

Perspectives of Future R&D on HLW Disposal in Germany

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ABSTRACT

The 5th Energy Research Program of the Federal Government “Innovation and New Technology” is the general framework for R&D activities in radioactive waste disposal. The Ministry of Economics and Technology (BMW_i), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Ministry of Education and Research (BMBF) apply the Research Program concerning their respective responsibilities and competences.

With regard to the Government's obligation to provide repositories for HLW (spent fuel and vitrified HAW) radioactive waste basic and applied R&D is needed in order to make adequate knowledge available to implementers, decision makers and stakeholders in general. Non-site specific R&D projects are funded by BMW_i on the basis of its Research Concept. In the first stage (1998 -2001) most R&D issues were focused on R&D activities related to HLW disposal in rock salt. By that time the R&D program had to be revised and some prioritization was demanded due to changes in politics. In the current version (2001 -2006) emphasize was put on non-saline rocks. The current Research Concept of BMW_i is presently subjected to a sort of revision, evaluation, and discussion, inter alia, by experts from several German research institutions. This activity is of special importance against the background of streamlining and focusing the research activities to future demands, priorities and perspectives with regard to the salt concept and the option of disposing of HLW in argillaceous media.

Because the status of knowledge on disposal in rock salt is well advanced, it is necessary to take stock of the current state-of-the-art. In this framework some key projects are being currently carried out. The results may contribute to future decisions to be made in Germany with respect to HLW disposal. The first project deals with the development of an advanced safety concept for a HLW waste repository in rock salt. The second project (also carried out in the frame of the 6th Framework Program of the European Commission) aims at completing and optimizing the direct disposal concept for spent fuel by a full-scale demonstration of the technology of emplacement in vertical boreholes. The third project is devoted to the development of a reference concept to dispose of HLW in deep geological repository in clay in Germany.

In the following a brief overview is given on the achievements, the projects, and ideas about the consequences for HLW disposal in Germany.

INTRODUCTION

In 2007, 17 reactors at 12 nuclear power plants (NPP) are in operation with an expected total output power of about 140 TWh. This is less than 2006 because two NPP were non-operational. However, still nearly 25 % of the total electricity production is contributed by the German NPP. Besides these nuclear facilities, 12 research reactors, and 3 facilities for fuel supply and disposal are currently in operation.

To date 54 nuclear facilities (power reactors and prototype reactors, research reactors, and facilities for fuel supply and disposal) are in the decommissioning phase or have been decommissioned. (1).

Nuclear matters still are a matter of political and societal discussions esp. against the background of the German decision to phase out nuclear, climatic change and future energy policy.

The decisions made in the consensus agreement of 2001 are still valid. The coalition parties still acknowledge that the safe disposal of radioactive waste has to be ensured. The Government's intention to "*tackle this issue in a speedy and result oriented manner. We intend to solve this question by the end of the current electoral term.*" still exists. However, substantial progress and decisions are still pending, despite of some high-level meetings and conferences. (2)

CURRENT NUCLEAR WASTE POLICY

Reprocessing of spent fuel elements in France and in the UK has been terminated. The shipments to the reprocessing plants in France and the UK were discontinued.

The vitrified high-level waste (HAW) stored in France and in the UK will be taken back according to the existing international treaties. Shipment of the reprocessed waste from France and the UK to the central interim storage facilities is allowed. Shipment of HLW and spent fuel (SF) from the interim storage facilities or the on-site storage facilities to the repository site will be postponed until a deep geological repository is available.

Two central interim storage facilities are operational at Ahaus (North Rhine-Westphalia) and at Gorleben (Lower Saxony).

The Ahaus-facility hosts both spent fuel elements and thorium high-temperature reactor (THTR) fuel elements, whereas the Gorleben facility hosts spent fuel elements and the reprocessed vitrified waste.

