SAFETY STRATEGY AND ASSESSMENT FOR A GERMAN HLW-REPOSITORY IN SALT

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The German Gorleben site is being explored as a potential site for a HLW-repository. For this purpose an exploration mine was built in the Gorleben salt dome at a depth of 840 m below surface. In 2010 the German federal environment ministry initiated a preliminary safety case for the Gorleben site, which has to be finished by the end of 2012 and afterwards will undergo an international peer review conducted under the auspices of OECD/NEA. The ministry determined that this preliminary safety case for the Gorleben site shall be based on the ISIBEL concept. The ISIBEL concept emphasizes the capability of domal rock salt to provide a safe containment of the deposited radioactive waste. Domal rock salt is characterized by the absence of far-reaching interconnected pore-networks. Therefore neither pressure driven hydraulic flow nor concentration gradient driven diffusive flow can occur in the tight parts of this host rock type. This difference between domal rock salt and other host rock types affects the contents of the safety case.

I. INTRODUCTION

The idea to use salt as host rock formation for a geological repository for radioactive waste in Germany traces back to the 60s. Since that time numerous research projects were carried out to investigate the processes relevant for the long term safety of a repository in salt. Looking at the geological conditions in Germany, the host rock type salt shows particularly advantageous features, i.e. its high heat conductivity and its hydraulic tightness.

In 1977 the German federal government decreed to explore the salt dome at Gorleben with respect to its suitability to host a radioactive waste repository. Subsequent to an extensive exploration program of the overlying rock, two shafts were sunk into the salt dome to depths of 840 and 930 m below surface. After having excavated a total of some 7 km gallery length, the government at that time in force decided in the year 2000 to interrupt the exploration of the Gorleben site for the clarification of not site specific questions. Within that exploration moratorium the project “review and evaluation of the instruments for assessing safety of HAW repositories” (ISIBEL) was launched. The project is run by BGR, DBE Technology and GRS. The acronym ISIBEL is formed from the German name of the project. The project deals with the host rock type salt and applies to the situation typical for a salt dome in northern Germany.

The initiative for the ISIBEL project is due to the fact that up to now no safety case for a HAW repository in rock salt has been presented.

II. METHODICAL APPROACH

Within the project the safety strategy *complete containment within a tight geological barrier* was established and an adapted strategy for the safety assessment was developed and deployed. The period for which long-term radiological safety has to be demonstrated was set at one million years.

II.A. Safety Assessment Strategy

The assessment of the long-term radiological safety is based on the consideration of possible developments of the final repository system. In order to determine all repository evolutions that are conceivable within the limits of human rationality, it is necessary to elaborate a comprehensive set of scenarios.

In the past, long-term safety assessments of HLW repositories in rock salt primarily considered conservative release scenarios. In this process, no difference was made between likely and unlikely developments of the final repository system. An example of a conservative scenario considered was to assume the development of a continuous pathway via the Main Anhydrite from the emplacement area up to the overlying rock. It was assumed that along this pathway fluids can be transported down to the waste and radioactive nuclides can be released into the overburden and subsequently into the biosphere. Since then, studies of the Gorleben salt dome carried out by BGR have revealed that the Main Anhydrite there was broken up during the upward movement of the salt on the occasion of the development of the salt dome. Therefore the Main Anhydrite now consists of isolated blocks floating in impermeable rock salt. For this reason, a continuous pathway via the Main Anhydrite from the emplacement area to the overburden doesn't exist.

The preferential consideration of conservative release scenarios has the serious disadvantage of not appropriately emphasizing the advantages of salt as host rock namely its isolating capacity. Although in past projects the confinement of the waste was considered to be safe in the long term due to the impermeability and the self-healing properties of rock salt, the systematic demonstration of safe confinement was not the primary goal of the safety assessment but the elaboration of conservative release scenarios. This approach has considerably complicated the communication of the advantages of the safety concept concerning the encapsulation of the radioactive waste in impermeable rock salt.

Thus, a safety assessment concept was developed that takes full account of the advantages of rock salt. In this concept the main focus of the long-term safety assessment is the demonstration of the long-term safe confinement of the waste through the demonstration of the integrity of the geologic barrier and of the geotechnical barriers. The evaluation of releases is done for those developments of the final repository system for which an impairment of the barrier integrity and therefore the development of a continuous pathway for radionuclides cannot be ruled out.

