Methodology for Design and Performance Assessment of Engineered Barrier Systems in a Salt Repository for HLW/SNF

***(Paper N°21132*)**

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ABSTRACT

The isolation of radioactive waste in a high-level waste (HLW) repository in salt formations is provided by a multi-barrier system based on a combination of engineered and natural barriers. The natural barrier is provided by salt rock itself, whereas the engineered barrier is comprised of sealing components installed at specific locations in the repository. In Germany, for the long-term safety assessment the integrity of the natural barrier has to be demonstrated for a time period of 1 million years. In parallel, the engineered barrier system (EBS) of a HLW repository has to maintain its structural and functional integrity until the function of the long-term sealing, e.g. the backfill material, is completely established. Currently, a functional period of 50,000 years, up to the next ice age, is considered for EBS.

Based on an extensive knowledge and experience with respect to geotechnical barriers in salt formations, BGE TECHNOLOGY GmbH and SNL are jointly developing a methodology for the safety assessment of EBS for an HLW repository in salt in the R&D project RANGERS. The developed methodology is based on the identification of impacts and loads on the EBS by use of a FEP catalogue and scenarios. Thus, the methodology considers the interactions between the integrity of the EBS and its role in the general performance assessment of repository systems. This methodology will ultimately be used to demonstrate performance assessment of a common generic repository system. The obtained results will allow an evaluation of the proposed methodology.

In this conference paper, the authors describe the RANGERS project in general terms and give an overview of the methodology for design and performance assessment of EBS in repositories in salt.

INTRODUCTION: THE R&D PROJECT RANGERS

The EBS includes geotechnical structures used for the closure of repositories for high level waste (HLW) as well as spent nuclear fuel (SNF). They are elements of a multi-barrier system together with a part of the salt host rock as geological barrier (containment providing rock zone, CRZ). The main purpose of EBS is to ensure - in combination with the geological barrier - the waste isolation (confinement in a designated domain) over a defined functional period until the long-term sealing has gained its function [1]. During that period, the EBS has to maintain its structural and functional integrity. Recently a functional period of 50,000 years, up to the next ice age, is considered in Germany [2]. During the ice age, it is expected that the hydro-geologic and topographic conditions will change significantly so that an accurate prediction of the geochemical composition of the inflowing waters becomes impossible.

In Germany, several safety and performance assessments of repositories in salt formations have been carried out in the course of several research projects. As part of the preliminary safety analysis for the Gorleben Site (VSG), an assessment method for the integrity of sealing elements in an HLW/SNF repository in a domal salt formation was developed [2]. Thus, it was possible to carry out a comprehensive verification for a shaft seal design for the Gorleben site. In the ELSA project, a modified design of shaft seals for HLW repositories was developed by Kudla et. al. [3]. Further research projects such as KOSINA [4] and DOPAS [5] investigated different aspects of geotechnical closure systems.

Apart from generic concepts, BGE TECHNOLOGY GmbH has a broad experience with design and construction of drift seals for the Morsleben repository and the Asse mine.

In the US, Sandia National Laboratories (SNL) has a long history of research, design, and engineering of nuclear waste repositories in salt host media. SNL led the design and testing of geotechnical barriers (i.e., drift and shaft seals) at the WIPP [6] [7] [8] [9] barriers and seals in a generic HLW repository in a bedded salt host media. Updated designs concepts for a generic, i.e. not site specific, HLW/SNF repository in salt have been produced in recent years [10] [11] [12].

Within an ongoing joint project, BGE TECHNOLOGY GmbH (Germany) and Sandia National Laboratories (US) are combining their effort to develop a common methodology for the design and performance assessment of EBS. This methodology will be tested to develop a repository design based on a generic site in a salt host formation.

