An Overview of R&D on Retrievability and Retrieval Technology in Germany– 20462

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ABSTRACT

Retrievability is a term that is included in most radioactive waste management programs around the world. Although national definitions vary, the overall understanding of retrievability concerns the ability to recover waste packages from the repository mine after their emplacement. Different countries may implement retrievability in very different ways, ranging from a built-in reversibility into the emplacement process to the stipulation that retrievability may in no way impede passive safety in the post-closure phase. Germany takes a middle course such that retrievability in a HLW repository (repository for high-level radioactive waste) may have no significant detrimental effect on passive safety.

In Germany, the current siting process considers rock salt, clay rock, and crystalline rock as potential host rocks. Therefore, Research and Development (R&D) has been investigating repository concepts and retrievability in all host rocks. After introduction of retrievability in 2010, existing repository concepts were modified to facilitate retrieval. The changes made comprised, for example, equipping boreholes with steel liners, developing new technologies, and modifying existing emplacement devices.

Apart from retrieval of HLW, retrieval of other wastes from underground repositories that were designed and operated without retrievability in mind, poses major technical and scientific challenges. Currently, studies are under way to investigate the feasibility and costs of partial retrieval of waste from an underground repository for hazardous and highly toxic waste in France, Stocamine. With regard to retrieval, the rock-mechanical conditions are deteriorating rapidly, so time is of the essence.

In the Asse II mine in Germany, about 126,500 waste casks with low and intermediate level waste await retrieval. The repository mine suffers from difficult rock-mechanical conditions and inflow of brine, locally into emplacement areas. The Federal Company for Radioactive Waste Disposal (BGE) is legally required to retrieve all wastes from the Asse. Due to the specific challenges, R&D is needed to develop technical solutions for the safe retrieval from each of the emplacement chambers.

R&D on retrievability and retrieval technology does not only address challenges in radioactive or toxic waste retrieval but may also help to germinate innovation to better master complex underground situations in general, e.g. in deep mining, tunneling, or repository construction.

INTRODUCTION

The core idea of underground radioactive waste disposal is long-term containment. Nevertheless, almost all national nuclear waste management programs mention retrievability of the waste. It often is a regulatory requirement for the licensing of a repository for high-level waste (HLW). In other cases, the respective national waste management agencies have made the strategic choice to include retrievability in their future national safety case. For the purpose of this paper, the definition of the term "retrievability" in [1] will be used: "*Retrievability is the ability in principle to recover waste or entire waste packages once they have been emplaced in a repository in order to allow retrieval should it be required*". Retrievability will only be considered in this paper during the operating phase of a repository, which means up until final closure.

The national approaches to include retrievability in the respective nuclear waste management programs differ in detail. Switzerland, for example, demands that retrieval shall be possible without great effort during the operating phase of the repository and during a subsequent monitoring phase, means intended to facilitate retrieval may not impede passive safety [2]. In France, regulations stipulate retrievability during the exploitation and subsequent monitoring for 100 years. The repository design therefore foresees to emplace waste packages in such a way that they can easily be retrieved by the technology already in use for emplacement [3]. The effect on the repository design of such a built-in retrieval option is quite significant, but the effort of retrieval would be comparatively low. Switzerland and France have thus very different approaches with regard to retrievability. In Switzerland, retrievability may not impede passive safety. In France, retrievability is a major factor in the technical repository design.

Many countries' ideas about the permissible effect of retrievability on passive safety are similar to that of Switzerland. Retrievability may not impede passive safety in Canada [4], Belgium [5], or the United Kingdom [6]. In Germany, the emphasis on retrievability is slightly stronger though not as strong as in France: means developed to facilitate retrieval may generally compromise long-term safety, although not in a significant way and should be kept to a minimum. In addition, the technical effort and time required for retrieval may not unreasonably exceed that of emplacement. The requirement for retrievability in Germany is especially interesting because the current siting process considers clay rock, rock salt, and crystalline rock alike. Research and development (R&D) by BGE TECHNOLOGY GmbH has been developing solutions for emplacement and retrieval of HLW in all three types of host rock. All three host rocks pose very different challenges in terms of quantity and complexity. The continuous coordination between design engineering and aspects of long-term safety has been of utmost importance during the implementation of retrievability in repository concepts, some of which already existed before the requirement came into effect. Retrievability presents an ongoing challenge to scientists and R&D engineers to come up with practical solutions in order to make retrieval feasible and to reduce its impact on passive/long-term safety.