At the sites of two decommissioned reactors (Mecklenburg-Vorpommern) two de-centralized interim storage facilities for spent fuel elements are in operation. At each NPP site an on-site storage facility will be operated to store the spent fuel elements for a period of 40 years. To date all facilities are licensed by the Federal Office for Radiation Protection (BfS).

The lifetime of existing NPP is determined by the limited electrical output and fixed in the Atomic Energy Act (AEA). Each year calculations, based upon the AEA, are performed and published by BfS to report about the present state of the residual energy production, and implicitly the residual lifetimes of the NPP. Considering nuclear phase-out, the production will stop in the year 2022. Especially the issue of lifetime prolongation still is a matter of controversial national discussion against the background of current international developments concerning the extensions and developments in nuclear technology, future fossil energy shortage and climatic change. General consensus prevails to dispose of all types of wastes in German deep underground repositories. Neither export nor import of radioactive waste will be allowed.

A decision about the rock type that will finally host the repository for heat generating waste is still pending. There are mainly politically motivated discussions about the necessity to have a sort of new site selection process, using some of the ideas of the AkEnd (3) and internationally favored approaches. However, this might severely postpone the target to start the operation of a HLW repository in 2030.

In Germany, rock salt still is the favorite rock type to host a deep underground repository for HLW. This opinion is supported not only by the results of decade-long successful R&D that lead to a sound base of knowledge about the features of this host rock, but also supported by years of experience in mining and the operation of salt mines, and the technological state-of-the-art for HLW disposal.

The year 2000-moratorium of the Gorleben salt dome still is effective. Further exploration is still postponed, only on-site maintenance measures are permitted.

A key requirement with regard to the moratorium was to clarify questions related to conceptual and safety-related issues for all suitable host rock types. There were no objections recognizable against Gorleben's suitability. However, there is no indication that the moratorium would be finished prematurely. Furthermore, after an expert report made by GRS, the German TSO, the idea to have only one single repository for all kinds of radioactive waste is no more a matter of discussion. (4)

For non-heat generating intermediate and low-level waste the Schacht Konrad is finally licensed as a repository. After more than two decades and several lawsuits license was decreed in spring 2007. Operation is planned to start around the end of 2013.

In Morsleben the stop of short-lived long- and intermediate-level waste emplacement was decreed. At present, among others things, the main activities comprise activities necessary for licensing and closure of the mine and the repository areas.

BASICS OF R&D RESPONSIBILITIES

The 5th Energy Research Program of the Federal Government "Innovation and New Technology" is the general framework for R&D activities in radioactive waste disposal. (5) The Ministry of Economics and Technology (BMW_i), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Ministry of Education and Research (BMBF) use the Program for their particular responsibilities and competences. Besides the topics "Renewable energies" and "Energy efficiency" nuclear safety research and waste disposal are parts of the program. Leading principles are safety and responsibility for present and future generations, thus being in line with international conventions.

Application-oriented fundamental R&D, as it is defined by the Frascati Manual (6), is "fundamental research being conducted with the expectation to achieve in the long perspective a broad knowledge that serves as a basis to solve identified or expected, existing or future problems or developments". In this sense it adequately fits to HLW disposal.

In Germany, so called non-site specific R&D projects are funded by BMW_i on the basis of its Research Concept. The first edition (1998 -2001) most R&D issues were focused on R&D activities related to HLW disposal in rock salt. By that time the R&D program had to be revised and some prioritization was demanded due to changes in politics. In the phase 2001 -2006 (7) emphasize was put on non-saline rocks and R&D on rock salt saw a decline in funding. The research concept of BMW_i for the follow-up phase is subjected to a sort of revision, evaluation, and discussion, inter alia, by experts from several German research institutions and is presently in the final discussion phase. This activity is of special importance against the background of

streamlining and focusing the research activities to future demands, priorities and perspectives with regard to the salt concept and the option of disposing of HLW in argillaceous media. (8)

Its main objectives or priorities will focus on R&D activities with regard to firstly rock salt, secondly argillaceous rocks and thirdly - on a minor scale - on crystalline rocks. This so-called rock type R&D prioritization emphasizes on the first hand the different levels of advancement in knowledge about these rock types and their significance as potential host rocks for a German HLW repository. On the other hand it is an expression for the conceptual and geological reasoning concerning the selection of potential host rock types.

