and backfilling and sealing of the mine openings have to be carried out as designed in the existing concepts. Nevertheless, it is possible to implement different design optimizations to facilitate retrievability. If a decision to retrieve is made, the already backfilled and sealed mine openings will be excavated again. Due to this excavation, the waste packages will be exposed. Suitable equipment picks up the waste packages and hauls them in reversed operation back to the surface. Arrival at the surface marks the end of the retrieval process. Retrieval comprises just the actual action of waste package removal from the repository.

Based on this strategy, DBE TECHNOLOGY GmbH investigated the implementation of retrievability into the existing emplacement concept "Drift Disposal of the POLLUX® Casks" and "Deep Vertical Borehole Disposal of Spent Fuel Canisters" for the host rock salt. This included an analysis of the operation processes during excavation and retrieval, specification of necessary technical equipment, and an analysis of the expected geo-mechanical and climatic underground conditions. Suitable geo-mechanical conditions and suitable ventilation are fundamental requirements for human comfort and operational safety.

## RETRIEVABILITY FOR DRIFT DISPOSAL OF POLLUX® CASKS

The most recent application of the drift disposal concept was carried out during the "Preliminary Safety Analysis for the Gorleben Site (VSG)" [3]. The retrieval considerations of this current R&D project are based on this repository design, which considers the known geology at the Gorleben site and includes a complete thermal design. The safety requirements [1] had to be applied several months after project start of VSG. This is why the already completed VSG considers retrievability only at a first conceptual design.

Due to the still ongoing discussion and site selection, the occasion, conditions and timing for retrieval are not known. To cover all possibilities, the following considerations assume that retrieval starts after the emplacement process has been completed. All waste packages are placed inside the drifts, all drifts are backfilled and all drift seals are constructed. The remaining repository openings comprise the two shafts and the underground infrastructure area.

### Emplacement concept, so far

The emplacement level at [3] is located 870 m below surface, in the center of the salt dome. The repository for drift disposal is characterized by two access drifts, covering the complete emplacement area. At regular intervals, cross-cuts between the access drifts create the entries to the emplacement fields. The emplacement drifts branch from the cross-cuts. All emplacement drifts are dead-ended. The maximum length is limited to 250 m. All emplacement drifts are located within the rock salt layer of the salt dome. The repository is designed for a maximum temperature of 200°C at waste package surface. On the right side of Figure 2, the repository layout designed in [3] is shown.

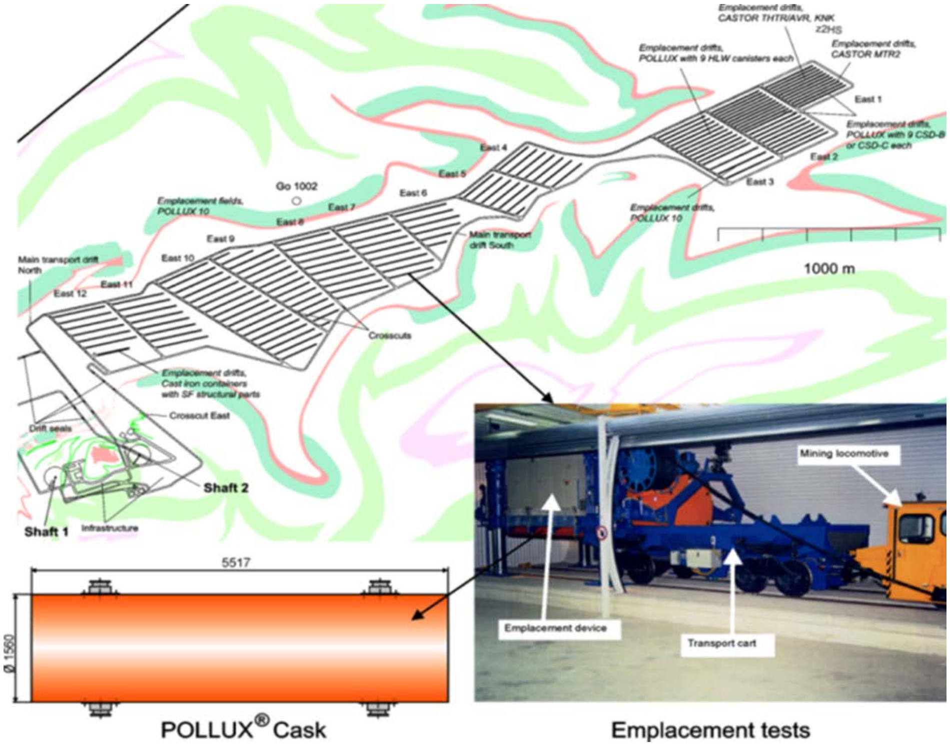


Figure 2: Repository layout designed for emplacement [3] and demonstration facility for Drift Disposal Concept [5]