The project RANGERS is an acronym for "Methodology for design and performance assessment of geotechnical barriers in a HLW repository in salt formations". It aims to develop a methodological approach for the design of the EBS and how to represent the EBS in the preliminary performance assessment. The methodology will be based on the existing knowledge and experience in EBS design and construction from BGE, BGE TECHNOLOGY GmbH, and SNL. The methodology will then be used on a selected generic repository system in Germany. Four project sub-goals are formulated:

1. Compilation of existing knowledge and experience for the design geotechnical barriers and compilation of new concepts and technologies on the subject of geotechnical barriers.
2. Development of a methodology based on the state of the art in science and technology for the design and verification of geotechnical barriers.
3. Preliminary design and verification of the geotechnical barrier system for the selected repository system based on the developed methodology.
4. Comparison of design results according to the new methodology with results of previous design and assessment.

The current priority roadmaps of DOE's Spent Fuel Waste Science and Technology (SFWST) campaign, as well as of Federal Ministry of Economics Affair and Energy of Germany, highlight the value of international collaboration. BGE TECHNOLOGY GmbH and SNL envisage therefore a deep collaboration in the project. The expertise of BGE TECHNOLOGY GmbH on numerical based design of EBS will be used for the dimensioning of the components of the EBS. The expertise of SNL in the performance assessment of large repository system will serve to analyze the geochemical evolution and radionuclide transport through the EBS in the in the selected generic repository.

METHODOLOGY

Overview

In the US and Germany, design concepts have been analysed for salt domes (i.e. Gorleben site) and bedded salt formations – notably for WIPP in the US (for transuranic waste) and generic German sites (via the German KOSINA-project). Basing on the international methodological standards, the evolutions of HLW/SNF repositories in salt formations are analysed in terms of a safety assessment, which means an assessment of the total system performance [13] [14]. Safety and safety demonstration concept for repositories in salt take full credit of the favourable properties of salt formations [15] [16]. The German concepts are based on the safe containment of radioactive waste in a specific part of the host rock formation (the containment providing rock zone – CRZ), in combination with the EBS as well as the backfill (crushed salt) to seal the perforation of the geological barrier by the mine excavations [1]. The long-term safety of the mined excavations will be ensured by backfilling with crushed salt. Crushed salt acquires its sealing capacity through compaction due to the convergence of the rock. Convergence increases by the heat produced by the disposed waste and by humidity in the repository and the water content in the rock. After several thousands of years, it is expected that crushed salt will reach the same mechanical and hydraulic properties as the intact salt host rock. Until this time, the EBS ensures the waste isolation.

The following methodology for the design and performance assessment of EBS in the salt repository uses all aspects of design and the integrity assessment of the EBS, as well as their treatment in the scope of an eventual integrated total performance assessment. Starting from the regulatory framework, a safety concept is defined. This is a basis for the development of a repository concept and a sealing concept for the selected geological site. The evolution of the resulting repository system can be analysed by developing a Features, Events, and Processes (FEP) catalogue that describes all properties and evolutions that occur in the repository system over the performance period. Based on the FEPs, the relevant loads (disturbances) affecting the EBS can be identified for the integrity assessment. The relevant processes have also to be modelled and considered in the performance assessment. FEP interactions are described in scenarios. The relevant scenarios impacting the EBS, as well as the repository, can be derived from the FEP catalogue. A different procedure is provided for human intrusion impacts that are analyzed by stylized scenarios.

While a comprehensive FEP analysis is not usually performed until after a site has been selected and characterized, RANGERS proposes that there are certain important aspects of EBS performance that can be studied by means of a preliminary FEPs analysis focused on EBS relevant FEPs. Ultimately, process models, based upon numerical models and experiments, are used to assess the integrity of the EBS as well as their impact in the integrated performance assessment simulations. For this purpose, the link between the (preliminary) FEPs and performance assessment is a key aspect of the proposed methodology. The main goal is to improve the representation of the EBS in the performance assessment (PA) of the repository, by comprehensive and specific analyses of the behaviour of the EBS under thermo-hydro-mechanical and chemical (THMC) conditions. The results of these analyses can be considered in the PA model and thus reduce the material and model uncertainties describing the EBS in the PA model.

Figure 1 gives an overview of the proposed methodology. The components of the proposed methodology will be described in the following sections.