II.B. Safety Concept

The safety concept is based on the attempt to design the repository layout in such a way that the integrity of the geologic barrier, i.e. the Main Salt of the Staßfurt layer (z2HS), can be demonstrated. For this purpose, the emplacement cavities must be located at sufficient depth and at a suitable distance away from potential fault zones or strata boundaries. An essential boundary condition is the temperature criterion of 200°C max. in order to prevent heat caused alterations of the geologic barrier.

The entire void volume of all boreholes, drifts and galleries in the final repository mine will be backfilled with crushed salt. The crushed salt will be compacted by convergence of the surrounding salt rock. During compaction, the porosity and permeability of the crushed salt decreases until, in the long run, it has the same barrier properties as rock salt.

The drifts and the access areas to the emplacement sites will be sealed by means of shaft and drift seals. These geotechnical barriers must be placed and – as regards their hydraulic resistance and long-term stability – designed in such a way that brine intrusion to the waste via the shaft and the drifts will not occur in probable repository evolutions. The geotechnical barriers must persist functionally until the compacted crushed salt can ensure the sealing of the drifts. The compliance with these requirements has to be demonstrated by the engineering-based assessments of the barrier integrity (Fig. 1).

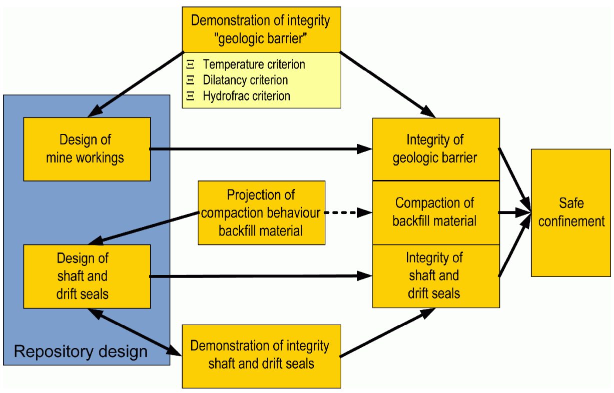

Fig. 1. Safety concept "Safe Confinement".

No special requirements are made on the integrity of the containers during the post-closure phase. Possible additional measures for the retention of radionuclides in the event of brines reaching the waste are not envisaged.

III. RESULTS

The results of ISIBEL are being continuously published, a number of 15 reports has been released by 2010.

III.A. Geological Model of the Reference Site

To demonstrate the applicability of the safety assessment strategy it was deployed to a repository at a reference site. For this reference site a geological model was generated, which comprehends the description of the geology and hydrogeology. The data was compiled based on the results of the explorations already carried out at the Gorleben site (Ref. 1).

The structure of the salt dome at the reference site is composed of rock salt of the Zechstein series z2 to z4 (Staßfurt, Leine, and Aller series). The primary thickness of the salt layers before the formation of the salt dome was approx. 1080 to 1330 m.

The development to form the salt dome mainly took place within the period from the Triassic to the Late Cretaceous epochs. The internal structure of the salt dome is characterized by a significant folding of the series of strata. As a consequence of the salt uplift, the competent strata of the Main Anhydrite were broken up into isolated blocks.

In the Gorleben salt dome, and generally in all salt domes in Germany composed of strata of the Zechstein series, two different deformation levels exist. One level consists of rock salts of the Staßfurt series (z2) and the other consists of the younger strata of the Leine and Aller series (z3 and z4). All in all, four different tectonic-stratigraphic units can be distinguished at the reference site. Unit one comprises the NW flank of the salt dome with strata of the Leine and Aller series. In SE direction, the dome continues with unit 2 which forms the core zone of the salt dome and consists of a simply structured anticline of the Main Salt of the Staßfurt series. In SE direction it is followed by Unit 3, comprising the SE flank of the salt dome, which outlines a marked inverse basin and contains z3 and z4 strata. Unit 4, a salt overhang in SE direction adjacent to unit 3, predominantly consists of overthrust faults of Main Salt from the core zone. The described layout of this salt dome profile can be explained by the movement history of the uplifting salt. During the diapir period, the remaining, more slowly creeping salt rocks of the Leine and Aller series were overthrust by the Main Salt of the Staßfurt series, which has better creep properties and which subsequently formed a salt overhang over the older adjoining rocks of the Upper Cretaceous series, at least in SE direction. During this process, the rock salts of the z3/z4 series were shaped into an inverse basin.