Apart from HLW repositories, the need for retrieval, although rare, does exist. When an underground repository for radioactive or toxic waste has been built and operated without retrievability in mind, a decision to retrieve waste creates a major challenge. In such a case, retrieval often has to start urgently. The boundary conditions are often not very clear nor well documented. The environment from a mining perspective can be difficult. Technical equipment has to adhere to the highest standards of mining and safety with regard to hazards from toxic or nuclear waste. Due to the singular nature of such an endeavor, machinery for special purposes may be essential. If not readily available, it has to undergo the complete process of development, manufacturing, and testing before deployment in retrieval operations. On top of this, all working processes in the underground have to take protection of personnel and environment from radioactivity and/or toxicity into account.

IMPLEMENTATION OF RETRIEVABILITY IN HLW REPOSITORY CONCEPTS IN GERMANY

Possible reasons for retrieval of radioactive waste from a repository for HLW vary and are up to speculation. There may be safety reasons, technical, financial, or social/political reasons. Since these reasons are outside the scope of this study, they are not discussed in this paper. Funded by the Federal Ministry for Economic Affairs and Energy, BGE TECHNOLOGY has investigated retrievability for generic HLW repositories in rock salt, clay rock and crystalline rock, which are all potential host rocks in Germany. The following paragraphs exemplarily describe elements of repository concepts and technological developments that aim at satisfying the requirement of retrievability.

Retrieval of waste casks emplaced in vertical boreholes in rock salt

In rock salt structures such as salt pillows or salt domes, the emplacement of waste casks in vertical boreholes is one option for HLW disposal. A corresponding repository concept was developed in [7] before the requirement of retrievability came into effect in [8]. It foresees the drilling of vertical boreholes from horizontal galleries in the underground. The diameters of the boreholes are only slightly larger than those of the waste casks. In this concept, a hoisting device lowers the waste casks through an air lock into the boreholes. The remaining space in the annulus and between the vertically stacked waste casks is filled with crushed salt. The backfilling takes place alternately with the emplacement of waste casks. On top of the uppermost-emplaced waste cask, a 10 m thick backfill layer of crushed salt allows sufficient radiation protection for the gallery above the borehole. With regard to passive safety, it is expected that the convergence of the rock salt (accelerated by the induction of heat from the waste) will quickly compact the crushed salt backfill and provide fast enclosure of the waste casks within the rock salt. However, with regard to retrievability, the enclosure of waste casks in vertical rows in the rock below the working level of the repository mine poses significant challenges with regard to exposing the waste casks for their safe lifting out of the borehole.

With the compulsory introduction of retrievability by [8] an adjustment of this concept was necessary. [9] and [10] equip the freshly drilled borehole with steel liners of 5 cm thickness. The waste casks are emplaced in the same way as before but instead of crushed salt as backfill, quartz sand fills the voids in the borehole. The quartz sand serves as a good heat conductor and ensures a stable position of the waste casks in the borehole. On top of the uppermost-emplaced waste cask, a backfill of 10 m of quartz sand now allows sufficient radiation protection for the gallery above the borehole. In addition, a cover plate on top of the liner provides further sealing. The design of the steel liner provides enough stability for the expected loads from the surrounding rock und thus ensures stable and clearly defined conditions for retrieval inside the borehole at least up until closure of the repository (Fig. 1).