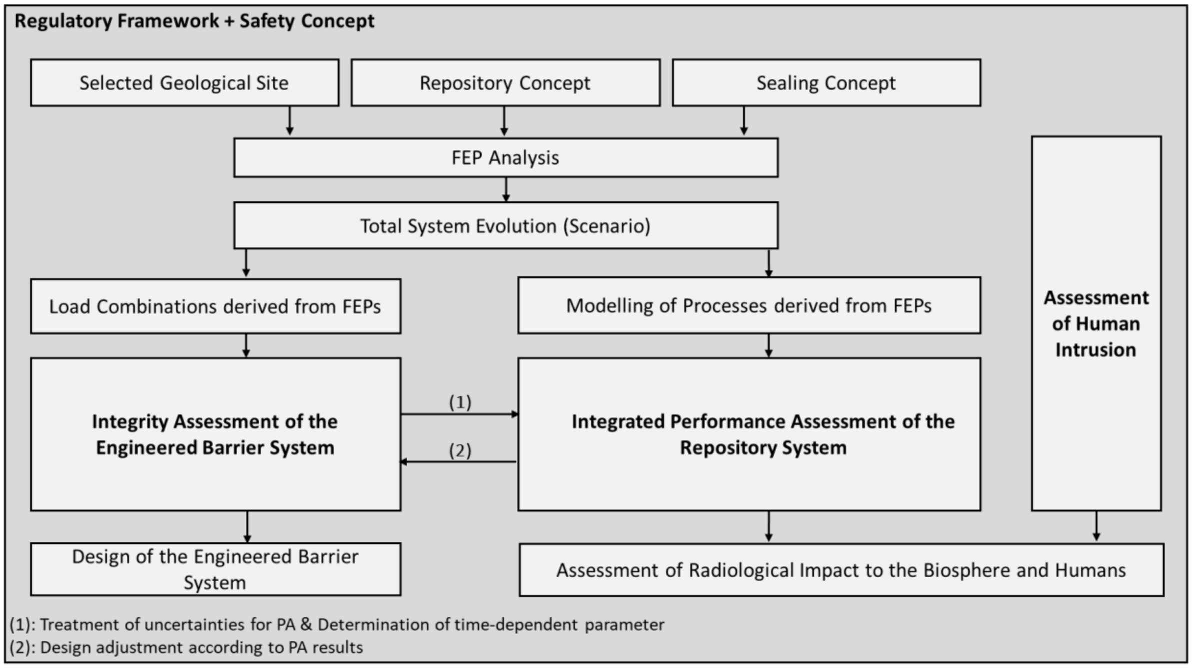

Figure 1. Methodology for the design and performance assessment of EBS in repository in salt

Regulatory framework and safety concept

If available, the regulatory framework can be the starting point of the methodology. In Germany, the Site Selection Act [17] together with the Ordinance for Safety Requirements [1] form the key legislations which rule the disposal of HLW/SNF in deep geological formations. They are supplemented by regulations for basic aspects of safety demonstration and threshold values of acceptable radiological releases for different system evolutions (Atomic Energy Act, Radiation Protection Ordinance) as well as regulations from other fields (e.g. Mining Act). In the US, DOE-funded research into salt repositories for high-level waste are being performed generically, or in site-independent manner. The Nuclear Waste Policy Act (NWPA) [18] and the NWPA Amendment [19] dictate the site selection process for the US, while [20]10 CFR 60 (NRC) and 40 CFR 191 [21] (EPA) would likely provide the main regulatory specifications for deep geologic repository [22].

In Germany the Ordinance for Safety Requirements [1] demands that the integrity of the engineered barrier system (EBS) should not be compromised by any hydraulic, mechanical, thermal and chemical processes taking place in the repository. Concerning the long-term safety of the repository, it also recommends that the required specifications of the engineered barrier system should be defined in the safety concept of the repository. The design and construction of the engineered barriers can then be performed by fulfilling these specifications. The specifications of each component of the EBS can be incorporated in the performance assessment of the repository system.

The safety assessment of the repository serves as the basis for the development of the repository system in which the radioactive waste will be confined. The repository system includes the surrounding geosphere (host rock and overburden formations) as well as the underground excavations. After completion of waste disposal, the openings in the repository are backfilled and sealed.