Inside the emplacement drifts, the POLLUX® casks will be placed directly on the floor. The POLLUX® casks are 5.5 m in length, with a diameter of 1.56 m and a total weight of 65 tons. The remaining space around the casks will be backfilled with crushed salt immediately after emplacement. During progressive emplacement, the emplacement fields already filled and the connecting drifts will be backfilled, too.

The emplacement device was successfully tested by DBE during surface demonstration tests in the mid-1990s [5]. Figure 2 shows the emplacement device and the transport system at the demonstration facility.

**Retrieval concept**

The retrieval of the waste packages starts with a re-excavation of the already backfilled access drifts and cross-cuts. Each emplacement field is covered by two access drifts and two cross-cuts. To simplify underground operations, a third access drift is excavated at the northern side of the repository layout, see also right side of Figure 3. The third drift allows an increase of intake air and a separation of operational processes. Contrary to the emplacement period, a minimization of drifts is not necessary anymore.

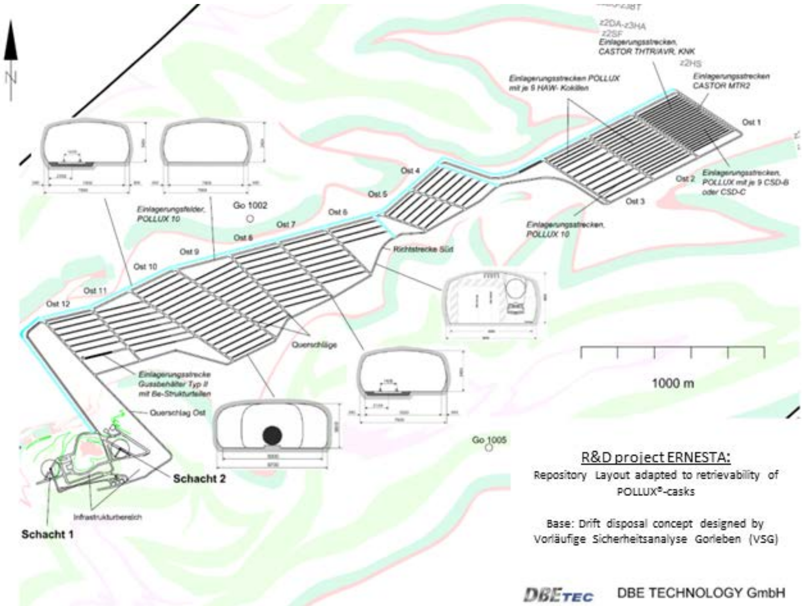


Figure 3: Repository design considering retrievability with illustration of drift cross sections

The excavation of the retrieval drift is divided into three steps, see Figure 4. The excavation starts at the cross-cut averted from the shaft. First, a sub retrieval drift is excavated by a road header parallel to the emplaced waste packages. The drift provides a safety distance of 0.5 m to the waste packages. The initial position of the waste packages is known from emplacement. Possible deferrals due to thermal impacts and floor lifting are detected by an excavation that is executed in parallel. The sub-drift is connected to both cross-cuts. This improves ventilation and cooling conditions. In the same manner, a second sub-drift is constructed at the other side of the waste packages. The final cross section of the retrieval drift is formed with the removal of the remaining pillar between the two sub-drifts. The pillar is removed stepwise. The waste packages inside the pillar are exposed by a remote-controlled demolition robot. The robot is equipped with quick-change tools, such as hydraulic jacks, brushes and small cutter heads.