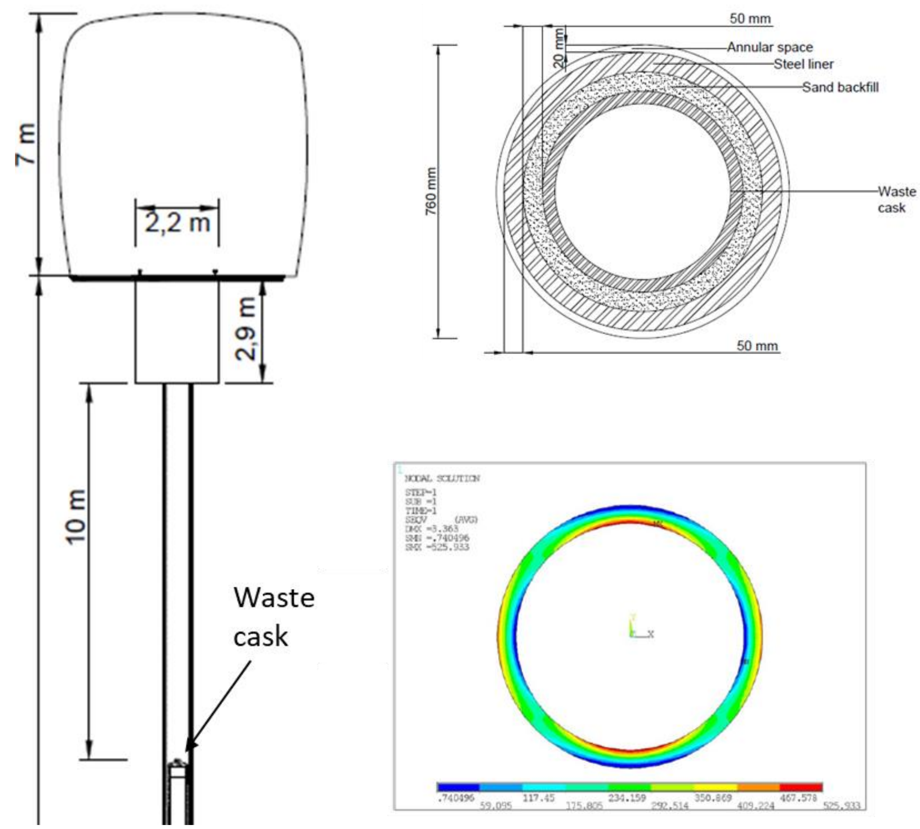

Fig. 1: Conceptual drawing of gallery cross-section, emplacement borehole, borehole cellar, borehole, and upmost waste cask (left), conceptual drawing of borehole cross-section (upper right) and analysis of borehole liner stability in N/mm² (lower right)

[11] recently investigated retrieval of waste casks from such boreholes. It requires several steps:

1. Exposing the borehole opening in the gallery above
2. Opening the cover plate
3. Removing the sand backfill
4. Lifting a waste cask out of the borehole
5. Repeating steps 3 and 4 until all waste casks have been retrieved

Steps 1 and 2 can be performed with the help of standard mining tools. Step 4 requires the use of the hoisting device already used for emplacement. The challenge to remove the sand backfill (Step 3) in the tight space of the borehole was solved by the development of a cylindrically shaped device for extracting the sand backfill by suction. For backfill extraction, the existing hoisting device lowers the suction device into the borehole (Fig. 2). A two-stage axial flow turbine, electrically powered, provides sufficient flow velocity to pick up the sand grains. The suction device also hosts a reservoir for approximately 1 m of backfill from the borehole, which corresponds to the vertical space envisaged between two emplaced waste casks. Emptying the reservoir of the suction device has to respect nuclear safety as the interior of the borehole classifies as an exclusion area.