Geological site, repository and sealing concept

The conditions at the geological site dictate major boundary conditions for the repository, and to some extent, play a role in the design of the repository. The use of salt as host rock media is justified by the very low hydraulic conductivity, the tolerance against high temperatures (owing to high thermal conductivity) and the mechanical behaviour including eventual self-healing and comparatively easy mining with no need for regular lining. The creep behaviour of the rock salt supports long term sealing and is an important element of the long-term sealing. The actual dimensions and the thickness of the formation influences the choice of an emplacement concept and the location of the emplacement areas, access drifts and other subsurface facilities e.g. infrastructure areas. The repository depth and the radioactive waste inventory influence the thermal design. The higher are waste package temperatures and the deeper (and thus hotter) is the disposal level of the repository, the greater drift and waste package spacing is needed to comply with the temperature limits and thus increase the repository footprint.

The repository concept is significantly influenced by the waste type, waste package design, and corresponding emplacement concept. In general, various emplacement concepts such as the vertical and horizontal borehole disposal or the drift disposal are available. Operational aspects such as the use of shielded or unshielded waste packages present additional design options. Given a specific waste package and basic design of the emplacement drifts or boreholes allow the equipment selection and design of drift geometry and lengths. A repository concept should include basic information of the needed equipment for excavation, emplacement and other relevant processes. In Germany, repository ordinance requires the possibility of retrievability and the keeping ready of corresponding equipment. Keller et al. [23], provide more detailed information regarding the design methods for HLW/SNF repositories in Germany and the US. The repository concepts play an important role in the design of the sealing elements.

Long term safety is provided by the host rock as natural barrier interacting with engineered barrier systems. In the German context, a further separation of EBS in technical (e.g. waste package) and geotechnical barriers (e.g. drift seal) is common. As already mentioned, the waste package as technical barrier has no long-term sealing function of repositories in salt, in that performance credit is typically not taken for the waste package. The EBS includes shaft, borehole and drift seals for the short term and backfill made of crushed salt for long-term sealing. Over time, the creep behaviour of rock salt and the heat from waste packages will lead to compaction of crushed salt, which, in turn, provides similar hydraulic and mechanical properties approaching those of the intact salt host rock. Because the compaction of crushed salt is a relatively slow process, additional geotechnical barriers, such as borehole seals, drift seals, and shaft seals provide early time waste isolation. Their functional period is typically limited to a defined time, e.g. specified time from installation to the sufficient compaction of backfill or to the next ice age.

FEP Analysis

The comprehensive description of the repository system is the basis for long-term safety assessment. An internationally accepted tool for the task is the development of a FEP catalogue for which NEA [24] published an appropriate standard. The first step of the performance assessment is to establish a base case, which characterizes the overall performance of the host rock without intervening influence of FEPs. Next, the base case is screened for FEPs that are relevant for the future evolution of the repository system. In this context, the FEP catalogue has to comply with requirements for demonstration of long-term safety assessment (e.g. scenario development) on one hand, and on requirements to increase the clarity and the traceability of the evaluation (e.g. for public acceptance) on the other hand.

Using the NEA-FEP-catalogue [24], specific FEP catalogues for repositories in salt formations have been developed for the Gorleben and the Morsleben sites (projects ISIBEL [25] and VSG [26]) in Germany. The content of the German FEP catalogue has been especially adapted to the requirements of scenario development, addressing information like:

- the descriptions of relevant components, events and processes
- the dependencies of FEP
- the likelihood of FEP occurrence and characteristics
- the impact of processes on geological and geotechnical barriers ("initial FEP")
- relevant processes for radionuclide mobilization and transport
- chronological restrictions of FEP occurrence and characteristics, and
- effects of FEP in subsystems

The important barriers mentioned in this list have been taken from the safety assessment. The geological barrier is called the Containment Rock Zone (CRZ) in Germany. The content of the FEP catalogue includes the description of the geology (incl. results of geoscientific long-term prognosis), the repository design (incl. radioactive inventory, the repository layout, and the closure measures), as well as recently occurring processes and events and processes and events that are expected to occur in future.