In the interior of the salt dome, various brines and gases were found that are limited to specific horizons and bound to regional joint deposits (e.g. Main Anhydrite, boundary z2/z3) due to stratigraphic and structural conditions. The potential emplacement areas in the core of the salt dome (Main Salt of z2) are almost completely free of such inclusions. During the salt uplift, the fluids were fixed in their current positions and can be determined to be older than the Upper Cretaceous, i.e. at least 100 million years old.

From the point of view of tectonics, the reference area is regarded as having been stable as of the later Tertiary. Only slight subsidence movements are expected during the reference period. Another salt uplift is not expected under the given conditions.

Adjacent to and above the salt structure, rocks with differing facies developments from the Triassic epoch to the Tertiary can be found. Their structure was shaped by the salt uplift. The upper sandy and clayey layers are from the Quaternary period. They are particularly thick in a glacial channel that crosses the salt dome and cuts through older rock formations, and in some parts they lie directly above the salt level. Depending on possible hydraulic and geochemical changes, these rock deposit conditions and a permeable cap rock still allow for a leaching of the rock salt during the reference period. It is expected that the leaching rates will reach average values in the range of several hundreds of millimeters per year.

The Tertiary and Quaternary cap rock strata in the surroundings of the Gorleben salt dome form a system of aquifers and aquitards which has a maximum thickness of 430 m. The characteristic hydrogeological structural element in the cap rock of the salt dome is the Gorleben channel.

From a hydrogeological point of view, the strata above the salt dome and in the rim synclines can be divided into an upper and a lower main groundwater level which are separated hydraulically by aquitards. Lower lignite sands and channel sands from the Elsterian period form a lower aquifer which is hydraulically connected in the north and south of the salt dome, and the sediments of the Weichselian and Saalian stages form the upper aquifer. These two systems are separated by aquitards of Hamburg clay and of the Lauenburg clay complex. The separating layers are uninterrupted in the area of the Gorleben channel and the area north of the Elbe river, while in the south-east and north-west there are large gaps in the separating layer so that both aquifers are in direct contact with each other.

III.B. Repository Layout

An existing reference concept for the disposal of waste from reprocessing (HLW) and of spent fuel elements in salt was refined. During the further devolopment of the concept, four major fields were considered: the prospective waste quantities, a mine layout tailored to these quantities, the transport and emplacement technology, and the geotechnical barriers.

III.B.1. Radioactive waste inventor

The amount of high-level and heat-generating radioactive waste determined within the scope of this project is based on the prospective waste quantities stated in the draft of the National Disposal Plan. This plan is based on the termination of the use of nuclear energy in accordance with the consensus agreement between the German Federal Government and the power supply companies of June 14, 2000. The amount of waste due to the recent agreement of the government and the electricity companies on the extension of reactor lifetimes has to be added. The quantity breakdown was updated by consulting the main companies under obligation to dispose of radioactive waste (main waste producers).

The waste resulting from the reprocessing of spent fuel elements includes HLW canisters (CSD-V) with vitrified high-level radioactive fission products and feed sludge, vitrified medium-level radioactive decontamination and rinsing waters (CSD-B), and compacted medium-level radioactive fuel element cartridges, structural parts, and technological waste (CSD-C). The quantity breakdown includes the HLW canisters produced at the vitrification plant of the Forschungszentrum Karlsruhe (Karlsruhe Research Centre) as well as the waste from reprocessing being returned from England and France. BN-GS (British Nuclear Group Sellafield, formerly BNFL British Nuclear Fuels) returns waste from reprocessing in the form of HLW canisters only. AREVA-NC (formerly COGEMA, La Hague) returns both, HLW canisters (CSD-V) and medium-level radioactive waste from reprocessing (CSD-C and CSD-B). In this project, the quantity of fuel elements to be disposed of is assumed to amount to a total of 10,678 tHM coming from PWR, BWR and from PWR of Russian design (VVER-PWR). It is intended to emplace waste from reprocessing directly in boreholes, i.e. without additional packaging. For the fuel elements originating from nuclear power reactors (PWR, BWR, VVER-PWR), drift disposal in POLLUX casks and, alternatively, borehole disposal in fuel rod canisters (BSK) is considered. For CASTOR casks of the AVR/THTR, MTR 2 and KNK (compact sodium-cooled nuclear reactor) type containing fuel elements from research reactors, drift disposal is primarily considered; reconditioning for emplacement in vertical boreholes would be subject to further investigation.