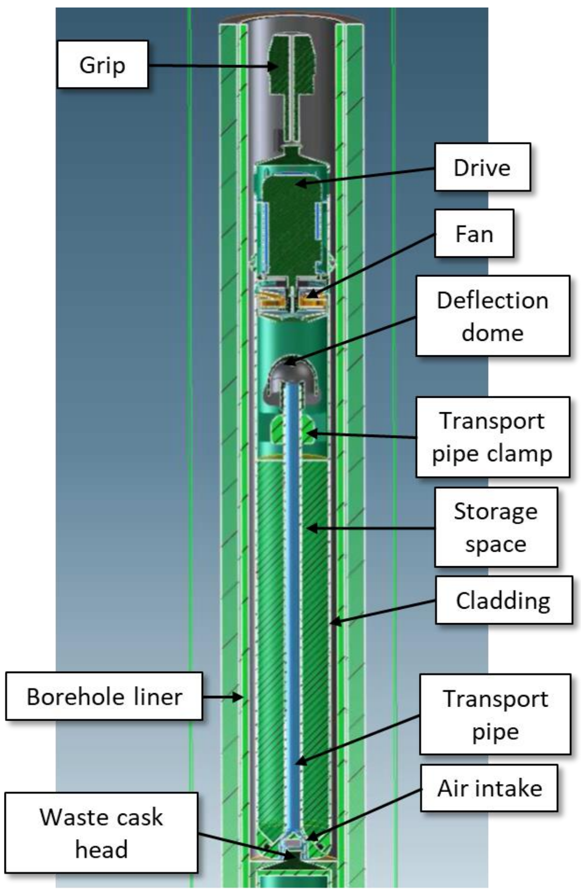

Fig. 2: Conceptual drawing of device to extract sand backfill by suction

Retrieval of waste casks emplaced in drifts in clay rock

Another option for HLW disposal in Germany is to emplace waste casks directly in horizontal galleries. [12] developed a corresponding repository concept. Individual waste casks are mounted on top of a pedestal made of compacted bentonite blocks in the center of an emplacement gallery (Fig. 3). After emplacement of an individual waste cask, the remaining void around it is backfilled with compacted bentonite pellets (buffer). In the concept for emplacement in horizontal drifts, the emplacement device is rail-based. Before backfilling, the rails are removed to reduce the amount of remaining steel in the repository.

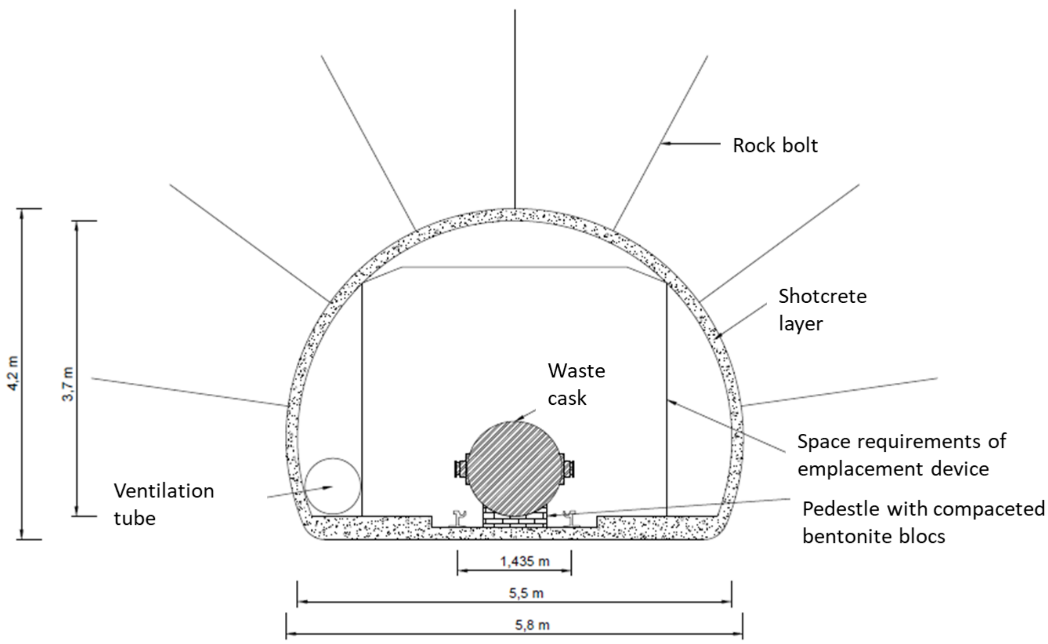

Fig. 3: Conceptual drawing of an emplacement drift for emplacement in horizontal drifts (ongoing R&D) in clay rock

In case of retrieval, removal of the bentonite backfill, or buffer, is possible with standard mining equipment and tools, e.g. by small excavators. In principle, the emplacement device is capable to lift and remove exposed waste casks from the drifts. Due to the removal of the rails before backfilling, modifications to this device are necessary. [11] adjusted the device in order to make it suitable for retrieval. Most notably, crawler tracks replaced the rail-bound wheels. In addition, the trunnions, which were used to handle the casks during emplacement, may have become unsuitable to bear the load of the waste casks decades after emplacement. Therefore, the modifications to the emplacement device also have to entail a means to grip a waste cask around its circumference instead of at the trunnions (Fig. 4).