To simplify discussion in the RANGERS project, it has been decided to focus on bedded salt and salt pillow formations. In Germany, generic bedded salt formations (also including salt pillows) have been described and discussed in the KOSINA project [4]; for US similar efforts for a SNF/HLW repository in salt have been produced [10] [11].

For the generic German site, the reference FEP catalogue for the Gorleben salt dome [26] has been slightly modified to meet a salt pillow formation. Furthermore, FEP lists for the nearfield of a shaft seal and a drift seal have been prepared as a basis for the analysis of the impacts on the EBS and the integrity proofs. Here, processes that directly affect the EBS function are identified. To specify the intensity of impacts on the EBS, it is necessary to consider the total system evolution as processes in the near-field are also influenced by processes in the far-field.

As a next step, expected and alternative scenarios have to be developed as boundary conditions for quantification of the impacts and loads on the EBS.

Load combinations

For the verification of the engineered barrier system, it is necessary to identify those processes during repository system evolution that may impair the function of EBS and to evaluate the long-term integrity of the EBS during expected future boundary conditions. To focus on the most relevant processes in the nearfield of the barriers, subsystem-specific FEP lists and scenarios have to be identified and evaluated. For this procedure, it is also necessary to consider the interactions between the near-field and the far-field. These subsystem-specific FEPs define the loads affecting the EBS. In the scope of preliminary numerical-based safety demonstration concept, these FEPs can be aggregated in scenarios and translated to numerical models where all specific processes or coupling phenomena between those FEPs are directly considered. The greater the number of FEPs that are aggregated in a numerical model, the closer the model will be to the realistic evolution of the repository. But due to technical limitations of available numerical codes, as well as knowledge gaps in some physical processes, several models will be needed to take into account all FEPs acting on the EBS.

Because the EBS is an engineered structure, the procedure for EBS performance assessment can rely on adequate regulations or recommendations, if available. In Germany, a procedure proposed in the European Engineering Standards (EUROCODE, national implementation by DIN-EN-1997-1, DIN-EN-1990) [27] [28] can be used as an appropriate approach. With regard to construction integrity it is necessary that the resistance of EBS is higher than the impacts to the EBS. For performance assessment it is useful to define ultimate limit states for the mechanical, hydraulic, thermal, and chemical impacts and to consider uncertainties due to variations of representative values and imprecisions in modelling, e.g. by safety factors. The German methodology for the design and safety demonstration of engineered barrier system is defined in the next paragraph.

Integrity assessment of the EBS

In Germany, the integrity assessment of the EBS components is based on a design philosophy inspired from EUROCODE [27] [28] [2] [29] and adapted to meet the requirements of the stress state and chemical environments in the repository. The time frame on which the EBS has to retain its function has to be considered as well. The aim is to verify the required level of reliability of EBS construction up to 50000 years. For the integrity assessment, the contact zone to the surrounding rock as well as the excavation damaged zone (EDZ) have to be considered beside the constructed barrier itself. The component of the EBS will be dimensioned according to technical regulations available for each specific material under consideration. Adjustments are however needed to take into account the functional lifetime, since most building standards for conventional structures in civil engineering are developed for service life of 50-100 years.

In the US, a similar approach is used, although it is worth mentioning that the technical differences between domal and bedded salt have necessitated different approaches. Also, differences in the regulatory framework of the US, as well as a greater focus on generic repository research, have resulted in less emphasis on the FEP implementation and activities that depend more heavily upon site-specific details. Nevertheless, a FEP-based approach, focused on EBS design methodology, is an area where US and German programs find a common interest.

A schematic of the methodology is presented in Figure 2 and is based on the concept of ultimate limit states in combination with the partial safety factor method. Therefore, the quantitative values of processes (i.e., impacts) or loads that may impair a structure's safety function are compared with the value of the structure-specific expected functional lifetime (i.e. load resistances). With regard to construction design, it is necessary that the load resistance is higher than the impacts. If the ultimate limit state is exceeded, the construction fails. The long-term structural integrity of geotechnical barriers (i.e. ultimate limit state), can be described by:

- crack limits (e.g. material specific fracture strength and dilatancy)
- deformation limits (e.g. volume and shear deformations)

- tension limits (e.g. fluid pressure criterion)

In the case of hydrologic sealing, a separate criterion can be defined. To take into account the progressive degradation of the component of the EBS, one can rely on a long-term stability criterion that has to be fulfilled through geochemical analyses and the estimation of the degradation processes taking place during the service life of the EBS.

