A NEW INTEGRATED APPROACH TO DEMONSTRATE THE SAFE DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL IN A GEOLOGICAL REPOSITORY

N. MÜLLER-HOEPPE, J. KRONE, N. NIEHUES, R. RAITZ VON FRENTZ
Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (DBE)
Peine, Germany

Abstract
Multi-barrier systems are accepted as the basic approach for long term environmental safe isolation of radioactive waste in geological repositories. Assessing the performance of natural and engineered barriers is one of the major difficulties in producing evidence of environmental safety for any radioactive waste disposal facility, due to the enormous complexity of scenarios and uncertainties to be considered. This paper outlines a new methodological approach originally developed basically for a repository in salt, but that can be transferred with minor modifications to any other host rock formation. The approach is based on the integration of following elements: (1) Implementation of a simple method and efficient criteria to assess and prove the tightness of geological and engineered barriers; (2) Using the method of Partial Safety Factors in order to assess barrier performance at certain reasonable level of confidence; (3) Integration of a diverse geochemical barrier in the near field of waste emplacement limiting systematically the radiological consequences from any radionuclide release in safety investigations and (4) Risk based approach for the assessment of radionuclide releases. Indicative calculations performed with extremely conservative assumptions allowed to exclude any radiological health consequences from a HLW repository in salt to a reference person with a safety level of 99,9999 % per year.

1. SAFE ENCLOSURE OF HLW AND SNF IN A GEOLOGICAL REPOSITORY

Safe disposal of radioactive waste and spent nuclear fuel is considered to be a major challenge for the present generation independent from current and future scenarios of nuclear power use in different countries. Repository experience for short-lived low and intermediate level waste exists in several countries. Disposal in deep geological formations has been accepted world-wide as the basic approach for long term environmental safe isolation of long-lived high-level radioactive waste and spent nuclear fuel. Further decisions regarding site selection, site confirmation, licensing and construction of geological repositories are still pending in many countries. For several years extensive research and project implementation efforts have been in place in all leading industrial nations in order to enable a sustainable solution of the task. of disposing radioactive waste and spent nuclear fuel safely. Although isolation capability of geologic barriers is obviously fundamental for the performance of geological repositories, efficient quantitative measures are not available yet, and rating the isolation capability of a geologic barrier is still a difficult task. Especially in the case of HLW/SNF repositories in rock salt and clay the geological barrier is of main importance in order to retain radionuclides. Complete isolation of radioactive waste in rock salt for the basic case of undisturbed evolution of the repository is fundamental for the approach regarded in this paper. In the past the assessment of safe enclosure of radioactive waste in rock salt was relying on expert's experience, i.e. expert judgement only. In order to provide a stronger and methodologically well based justification a simple calculation method was derived and criteria were formulated to prove the long term isolation of radioactive waste in a geological repository in case of undisturbed evolution. The proposed method and the applied criteria are described in the following. First it is calculated if there is a rock salt barrier available around HLW/SNF, which fulfils the volume dilatation criterion [1]during the required assessment period. The volume dilatation criterion has been identified as a criterion that shows that the barrier properties of undisturbed rock salt are conserved, i.e. any kind of fractures are avoided if no volume dilatation takes place. Thus, permeability of rock salt is less than

$10^{-21}m^2$. Secondly, it is proved that the barrier is thick enough in order to ensure that any liquid cannot penetrate it during the required assessment period. If the assessment period is fixed, e.g. to 10.000 – 50.000 years, the required barrier thickness may be calculated so that the front line of any hypothetical liquid under site specific pressure conditions is remaining in the host rock during the assessment period regarded. Based on these requirements various calculation methods and models are available to prove the tightness of the barrier. The method and the criteria are not restricted to rate the geologic barrier, they are applicable to engineered barriers, as well. In addition the method and the criterion provide a smooth design basis for repositories, since both can be used to evaluate the necessary measures of the geologic and the engineered barriers as well as for the required physical properties of the engineered barriers if the complete isolation of the radioactive waste is aimed at. In Germany a comparable method and adequate criteria are generally accepted to prove the safety of constructions for environmental protection from hazardous liquids and implemented in technical rules in force [2]. This background offers the opportunity to simplify the licensing procedure because the licensing of technical solutions to comparable problems is relying on exactly these method and criteria.

In agreement with the IAEA Safety Series „Siting of Geological Disposal Facilities" [3] the distance of emplacement areas from geological discontinuities that could provide a rapid pathway for radionuclide transport, such as brecciated fault zones or flanks of a salt dome is recognised as a basic design criteria in order to ensure the safe enclosure of waste emplaced in a geological repository. Consequently, the described methodology is not only essential for the repository design, but is of importance at an earlier stage for the planning and construction of exploration mines, because future pathways for radionuclides shall be systematically prevented by keeping the required distance from critical geological discontinuities as mentioned in the IAEA Safety Series. Furthermore, the proposed method and the applied criterion are of such kind simple nature that nearly everybody can understand them, a fact that is important to explain the safety of a geological repository of radioactive and hazardous waste to the public. In this context, convincing the public that there is no special unacceptable risk arising from a geological repository for radioactive and hazardous waste is an outstanding task to be solved. Usually performance assessment calculations relying solely on the assumption of disturbed repository evolution are of such a complexity that the public is not able to understand or verify them. Thus, the public does not trust in the expert's performance assessment. The approach proposed in this paper can be verified in principle by everybody with little technical knowledge, the used parameters can be published and everybody can compare them with parameters given in literature. Thus, every touch of secret on performance assessment disappears and the results will become more transparent to the public. The advantages of the proposed criteria and methodology can be summarised as follows:

(1) A methodology has been developed to prove the null release repository in case of its undisturbed evolution.