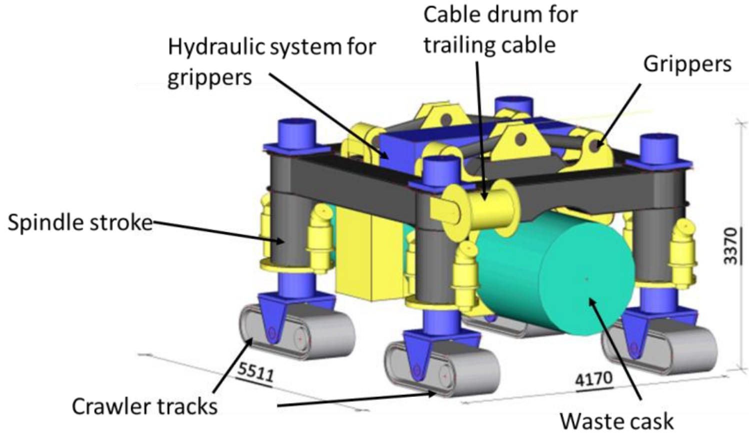

Fig. 4: Conceptual drawing of retrieval device

Reversible emplacement of transport- and storage casks (TSC)

The direct emplacement of transport and storage casks could be a cost- and time-saving alternative to the emplacement of HLW in waste casks specifically designed and built for a certain emplacement option. The respective repository concept in rock salt relies on an emplacement device that is capable to transport the TSCs through the repository mine in order to push them hydraulically into short horizontal boreholes. Each borehole receives a single TSC. The annulus is kept as small as possible in order to achieve good heat transfer between the waste casks and the converging rock salt soon after emplacement. Compared with waste casks for drift or vertical borehole disposal, TSCs pose major challenges for emplacement and especially for retrieval, notably by their large weights of up to 160 tons and high thermal outputs. A comprehensive investigation concerning the retrieval of TSCs does not yet exist. An ongoing R&D project that focuses on the further development of transport and emplacement technology (Fig. 5) in the underground has taken a first step with regard to technical development: The hydraulic cylinder of the emplacement device is capable of pushing the waste casks into the borehole. It is modified in order to also be able to pull a waste cask out of a borehole.

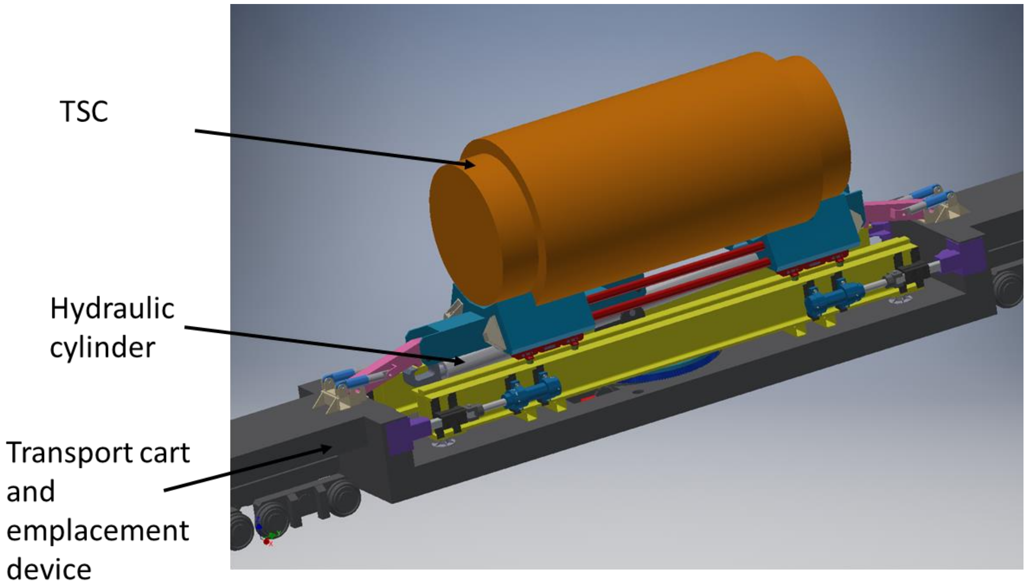

Fig. 5: Conceptual drawing of emplacement device the for direct disposal of TSC (ongoing R&D)

RETRIEVAL FROM THE SUBSURFACE REPOSITORY STOCAMINE, FRANCE

On request of Tractebel Engie, Belgium, BGE TECHNOLOGY takes part in a technical and financial study on the feasibility of partial retrieval of waste from the Stocamine, all the while not endangering the construction of seals for closing the underground site.