If the fuel rods extracted from spent fuel elements from nuclear power reactors are disposed of in POLLUX casks, the number of waste packages will amount to a total of 13,795 pcs. If, alternatively, BSK were used, the number of waste packages would amount to a total of 18,567 pcs. When using POLLUX casks, the total mass of the waste packages is estimated at 153,990 Mg and the total volume at 25,674 m³; using BSK, the total mass of the waste packages would be 57,195 Mg and the total volume 9,008 m³. The inventory of the total activity is estimated at a total of approx. 6.2E+20 Bq. The main proportion of activity is contained in the spent fuel elements from nuclear power reactors and the HLW canisters (Ref. 2).

III.B.2. Design of a Mine Layout

The safety concept of the final repository is based on the prerequisite that – with regard to the design and layout of the underground constructions – the integrity of the geologic barrier can be demonstrated. This means that the design and layout of the underground excavations required for the given waste quantity must be planned in such a way that the resulting stress conditions in the geologic barrier does not exceed the strength of the rock salt.

An important boundary condition for the design of the mine layout is the temperature criterion of 200°C, which must not be exceeded at any time and anywhere in the entire final repository. This requires a systematic planning of the layout of the emplacement drifts and boreholes and their filling with waste containers. Therefore, the respective drift and borehole spacing is determined in advance by means of thermal calculations. Appropriate calculation models are available for this purpose.

Based on the existing repository concept for the Gorleben site, two alternative mine layouts were designed based on the aforementioned quantity breakdown of waste packages. In one version, a combined emplacement of POLLUX casks in horizontal drifts and of HLW canisters and CSD-C in vertical boreholes was planned. As an alternative to this layout, the disposal of all types of waste containers (spent fuel rods in fuel rod canisters (BSK 3) as well as HLW canisters and CSD-C) in vertical boreholes was planned. The results of these designs were made available for the long-term safety assessment in order to carry out release calculations taking into account the revised waste quantities and the adjusted mine layouts.

The final repository is planned at a depth of 870 m and will be operated via two shafts, one of which serves for the transport of the disposal containers and at the same time for the discharge of return air. The second shaft, which is used for fresh air supply, serves for the transport of personnel and materials. The mine workings connected to the shafts must be equipped with separate ventilation systems for the nuclear-related areas (container transport and emplacement) and for the mining-related areas (drift excavation and backfill transport).

In addition to the aforementioned thermal boundary condition, a number of mining-related boundary conditions (e.g. minimum width of pillars, safety pillars in shafts, etc.) must be observed. As a consequence of the operational and thermal boundary conditions, the containers are emplaced rearwards, i.e. disposal starts in the fields farthest from the shaft and the corresponding drifts and boreholes are the first to be backfilled and sealed.

In the detailed plans of the mine workings, maximum lengths for emplacement drifts (250 m), and minimum lengths for drift seals (15 m) and minimum container-to-container distances (1 m) are assumed. When the geologic conditions in the emplacement area are known in detail, these assumptions have to be substantiated in more advanced designs. For the drift disposal of POLLUX casks, the 870-m level was selected as emplacement horizon; HLW canisters, CSD-C as well as BSK 3 are emplaced in 300-m-deep vertical boreholes that start from this horizon. Neither CSD-B nor fuel elements from research reactors, which are stored in Castor casks, were taken into account in the design of the mine layouts.

III.B.3. Transport and Emplacement Technology

The development status of the necessary transport and emplacement technology for POLLUX casks, BSK 3, HLW canisters, CSD-B, and CSD-C was assessed and described based on the two mine layouts described above.