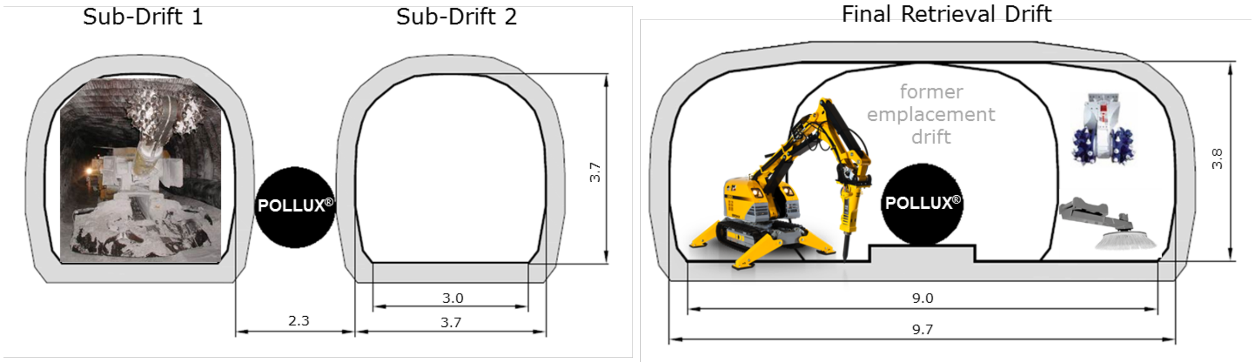


Figure 4: Excavation process of retrieval drift and illustration of equipment used

One measure to facilitate retrievability is the removal of the rails inside the emplacement drifts before backfilling. During retrieval, the relocation of the rails is not provided. Lifting and haulage of the exposed waste package is done by a modified emplacement device. The device hauls the POLLUX® cask out of the retrieval drift. Inside the cross-cut, the device delivers the cask to a rail-bound transport cart. A locomotive transports the cart to the hoisting shaft.

The removal of the rails inside the retrieval drift requires that the emplacement device be equipped with an alternative drive. A second important modification to the emplacement device is the use of a new lifting system for the POLLUX® cask. Contrary to emplacement, lifting of the cask by means of the trunnions is not envisaged for retrieval. It is expected that the load carrying capacity of the trunnions cannot be demonstrated after an undefined time of disposal. It is much easier to design a new lifting device. This device picks up the massive cast iron cask directly. Figure 5 shows two conceptual designs for the new lifting system. The transport cart will be adapted to the new system.

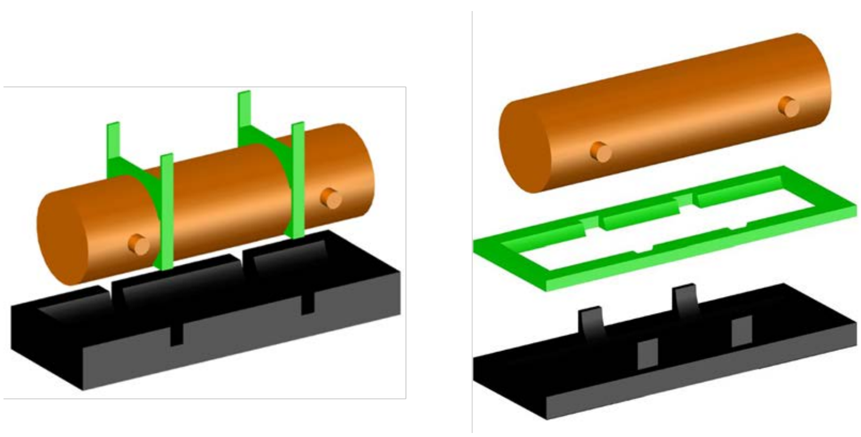

Figure 5: Conceptual designs for the lifting system of the modified emplacement device

The heat input of the waste inside the POLLUX® cask causes a steady increase of the rock temperature. Especially the near field around the casks is influenced by the heat. The temperature increase starts directly after backfilling. A thermo-mechanical simulation allows an estimation of the temperature development after emplacement. During the first years, the near field temperature rises very fast (see Figure 6). Dispersal into the far field depends on the backfill compaction and the development of the heat conductivity.