(2) The proposed methodology can be used to design the exploration mine in such way that future pathways for radionuclides can be avoided from the very beginning.

(3) The methodology leads to a design criterion for the repository mine.

(4) The approach at one hand is suitable to perform a ranking of the isolation potential of different host rocks and/or at the other hand to identify the necessary minimum depth of the final repository in the host rock formation.

In addition, the proposed method and the criteria provide the necessary basis for a risk based assessment of a stochastic radiation injury from a final repository of radioactive waste in the complementary case of disturbed evolution and limited release of radionuclides. The case of disturbed evolution is regarded in the next chapter.

2. RISK BASED APPROACH FOR THE ASSESSMENT OF LIMITED RELEASE

Although tightness of geologic and engineered barriers can be proved in the case of undisturbed repository evolution the performance assessment of the system of natural geologic and engineered barriers must hold in the case of disturbed evolution, too. Regarding the case of disturbed evolution some difficulties are arising. These difficulties are caused mainly by two conflicts.

(1) The performance assessment shall consider with certain acceptable level of confidence all relevant but in some extent uncertain undue impacts to the isolation properties of engineered barriers caused by different geological processes, the nature of the waste and/or additional scenarios. By experience a classic strongly conservative and deterministic worst case approach concludes in extremely negative non-realistic assessment results, on the one hand. Best estimate approaches, on the other hand, do not consider reliably the full scale of uncertainties.

(2) Since long-term containment and limited discharge caused by retardation of radionuclides are the main functions of geologic and engineered barriers, performance assessment is focused normally on producing evidence of barrier tightness. Due to the fact that mechanical tightness of any barrier is affected mainly by mechanical impacts and corrosion a system of several barriers working on the same principle would not allow to improve the performance capabilities significantly. The problem could be solved composing a system of diverse barriers with diverse working principles and sensitive to different kinds of undue impacts (e.g. a conventional geomechanical barrier combined with a geochemical barrier). Although such a system of diverse barriers would have significantly better performance capabilities, a classic worst case approach would conclude again in extremely negative and non-realistic assessment results and the cogency of any best estimate approach is relatively limited.

Similar conflicts regarding the assessment of technical safety of complex facilities considering relevant but in some extent uncertain undue impacts with an acceptable level of confidence are subject of concern in other areas as well. In this context, advanced methodologies for the assessment of technical safety became an important area of interest. They presently found their most adequate implementation in the series of „Structural Eurocodes“ comprising a group of standards for the structural and geotechnical design of buildings in civil engineering. The Eurocodes are based on the so called Methodology of Partial Safety Factors[4],[5].

The objective of the Methodology of Partial Safety is to consider any uncertain parameter or impact by an appropriate safety margin called Partial Safety Factor in order to ensure the safety of the whole system against failure at a reasonable level of confidence. Commonly used confidence levels are 10^{-6} per year or 10^{-4} for the complete lifetime of the construction. Following that approach and assuming an appropriate design of engineered barriers as well as a sufficient thickness of the geological barrier the safe enclosure of radioactive waste can be proved at a similar level of confidence. Consequently, any release of radionuclides can be handled as an unlikely event with a probability of occurrence not exceeding the failure rate for barrier tightness. In that case the individual risk of a health impact caused by the repository can be understood as the individual radiological risk arising from any limited release multiplied by the failure rate of barrier tightness.

Obviously, the risk of undue health consequences could be limited sufficiently by limiting the concentration of released radionuclides in relevant exposure pathways. Thus, a diverse geochemical barrier designed in the near field of waste emplacement should allow to provide such a positive effect. Indicative calculations performed for a phosphate buffer in the near field of emplaced SNF gave a reduction of radiological risk up to 10^{-2} per year. Assuming a usual confidence level for barrier tightness of 10^{-4} a total individual radiological risk of 10^{-6} per year was calculated, which is ten times less then the risk upper bound of 10^{-5} according to the IAEA Safety Series N° 99 [6]..

In detail the risk based approach consists of the following steps.

(1) Determining the concentration of activity in a hypothetical liquid that might have been in contact with the radioactive waste by taking into account a geochemical barrier.

(2) Calculation of the individual radiological risk arising from the release limited by the geochemical barrier.

(3) Multiplying the individual radiological risk arising from limited release by the failure rate of the barrier tightness, which is determined as described in the Eurocodes.

Thus, using the approach described above indicative calculations performed with extremely conservative assumptions allowed to exclude any radiological health consequences from a HLW repository to a reference person per year with a safety level of 99,9999 %. At this point it should be mentioned that the approach described in this paper rates the risk arising from total failure of a mechanical barrier, which is the main barrier in the case of safe enclosure under undisturbed repository evolution. An evolution of the mechanical barriers' behaviour which leads to retardation and to limited release as a consequence of retardation is not regarded. Thus, the approach described in this paper is supplementing the classical performance assessment methods.

3. CONCLUSION

In this paper an approach is presented to show the safety of an HLW/SNF final repository that is relying on the proof of the safe enclosure of the radioactive waste and a risk based assessment of limited release. Using this approach indicative calculations performed with extremely conservative assumptions allowed to exclude any radiological health consequences from a HLW repository to a reference person per year with a safety level of 99,9999 %. Such a positive result was achieved thanks to the integration of the following for major elements into that approach:

(1) Implementation of a simple method and efficient criteria to assess and prove the tightness of geological and engineered barriers;

(2) Using the method of Partial Safety Factors in order to assess barrier performance at certain reasonable level of confidence;

(3) Integration of a diverse geochemical barrier in the near field of waste emplacement limiting systematically the radiological consequences from any radionuclide release in safty investigations

(4) Risk based approach for the assessment of radionuclide releases.

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