The objective of the partial safety factor method is to cover uncertainties, e.g., variations of representative values and imprecisions in modelling. For application of this method, the values of the impacts / loads and the load resistances are multiplied by safety factors. The load resistances depend on construction material properties and the outline design of the EBS. The load resistances and the ultimate limit states are specific for a selected EBS design.

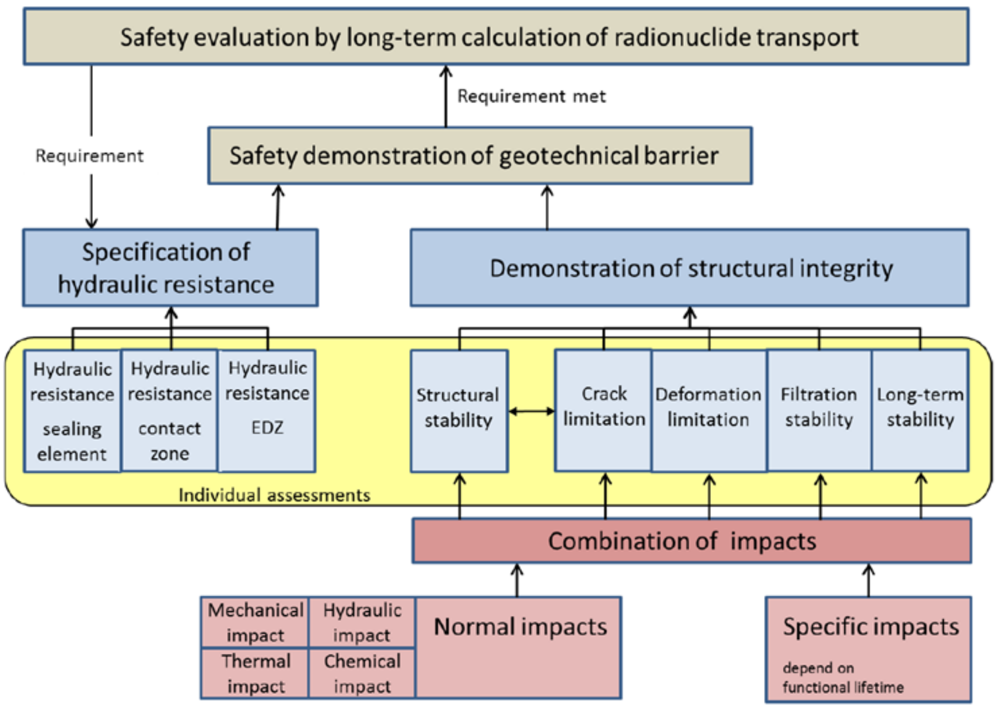

Figure 2: Methodology for the integrity assessment of EBS basing on Regulatory Requirements (EUROCODE)

The integrity assessment of the EBS focuses on the sealing function and consists of several specific proofs. The hydrologic sealing function (hydraulic resistances) needs to be evaluated for EBS, as well as for the contact zone between the EBS and the EDZ. In order to evaluate the structural integrity and stability of the EBS, the following should be considered: crack limitation, deformation limitation, filtration stability, and chemical/mineralogical long-term stability. In the context of the integrity assessment, the following impacts/loads have to be analyzed:

- Chemical impacts:
  - Chemical alteration by solutions and gases (hydrochemistry to be specified)
  - Chemical alterations induced by temperature changes (e.g. change of solubility)
- Mechanical impacts:

  - Loads induced by forces and stresses,
  - Dead load, rock and fluid pressure, abrasive forces, restraint stresses (e.g. induced by rigidity variations)
- Coupled effects including deformations and strains:
  - thermal expansion and contractions, swelling and shrinking, creep and relaxation, restraint strains due to barrier-rock-interaction (e.g. settling)
- Biological degradation (e.g. bacteria, fungi): resulting thermal and hydraulic impairments are covered by chemical and mechanical impacts indirectly

These impacts and loads can be directly linked to the processes identified in the FEP catalogue.