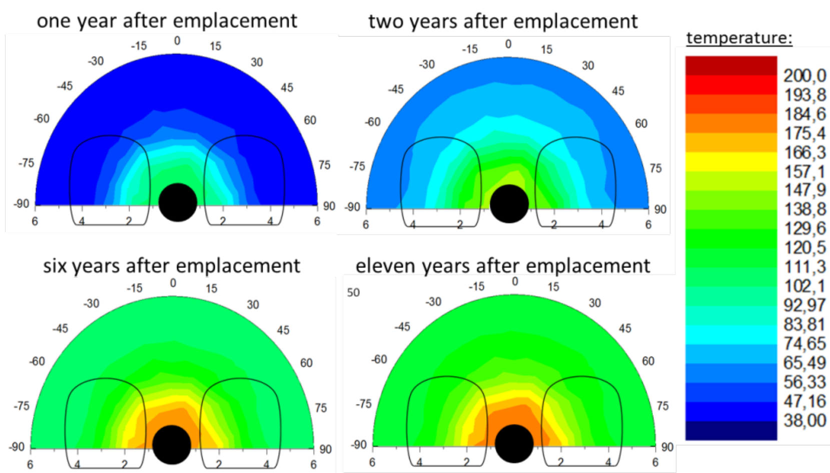


Figure 6: Development of temperature around POLLUX® and location of the sub-drifts for retrieval

The time needed for retrieval corresponds to the operational period of emplacement. The expected retrieval period starts intermediately after emplacement has finished (assumption: 40 years after first emplacement). In some parts of the repository the design temperature of 200°C is reached during the retrieval period considered. Figure 7 illustrates the temperature distribution inside the repository at the start of the retrieval operation. The figure illustrates the very high temperatures next to the waste packages and the high thermal gradients between the areas at larger distance. Any operations inside the very hot areas seem not to be possible at all. Experience in the mining industry gives examples on how to handle high rock temperatures. But the expected conditions next to the waste packages clearly exceed these examples. Furthermore, the situation inside the repository is slightly different from common mines. Because of the high thermal gradients, the excavation of access drifts and even the excavation of cross-cuts will take place in moderately heated areas. The expected temperatures vary widely, depending on the exact location. At the beginning of retrieval, the average temperature at the access drift is approximately 50°C. Over time, local hot spots reach a temperature of 85°C. An additional cooling of the excavations is absolutely essential, especially inside the cross-cuts with expected local hot spots of 100°C.

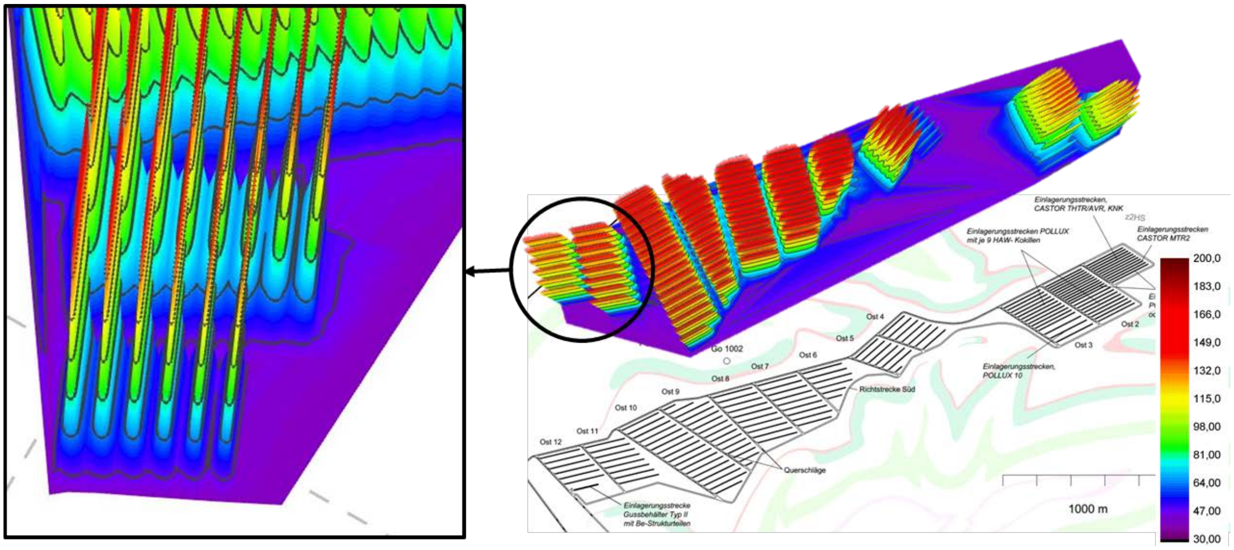


Figure 7: Temperature distribution in the entire repository

The temperatures at the planned location of the retrieval drifts are close to the design temperature of 200°C. To anticipate the results: The current repository design with an optimized waste container distribution has a negative effect on retrievability. The goal of the thermal design was to minimize the footprint of the repository. This includes a complete utilization of the temperature limit but impedes future mining operations at these locations.