For the concept of drift disposal of POLLUX casks, a rail-bound transport of the disposal container is intended according to [Filbert 1998]. The transport down into the mine is effected by means of a shaft hoisting system that is designed for this purpose and can hoist a payload of up to 85 tons. For the underground transport, a battery-operated mining locomotive and a transport cart specially developed for POLLUX casks are used. In the emplacement drift, the container is lifted off the transport cart by means of an emplacement device and subsequently placed on the drift floor. The components required for this type of transport and emplacement were developed and tested up to approvability within the scope of two R&D projects (simulation of shaft transport, handling tests for drift disposal) in the 1990s and are available for use.

Components for the transport and emplacement of HLW canisters were first developed and tested in the Asse research mine during the 1980s within the scope of R&D projects. These components were an individual shielding container for the safe transport of canisters from the surface to the emplacement site and an emplacement vehicle to extract the HLW canister from the shielding container and to emplace it in a borehole. Rail-bound transport was not intended at that time. When a new transport and emplacement technology for POLLUX casks was developed and tested, however, a fundamental decision in favour of rail-bound transport was made out of safety-related considerations.

In a recent project, a technology for BSK emplacement, ready for approval, was demonstrated. With only slight modifications, this technology, which employs a reusable transfer cask for the transport of fuel rod canisters, may also be used for the transport of HLW canisters, CSD-C, and CSD-B, as all these containers have similar geometries (same diameters, same grab appliance, mushroom-shaped protrusion at the head for handling).

A transport and emplacement technology for the final disposal of CASTOR casks containing fuel elements from research reactors still needs to be developed and tested.

III.B.4. Geotechnical Barriers

According to the final repository concept, the shafts and access drifts to the emplacement areas are to be sealed by means of shaft and drift seals. These geotechnical barriers are to be placed and designed in such a way that brine intrusion to the waste via the shaft and the drifts that are backfilled with crushed salt and a subsequent forcing out of contaminated solutions via the same pathway cannot occur.

As part of the decommissioning and closure of the repository mine, the entire void volume of all mine workings will be backfilled with crushed salt which will be compacted due to the convergence of the surrounding rock salt. During this process, the porosity and permeability of the crushed salt decreases so that – over time – it assumes the same properties as the rock salt. The rate of compaction of the crushed salt and the requirements concerning the hydraulic resistance and the life span of the shaft and drift seals deduced thereof, may result in special requirements on the borehole seals.

The requirements on the hydraulic resistance of the barriers are determined by the calculations on radionuclide transport carried out in the long-term safety analysis. Adequate structural integrity, crack restriction, and stability have to be demonstrated and documented for each barrier to be considered. Furthermore, their producibility has to be demonstrated. The documents on compliance with the required hydraulic resistance for the sealing elements, for the contact zone, and for the excavation damaged zone constitute the demonstration of integrity for the respective geotechnical structure.

III.C. Assessment of Long-Term Safety

The period for which long-term radiological safety has to be demonstrated was set at one million years.

III.C.1. Site Specific FEP Catalogue

The ISIBEL project partners decided to base the development of scenarios on a site specific FEP (features, events, processes) list, which therefore had to be created within the project (Ref. 3). The NEA FEP catalogue served as a starting point.

The development of the FEP catalogue was completed in particularly close cooperation of the project partners including more than 15 project meetings and a three-day closed session.

Due to the applied scenario development technique, it was necessary to include certain statements in the description of each FEP. These statements include information on whether the FEP directly influences the barriers and which interactions with other FEPs exist. To facilitate the specification of these statements the near field, the drifts and shafts, the host rock as well as the overburden and surrounding rock were considered individually and the future development was divided into chronological sections according to characteristic changes in the thermal output of the waste and to the succession of glacial and interglacial periods.

Two different methodical approaches were pursued and finally consolidated in order to contribute towards the completeness of the FEP catalogue. One methodical approach had the goal of identifying all the FEPs that, principally, may have an impact on the geological evolution at the reference site or on the geosphere of the final repository system, as well as their potential consequences on the waste emplaced. This method may be designated as a 'bottom-up' approach.