Total system evolution

The FEP catalogue describes the features characterizing the repository system as well as processes and events occurring future system evolution. The interaction between and features, events and processes are described in scenarios. The scenarios are systematically developed from analyses performed using the FEP catalogue. The corresponding methodology is described by Beuth et al. [30]. Future system evolution cannot exactly be predicted. Therefore, a spectrum of potential future evolutions (= scenarios) have to be identified to cover those uncertainties that are identified to be drivers of the repository performance. In the FEP catalogue, FEPs are categorized with regard to their probability of occurrence. But due to the uncertainties in future system evolution, there are also other evolutions that cannot be excluded, e.g. deviations from base case in evolution of hydrochemistry could intensify corrosion of the construction materials of EBS and thus result in a failure of one or more barriers.

Scenario development will be the next step of project work. It will be the basis for the integrated performance assessment of the repository system.

Conceptual modeling of EBS-specific processes for the PA

After a base case performance assessment is established, EBS-specific scenarios can be developed from the FEP catalogue. For modeling identified scenarios have to be broken down in processes/process groups affecting the components of the EBS and the geological barrier. Advection and diffusion phenomena (linked to alteration of EBS and to radionuclide transport), compaction of crushed salt, creep behavior of salt, heat propagation in the repository are examples of processes to be derived from the scenarios. Decisions regarding consideration of such processes in the performance assessment are sensitive. Because of the large domain and long-time scales of PA simulations, not all processes can be explicitly represented in the PA, but rather require separate process models to understand how key parameters may evolve over time and how these can be best presented in PA. The most relevant processes like the radionuclide transport through advection and diffusion or radionuclide decay will be directly integrated in the PA code. Other processes which are not yet well understood can be treated separately or their influence on the results of the PA can be assessed through sensitivity analyses. With the abstracted processes at hand, several simulation cases can be defined to represent a scenario under consideration. This approach is illustrated in Figure 3.

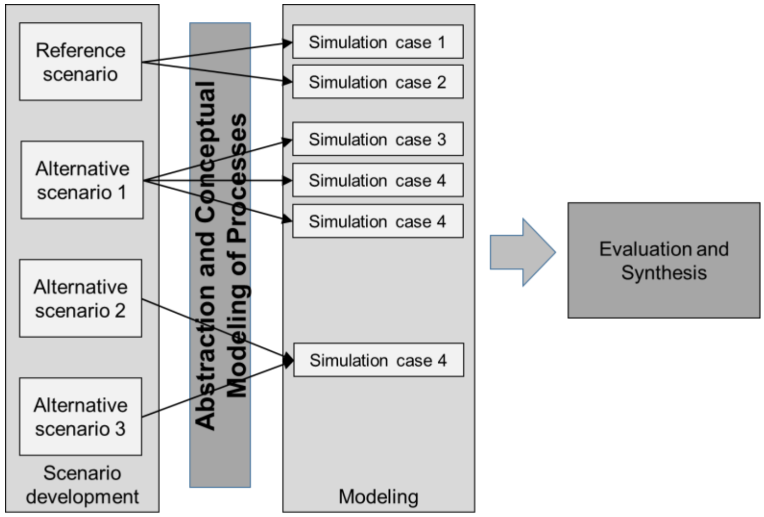

Figure 3: Schematic workflow describing the modelling of processes as intermediary step between the development of scenarios and PA simulations and Assessment after Beuth et. al. [30]

Integrated performance assessment of the repository system

The current approach for Performance Assessment in the US [12] builds upon previous salt reference cases [11] for deep geologic disposal of defense-related HLW and SNF was developed from (1) the reference case for a SNF/HLW repository in bedded salt, described in [31]and [32], (2) the repository designs proposed in [33] for a defense waste-only repository, and (3) elements of the engineered and natural barriers described in previous performance assessments of CSNF disposal in bedded salt [34] [35] [36] [37] [38].