Stocamine is a geological repository for hazardous and highly toxic waste located in rock salt and was operated between 1999 and 2002. A fire in the so-called block 15 put an end to the operation in 2002, and in 2003, it was decided to irrevocably stop operations. Following several studies, a license for closure of the site was obtained but it was decided to retrieve the mercury waste from the underground before closure. Between 2014 and 2017, 97 % of this waste was retrieved from the mine.

However, the retrieval of the other waste continued to be in the focus of the public. Hence, further retrieval options have been investigated in several studies since 2018. These studies all take into account the requirement that retrieval has to be realised parallel to the closure operations without impeding them. Another major constraint is the continuous geo-mechanical degradation of the rock salt, which progressively leads to an enclosure of waste packages (mostly drums and big bags) in the converging rock (Fig. 6). Based on this process, it is assumed that retrieval will only be possible until 2029 at the latest.

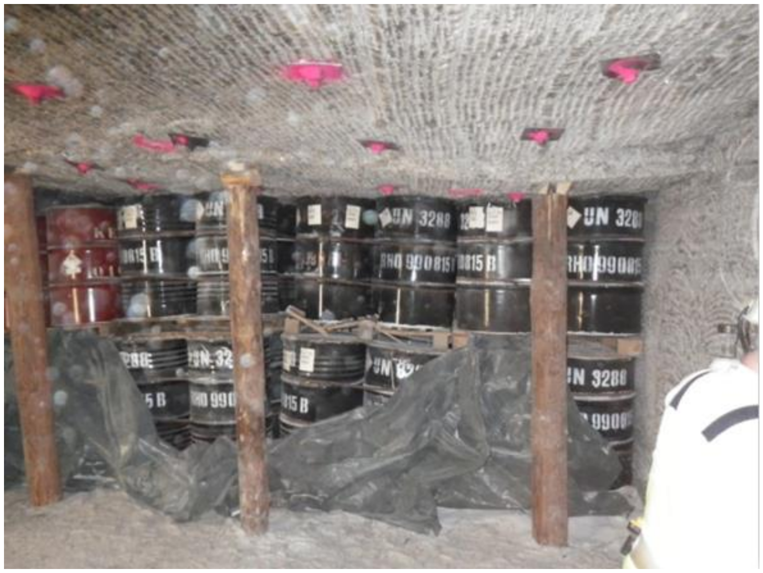

Fig. 6: Photo of waste drums in emplacement gallery; the degradation of the roof started to bear down on them [13]

The enclosure of the waste packages within the converging rock is the main challenge of retrieval. The waste packages have to be exposed by excavating part of the rock that has converged into the gallery. This may include rock from the floor, the walls, and the roof. After exposure, the new contour has to be stabilized at least for the duration of retrieval within this part of the mine. Means to handle the waste drums or big bags safely also need considering: The current concept foresees to seal the advancing retrieval from the infrastructural galleries and to repackage the wastes within the sealed off area.

Currently, solutions for retrieval are being developed. BGE TECHNOLOGY focuses on the rock-mechanical stability of the galleries, modifications to the shaft hoists for waste transport, and contributes to the development of retrieval processes within the emplacement chambers. Scheduling and a cost estimate of proposed measures will complement the technical work.

RETRIEVAL OF RADIOACTIVE WASTE DISPOSED OF IN THE GEOLOGICAL REPOSITORY ASSE 50 YEARS AGO

The geological repository Asse is located below a hilly and forested countryside south of the city of Brunswick, Germany. The hills were formed by salt tectonics approximately 110 million years ago. This process created the salt dome, in which the repository is operated today. The most dominant type of rock in the host rock is the rock salt of the Staßfurt series (upper Permian, 250 – 230 million years ago). Basement rocks and overburden are sedimentary. The basement rocks contain volcanic inclusions.