Thermo-mechanical simulations were used as an input for modelling the ventilation and thermodynamic simulation. The virgin rock temperature of the branches in the ventilation model was connected to the local temperature of the thermo-mechanical simulation. From the designed ventilation concept, the age of the drifts and the properties of the rock, the climate conditions inside the repository openings can be determined. Additional analytical calculations allowed a verification of the coupling between both models. The projection of the climate conditions and ventilation allows an evaluation of the excavation speed allowed and of the ventilation and cooling effort needed. This allows the definition of boundary conditions and acceptable temperature ranges.

Additional geo-mechanical simulations allow the evaluation of the drift stability and of the expected convergent evolution within the expected temperatures (see Figure 8). From both models (geo-mechanical and thermo-dynamical modelling), a temperature range where retrieval seems possible is defined.

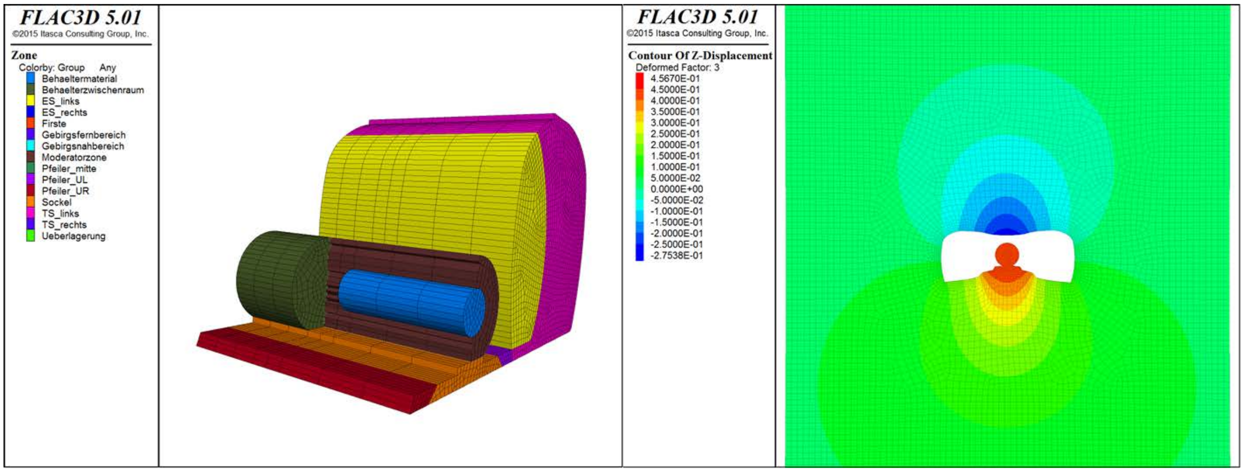


Figure 8: left: 3D-modell of a POLLUX® cask and one sub-drift for retrieval, right: expected displacements inside final retrieval drift

## RETRIEVABILITY FOR DEEP VERTICAL BOREHOLE DISPOSAL

In addition to drift disposal, a second concept of Borehole Disposal was developed in the last decade. The "Preliminary Safety Analysis for the Gorleben Site (VSG)" [3] includes a full repository design for borehole disposal.

### Emplacement concept, so far

The German disposal concept of deep vertical borehole disposal considers the emplacement of spent fuel canisters into 300-m-deep vertical boreholes. The repository level in [3] is designed at the same depth as in the drift disposal concept. The repository layout is covered by two access drifts.