The conceptual model includes a mined repository in a bedded salt host rock in a geologically stable sedimentary basin. The conceptual framework for the salt reference case focuses on the components of the engineered barrier and the natural barrier and assumes an undisturbed scenario outside the repository zone. In the same way, alternative scenarios can be assessed. Processes accounted for in the conceptual model include waste package degradation, waste form dissolution, equilibrium-controlled radionuclide sorption and precipitation/dissolution, radioactive decay and ingrowth in all phases (aqueous, adsorbed and precipitate), coupled heat and fluid flow, and radionuclide transport via advection and diffusion. Mechanical dispersion is conservatively neglected in this iteration of the salt reference case. Including it would result in earlier arrival of radionuclides at observation points, but lower peak concentrations.

The performance assessment of repository systems can be performed deterministically or probabilistically. Actual PA model simulations consist of up to 200 probabilistic simulations which are used to analyze seven uncertain parameters: the porosity of the dolomite, the permeabilities of the anhydrite, DRZ, backfill, and shaftfill (i.e., crushed salt), and the mean and standard deviation of the waste package degradation rate coefficient. All parameters are uniformly distributed except for the mean of the waste package degradation rate coefficient [12]. The use of sensitivity analyses in PA is an important method which helps to determine how EBS are affecting the main evolution of the repository system. Information gained from such analyses can help to optimize the design of EBS and understand critical parameters driving EBS performance.

Assessment of human intrusion

Since the technical bases of human intrusion scenario analysis are site-specific and issued by the regulator, more recent generic design cases in the US program have engaged the topic minimally. In the WIPP performance assessment, for example, there are five disturbed scenarios for human intrusion in the WIPP performance assessment [39], and they examine variables like when the intrusion occurs, and the locations transected by the intrusion (e.g., does it impinge upon waste panels, or does it encounter a pressurized brine pocket in the Castille formation below the repository horizon). The human intrusion scenarios in the WIPP case are the primary drivers of the performance assessment, as the undisturbed case presents exceedingly low probabilities for radiologic release exceeding the regulations. It is important to emphasize that human intrusion scenarios are specific to the WIPP site and may or may not be important drivers of the safety assessment at other sites.

The probability of human intrusion can be reduced by siting the repository at a sufficient distance from known geologic resources (other than the salt itself) such as extensive freshwater aquifers, ore deposits, fossil fuels, or high geothermal heat flux (which offers the potential for geothermal development). As a result, the focus of the generic salt reference case is on the undisturbed scenario, which is appropriate at this time because disturbed scenarios, e.g. inadvertent human intrusion, igneous intrusion, and seismicity, tend to rely on more site-specific information than the undisturbed scenario [11]. It is, therefore, not likely to be necessary to consider human intrusion scenario for the design of EBS and EBS-centric performance assessment.

SUMMARY

Within the framework of the project RANGERS a methodology for the generic design and performance assessment of EBS in repository in salt has been developed. The methodology aims at describing a workflow on how to assess the integrity of EBS of generic repositories in salt and how to handle them in the scope of integrated performance assessments. It is based on the experience gained in Germany and in the USA in the design, construction, and evaluation of seals from multiples research projects. The methodology focuses especially on the link between EBS integrity and performance assessment and helps to reduce the uncertainties concerning the treatment of EBS in PA modelling. It also brings an EBS-centric view on PA by focusing on the processes occurring at each component of the EBS and their evolution over the lifetime of the repository. The improved understanding of the repository system that may be gained from this approach will help to optimize the sealing concept of repositories in salt. In the next phase of the project, the methodology will be further developed and will be applied for the design of the EBS in a selected generic repository in Germany.

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ACKNOWLEDGEMENTS

The research work that is the basis of this report was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi, Bundesministerium für Wirtschaft und Energie) represented by the Project Management Agency Karlsruhe (Karlsruhe Institute of Technology, KIT) under contract number FKZ 02 E 11839. The authors alone, however, are responsible for the contents of this study.

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