Much of the underground structure that is still open today was built during the exploitation of potash and rock salt from 1906 to 1964. The mining operation left the salt dome exhausted and geo-mechanically fragile. Between 1967 and 1978, the so-called "Research Repository Asse" was subject to the experimental emplacement of low- and medium-level radioactive waste. In total, around 126,500 casks were disposed of in large emplacement chambers on various working levels of the former mine (Fig. 7 and Fig. 8).

Two main hazards dominate the repository today: geo-mechanical instability and inflow of brine. The instability is caused by the high level of exhaustion of the salt formation due to the former mining activities. Large cavities were excavated and many were left without backfill. A major part of the current activities focusses on stabilizing the cavities and on preventing the surrounding rock masses from further pushing into the underground openings. Most of the inflow is collected by the dewatering system and then pumped to the surface. A small part of the inflow is contaminated and is kept underground. Measures to counter these hazards are the backfilling of cavities and the installation of sealing elements to minimize radionuclide migration in case the repository is flooded.

To ensure long-term safety, the formerly responsible Federal Office for Radiation Protection (BfS) investigated three different options: complete backfilling of the repository, relocation of the waste within the repository to deeper levels, and retrieval of the waste. BfS judged the complete retrieval of waste as the only option to allow a reliable demonstration of long-term safety. The priority of retrieval of the waste from Asse was legally anchored in the Atomic Energy Act in 2013. It applies as long as this is technically possible and radiologically justifiable. Implementing further measures for emergency precautions (sealing), for the construction of new infrastructure, in particular a new shaft, and R&D to allow safe and reliable retrieval are now a priority of BGE, the Federal Company for Radioactive Waste Disposal.

A major part of said R&D is the development of technology required to retrieve the waste from various emplacement chambers. The main functions the technology has to fulfil are uncovering the waste from crushed salt backfill as well as loading and transporting it to the locks that seal the emplacement chambers from the rest of the mine. Means to secure the faces and roofs of the emplacement chambers have also to be arranged. The reliability and safety of the operations must be demonstrated in a suitable manner. According to nuclear law, the state of the art in science and technology is decisive for the protection of the personnel and the environment against radiation. For example, the minimization of dust formation is a major challenge for the work within the emplacement chambers since an entry of contaminated dust particles into the ventilation circuit poses a threat to the adherence to radiation protection thresholds. The retrieval technology thus plays an important role in the licensing procedure for the retrieval as a whole.

As yet, different retrieval concepts have been developed for various emplacement chambers. The development of retrieval technology so far focused on the challenges of the currently accessible Emplacement Chamber 7/725, for which knowledge about the local conditions leave only a comparatively small need for further exploration. In this chamber, waste drums were alternately dumped by a wheel loader and then covered with crushed salt to provide a new driving surface until the chamber was filled up to the current floor level, which is around 10 m above the initial floor. The concept for retrieval in this chamber envisages the use of remote-controlled tripod excavators. R&D work for other emplacement chambers will start in 2020.

Fig. 7: Emplacement technology used for low-level waste. Left: Emplacement of drums in combination with crushed rock salt backfilling in 1971. Right: Emplacement chamber with concrete-shielded drums [14].

Fig. 8: Left: Lowering of a waste drum into the emplacement chamber for Intermediate Level Waste. Right: Emplacement chamber for Intermediate Level Waste [15].

SUMMARY

Retrievability is a term that is included in most radioactive waste management programs around the world. In Germany, Research and Development (R&D) has been investigating repository concepts and retrievability for HLW in all host rocks. Apart from retrieval of HLW, retrieval of other wastes from underground repositories that were designed and operated without retrievability in mind, poses major technical and scientific challenges. These concern the control of difficult rock mechanical conditions, exposing and handling waste casks, radiation protection/protection from toxic substances, need for specialized technical equipment and urgency of retrieval. The challenges are highlighted using the examples of the underground repository for hazardous and highly toxic waste in France, Stocamine, and the Asse II mine in Germany, where about 126,500 waste casks with low and intermediate level waste await retrieval.