Another methodical approach for the identification of FEPs to be considered focused on the issue of if and how brines could be able to come into contact with the waste. All FEPs that play a role in this context were identified and described in this top-down approach.

The bottom-up approach should primarily be used to identify those FEPs that may be relevant to the site evolution. This contributes to obtaining a FEP catalogue that is as comprehensive as possible.

In the top-down approach, proving that the list of FEPs is complete is difficult. Furthermore, only those FEPs are included in the catalogue that play a role in the scenarios considered. In this method, expert opinions have a direct and major influence on the results.

Regarding the completeness of the FEP catalogue, pursuing and combining different methodical approaches can make a valuable contribution to achieving this goal. With corresponding revision, the FEP catalogue, whose site-specific geo-scientific characteristics were determined according to the data available for the reference site (Gorleben), can be adapted to any possible site where the geologic situation and the final repository concept are similar to the conditions at the reference site.

III.C.2. Scenario Development

The impact of future processes on the integrity of the barriers has to be evaluated in consideration of the interdependency of all active processes. The possible future evolutions of the repository system are described as scenarios, which comprehend all processes relevant for safety.

The scenarios for the assessment of the host rock integrity were deduced as a combination of the mechanical, thermal, hydraulic, and chemical processes that may change the barrier properties of the host rock. This bottom-up approach is based on identifying potential scenarios by combining all available FEPs. The assessment period can be limited to a certain section of the overall demonstration period in order to reduce the number of FEPs to be considered at the same time. The initial state was defined in terms of mechanical, thermal, hydraulic, and chemical boundary conditions. Using this method, the scenarios are generated depending on the safety function of the host rock, thus, it contains a typical element of a top-down approach.

Based on the top-down approach, conceivable scenarios were identified that could lead to the failure of one or more geological or geotechnical barriers. The starting points of these considerations were sequences of events which could make radionuclides be released from the waste and even be transported into the biosphere. As salt is an impermeable type of rock with only a few brine inclusions of macroscopic relevance, high-level radioactive waste emplaced in salt can only come into contact with large amounts of brines under very specific circumstances. In a final repository in salt rock, the waste emplaced can only come into contact with brines from the overburden and surrounding rock if one or more barriers have failed. Due to the choice of site and the design and layout of the final repository mine with its geotechnical barriers, a failure of the geological barrier or of the geotechnical barriers can only occur under specific boundary conditions. Although the probability that such events occur is generally very low, these events cannot be completely ruled out. Therefore, they need to be taken into account when defining the scenarios. A detailed understanding of the conditional probabilities of occurrence of the individual FEPs and of their interdependencies and interactions is therefore required for the safety assessment of the scenarios.

Due to the methods applied in the top-down approach, the scenarios considered can be used directly as a basis for the consequence analysis.

As a conclusion, it can be stated that for scenarios concerning a final repository in a salt formation which is characterised by the tight encapsulation of the waste, a procedure which suitably combines elements of a bottom-up approach with those of a top-down approach seems to be the most appropriate.

III.C.3. Scenario Analysis

During the analysis of the scenarios the impact of the active processes on the integrity of the barriers is determined. The term integrity is used in combination with the geologic barrier to describe the ability of the barrier to permanently prevent the inflow of fluids from the overlying and surrounding rock into the final repository mine as well as to prevent the potential leakage of contaminated fluids and gases from the final repository into the biosphere. Rock salt in a salt dome is dry and impermeable except for potential isolated fluid inclusions. It becomes permeable, if the applied stress exceeds the dilatancy boundary, at which micro cracks are formed within the salt. Comprehensive laboratory analyses of the petrophysical properties of rock salt showed that stress states below the dilatancy limit do not cause any damages, not even in the long term, which means that for stress states in this range, the impermeability of the salt rock is proven. Hence, for the assessment of the long-term barrier behaviour under the impact of mining activities and under the impact of heat input from the waste, all processes must be analysed that can influence the state of stress. For this purpose numerical calculations are carried out. Due to the necessity to provide statements for very long periods of time, geomechanical predictive models must be used that accurately describe the physical processes in the rock that are to be expected in the long term.