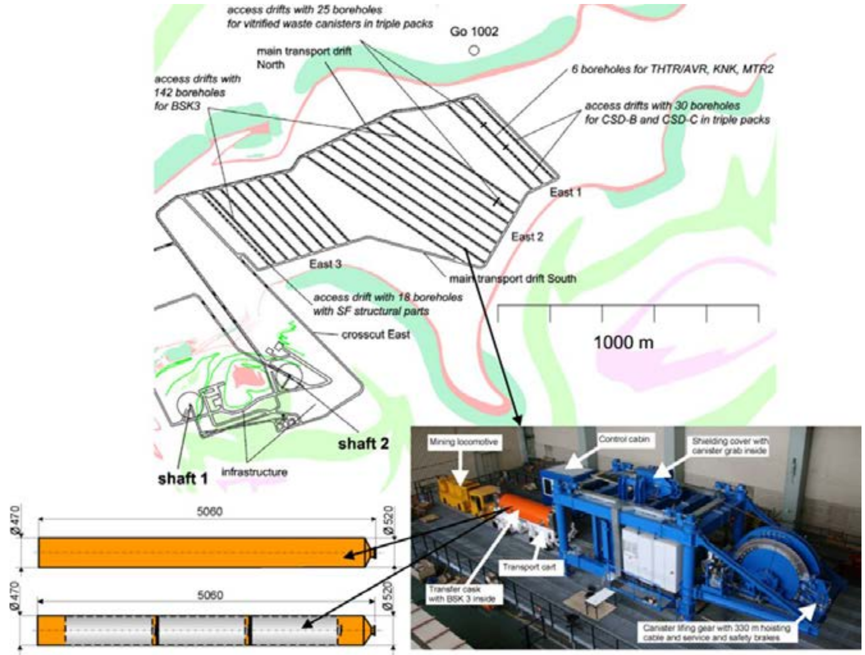


Figure 9: Repository layout and demonstration facility [3]

The emplacement drifts are located between the two access drifts, see also Figure 9. In each emplacement drift, boreholes of 300 m length will be drilled. The emplacement of the canisters will be realized by the already tested emplacement device [6]. The spent fuel canisters are approximately 5 m in length and 0.5 m in diameter. They are not self-shielding. During the transport and emplacement process, the canisters are packed into a shielded cask. This cask is equipped with two locks. A grab mounted to a rope will transport the canisters down the borehole. Each canister will be backfilled after emplacement.

To ease retrieval, the conceptual design of VSG [3] already considers first adaptations. The boreholes are furnished with a liner to resist the rock pressure. The remaining space inside the borehole will be filled with sand. The sand covers the canisters, thus providing a minimum canister spacing of 1 m. The backfill is not a compressible material like crushed salt. Additionally, the spent fuel canister is designed in a cone-shaped manner. These measures improve retrievability.

## Retrieval concept

In the case of borehole disposal, the retrieval concept is a reversed emplacement process. The access and retrieval drifts are at the same locations as during emplacement. Due to the larger distance of the drifts to the waste containers, the expected climatic conditions are more favorable than for the drift disposal concept. During the retrieval period, most of the heat will be concentrated in the areas between the boreholes and will then slowly dissipate into the surrounding areas and the entire working level. At the start of retrieval, the local temperature hot spots are between 45 to 60°C. Over time, the temperature will increase moderately. The highest temperatures are expected at the end of the retrieval process at the center of the large emplacement field. At this hot spot, 85°C are expected 70 years after emplacement of the first container (see also Figure 9). The retrieval concept schedules a fast excavation of all drifts. Considering this, early ventilation and cooling will generate comfortable climate conditions.