REFERENCES

1. Radioactive Waste Management Committee: Reversibility and Retrievability (R&R) for the Deep

Disposal of High-Level Radioactive Waste and Spent Fuel, Final Report of the NEA R&R Project (2007-2011), NEA/RWM/R(2011)4, 2011.

2. Thomas Fries: Thema Rückholung – Schweizer Konzepte ("Topic: Retrieval – Swiss Concepts"), Technisches Forum Sicherheit ("Technical Forum Safety"), 07.03.2013.
3. Agence national pour la gestion des déchets radioactifs (ANDRA): La réversibilité de Cigéo ("Reversibility of Cigéo"), booklet, December 2013.
4. Noronha, J.: Deep Geological Repository. Conceptual Design Report. Crystalline / Sedimentary Rock Environment. APM-REP-00440-0015 R001. NWMO. May 2016.
5. ONDRAF/NIRAS: Development of the requirements management system for the geological disposal of radioactive waste, NIROND-TR 2016-19 E V2, Brussels, 2017.
6. Office for Nuclear Regulation (ONR): ONR Guide NS-TAST-GD-101 Revision 0, Geological Disposal, March 2018.
7. Gesellschaft für Anlagen und Reaktorsicherheit (Global Research for Safety, GRS): Endlagerkonzepte, Vorläufige Sicherheitsanalyse Gorleben ("Repository Concepts, Preliminiary safety assessment Gorleben"), work package 5 – final report, GRS-272, Cologne, 2011.
8. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: Sicherheitsanforderungen an die Endlagerung wärmeentwickelnder radioaktiver Abfälle (Federal Ministry for Environment, nature conservation and reactor safety: Safety requirements for final disposal of heat generating radioactive wastes"), Berlin, 2010.
9. Gesellschaft für Anlagen und Reaktorsicherheit (Global Research for Safety, GRS): Endlagerkonzepte, Vorläufige Sicherheitsanalyse Gorleben ("Repository Concepts, Preliminiary safety assessment Gorleben"), work package 6, final report, GRS-281, Cologne, 2012.
10. Bollingerfehr, W., Bertrams, N., Buhmann, D., Eickemeier, R., Fahland, S., Filbert, W., Hammer, J., Kindlein, J., Knauth, M., Kühnlenz, T., Liu, W., Minkley, W., Popp, T., Prignitz, S., Reinhold, K., Simo, E., Völkner, E., Wolf, J. : Concept development for a generic repository for heat-generating waste in bedded salt formations in Germany, Project KOSINA, Synthesis Report (BGE TEC 2018-13), BGE TECHNOLOGY GmbH, Peine, 2018.
11. Herold, P., Prignitz, S., Simo, E., Filbert, W., Bertrams, N.: Entwicklung technischer Konzepte zur Rückholung von Endlagerbehältern mit wärmeentwickelnden radioaktiven Abfällen und ausgedienten Brennelementen aus Endlagern in Salz- und Tongesteinsformationen ("Development of technical concepts to retrieve waste casks with heat generating radioactive wastes and spent fuel elements from repositorie in salt rock and clay rock formations"), Project ERNESTA, Final Report (BGE TEC 2018-11), BGE TECHNOLOGY GmbH, Peine, 2018
12. Jobmann, M.; Lommerzheim, A.: Endlagerkonzept sowie Verfüll- und Verschlusskonzept für das Endlagerstandortmodell SÜD („Repository concept and closure concept for the repository site model SOUTH") – Technical Report, TEC-19-2016-AB, DBE TECHNOLOGY, Peine, 2015.
13. https://www.mdpa-stocamine.org, accessed 2020-01-09.
14. http://www.BGE.de, accessed 2019-12-11.
15. Bundesgesellschaft für Endlagerung mbH (Federal Company for Radioactive Waste Disposal): Rückholung der radioaktiven Abfälle aus der Schachtanlage Asse II – Konzeptplanung für die Rückholung der radioaktiven Abfälle von der 511 m-Sohle ("Retrieval of radioactive waste from shaft plant Asse II – conceptual design für retrieval of radioactive waste from the 511 m-level), design fundamentals"), BGE, Salzgitter, 2017.