In those cases where a release of radionuclides is possible, it has to be investigated, whether the radiological requirements are met. Usually, a radiologically relevant release of radionuclides from a final repository requires that the waste emplaced comes into contact with brines. As a domal salt formation is impermeable and contains only a few brine inclusions of relevant volume, release scenarios for a final repository in a domal salt formation always involve processes or features with low probability.

Developments of the final repository system that were considered in release scenarios, involved the failure of sealing constructions. It was found out that the failure of one single sealing construction, be it the shaft seal or any other sealing construction between the infrastructural part and the access drifts, does not cause any release of radionuclides during the assessment period of one million years. The investigation showed that the failure of the shaft seal has a higher impact on the model results than the failure of a sealing construction in the interior of the mine workings. Only if both types of sealing constructions fail coincidently, water from outside the salt structure can reach the emplacement areas resulting in the release of radionuclides into the geosphere (Ref. 4).

Furthermore, to test the methods and tools, a special scenario was defined, in which a total of six brine inclusions, each with a volume of 100 m^3 is assumed to be present in the host rock, each in contact with an individual emplacement borehole. In this special scenario, which due to the geologic conditions at the reference site and the corresponding explorations is to be categorised as a what-if-scenario, the results of the model calculations always show a release of radionuclides from the mine workings as the solution is contaminated and is pressed out of the mine due to convergence. If the sealing constructions are intact, the amount released during the reference period is very low. If the different FEPs – inflow from a brine inclusion in the host rock and failure of all sealing constructions – are combined in one scenario, the calculations yield significant radiation exposures.

IV. CONCLUSIONS

For the first time, a consistent concept for the safety assessment was developed and implemented that takes full account of the advantages of the final disposal of HLW in rock salt and consequently of its safe confinement. The focus of this adapted long-term safety assessment is the systematic demonstration of the long-term safe confinement of the waste disposed of by demonstrating the long-term effectiveness and integrity of the geological and the geotechnical barriers. Complementarily, an evaluation of release scenarios is carried out for those repository developments for which an impairment of the integrity of the barrier system occurs.

The assessment concept proposed herein is based on a reference site model that takes into account the latest findings of the exploration of the salt dome at Gorleben.

The findings about the geological integrity of the salt barrier and about the block structure of the Main Anhydrite at the Gorleben site are of vital importance in this context. For the probable development of the final repository, a release path via the Main Anhydrite can thus be excluded. At the same time, the release of radioactive nuclides via the Main Anhydrite, often regarded as an all-encompassing reference scenario in the past, became irrelevant. As a consequence, the demonstration of safe confinement has become the core issue of the safety assessment.

The main prerequisite for the demonstration of safe confinement is the demonstration of the integrity of the geological barrier. The analysis of the exploration results for the Gorleben salt dome showed that no relevant geological impacts that could lead to an impairment of the integrity are to be expected during the assessment period of one million years. Furthermore, the criteria have been developed that enable the designing of a repository mine with regard to its depth and distance to the relevant strata boundaries. It is possible to demonstrate the barrier integrity taking into account the geomechanical impacts to be expected. Hydraulic fracturing of the salt barrier can be excluded due to the slow increase of gas pressure.

One major prerequisite for a well-founded determination of design requirements is adequate knowledge of the convergence-related decrease in porosity and permeability of crushed salt backfill over time Currently, reliable predictions are possible for residual porosities down to approx. 10%. For porosities below this value, assumptions should be as conservative as possible.

The identification and subsequent quantitative analysis and evaluation of scenarios, each of which represents one of the possible future developments of the final repository system, are essential components of the long-term safety assessment for a final repository. For this purpose, a systematically developed FEP catalogue for a final repository for HLW in the host rock salt was compiled for the very first time. In addition to this, various methods were investigated with regard to their suitability for the development of scenarios. The knowledge gained in these investigations was taken into account when defining the contents and structure of the FEP descriptions in order to systematically identify those release scenarios that, due to the probability of their occurrence, cannot be ruled out.

For the assessment of release scenarios, well-advanced procedures, models, and programs are available for numerical modelling. They have been tested successfully in numerous examples and are generally suitable to model the relevant processes in the near field, in the far field, and in the biosphere within the scope of the consequence analysis. Together with the demonstration of safe confinement, they form the basis for the long-term safety assessment concept for a final repository for HLW in salt formations.

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