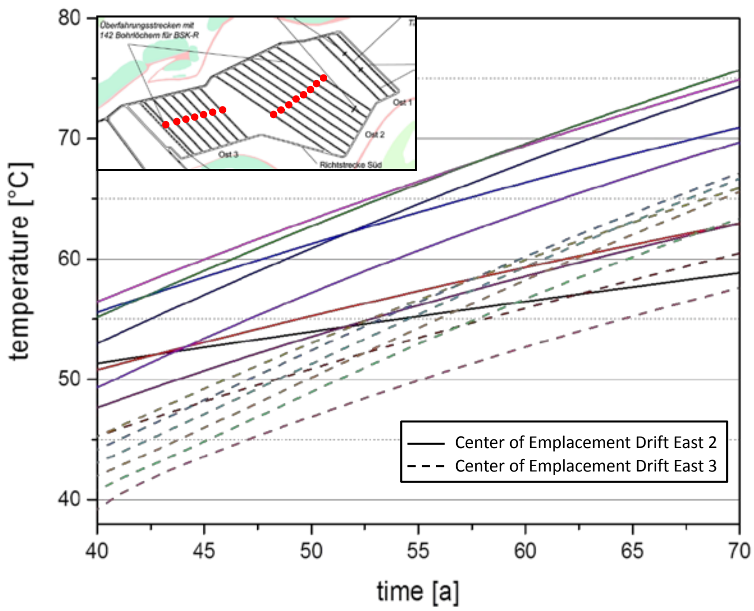


Figure 9: Expected temperature increase at the center of the emplacement drifts

After emplacement, each borehole is closed with a cap, which facilitates detection of the borehole during re-excavation. A borehole lock will replace the cap. The removal of the canisters will be realized by means of the emplacement device. Although this was not intended, the existing prototype already demonstrated its suitability for retrieval. At the demonstration facility only one canister dummy was available. To be able to realize the planned 1,000 emplacement processes, the canister had to be retrieved after each emplacement test. Only several small adaptations are necessary to reach full compliance with the current German regulatory framework and to further facilitate retrieval. Figure 10 illustrates the removal of the canister.

The remaining technical challenge during retrieval will be the removal of the sand between the BSK canister and the steel liner. The sand is needed as a heat spreader to facilitate sufficient heat dissipation into the rock. The sand has to be removed with a specially-constructed suction device that will be lowered into the borehole and suck off the sand step by step.

The new suction device will have an outer diameter of 0.51 m and a length corresponding to the waste canister. It will be transported in its own transport cask. This promises a constant separation of the borehole interior from the remaining repository. The suction device consists of three major parts, i.e., suction intake, reservoir, and fan. The suction intake is centered at the base to place it on the head of the canister. Inside the device, a small suction line catches the air flow and guides it to the reservoir. A fan at the top of the device produces the required air flow. The suction process is driven by a steady circulation of air through the device and the annular gap between the device and the borehole liner. Additional filters inside the device are not considered. This increases the demands on the fan and requires high resistance against abrasion. When the reservoir is full, the suction device will be pulled out of the borehole and drained. The process will be repeated till the sand above the canister is removed sufficiently. Currently, two sequences are planned. It is not necessary to remove the full amount of sand. When the head area of the canister is exposed, it is possible to pull it out. The cone-shaped design and an additional jogger at the claw ease the process.

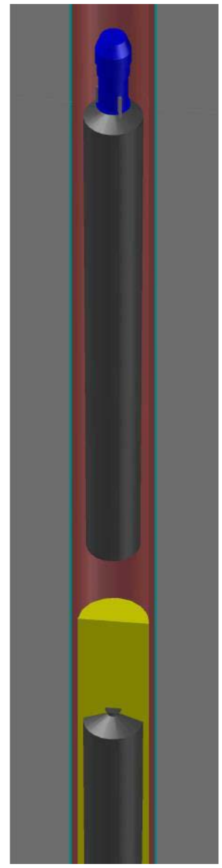

Figure 10: Illustration of borehole during retrieval process

## CONCLUSIONS

The presented study was prepared to refine the existing retrieval concept for drift disposal of POLLUX® casks. The operational processes and the required equipment for retrieval were specified. This includes a first conceptual design of the modified emplacement device. Investigations showed that the current repository design with focus on minimization of the repository footprint leads to an exhaustion of the temperature limit. This impedes the retrieval process. As a consequence, former repository designs have to be adapted.

Retrieval in the borehole concept is a reversal of emplacement. The latest investigations refined the existing concept. A major part of these works was the design of a technical concept to remove the backfill in the borehole. The designed suction device promises a technically feasible system for sand removal. Currently, the device is just a draft on paper; its feasibility still needs to be demonstrated.

Within the scope of the current R&D project, DBE TECHNOLOGY GmbH refines retrieval concepts for emplacement concepts for salt formations in Germany. The investigation shows that the high design temperature of 200°C is not a knock-out criterion for retrievability. The feasibility of retrieval depends rather on the design of the repository mine. The Borehole Disposal Concept allows acceptable conditions for human comfort at the repository level. The current repository design for drift disposal impedes the retrieval process. This is a result of the efforts to minimize the footprint. Retrievability and footprint minimization are conflicting optimization goals. Their advantages and disadvantages have to be weighed up during the design process.

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