BMBF - as a partner associate - is funding primarily basic research conducted by the national research scientific-technical and biological-medical centers that constitute the Helmholtz-Association. Research on waste disposal is carried out in the national research centers Karlsruhe and Jülich.

BMU is both the German regulatory body and responsible for the disposal projects (Konrad, Morsleben, and Gorleben) and the related facility- / site-specific R&D. On behalf of BMU, BfS initiates and coordinates this R&D, whose results are used for site characterization, performance assessment, and license application. BfS is in charge of all activities regarding construction and operation of facilities for disposing of radioactive waste. The expertise of third-party organizations is used. Project-specific activities are performed mainly by research centers, consultants, universities, and industrial companies.

By law, the costs for facility-specific R&D are paid according to the "polluter-pays-principle".

ACHIEVEMENTS

During the past decades a lot of know-how, technologies, and scientific expertise have been developed and accumulated and lead to a very advanced status of knowledge concerning disposal in rock salt. Therefore it seemed reasonable to take stock of the national current state-of-the-art not at last to identify open questions and priorities.

- A very significant achievement was the development of the direct disposal concept in the "Programm Direkte Endlagerung". Direct disposal of HLW is presently the only legally allowed disposal option in Germany.

Starting in 1985 with a sort of feasibility studies, this ambitious research program was successfully finished in 1995. It comprised of four subprograms, a) spent fuel conditioning and cask development (POLLUX casks and canisters), b) large-scale demonstration tests (emplacement and handling technologies for heavy payloads, THM behavior of crushed salt backfill, TSDE experiment), c) conceptual design of the disposal systems (System analyses), and d) laboratory tests. All large-scale tests were successfully executed and could be concluded according to schedule. All program objectives were accomplished. (9)

- The TSDE (Thermal Simulation of Drift Emplacement) experiment (or EC-co funded BAM-BUS experiment) was prolonged for scientific reasons. It was finished in 2004 (10).

The main points that lead to the success of this program were:

- The close combination of laboratory experiments, modeling and performance assessment was successful.
- To show that performing large-scale or full-scale in-situ demonstration experiments and experiments in underground research laboratories is necessary.

- The feasibility, the validation of the function, and the proof of the reliability of large technical equipment was demonstrated.
- The behavior of rock salt can be described adequately by experiments and models.
- It could be shown that legal requirements can be fulfilled.

The reward was the amendment of the Atomic Energy Act with regard to this disposal option.

Some other projects that contributed substantially to the technical and scientific knowledge were also performed. These projects were started nearly at the same time as the Programm Direkte Endlagerung, but were mainly performed in the Asse research mine exclusively with international cooperation partners. Then the Asse served as a first-generation underground laboratory.

The most essential projects were:

- The Brine Migration Test (11)
- MHV – Project (ILW and HTR fuel element test disposal in boreholes) (12)
- The HAW-Project (test disposal of highly radioactive radiation sources) (13)
- The Dam construction project (14)
- The AHE – project (Active handling experiment with neutron sources) (15)
- Development of deep borehole drilling techniques (600m deep boreholes) (16)

Summarizing the knowledge and expertise gained both from these projects and accompanied R&D activities (laboratory, modeling, and engineering work), it is realistic to say that essential know-how and techniques for the disposal of spent fuel and vitrified waste in rock salt are available. A lot of knowledge has been accumulated about the features and the behavior of rock salt and crushed salt backfill. Databases and models have been permanently improved. Finally, instruments to be applied in safety assessments exercises have been substantially further developed. A German reference disposal concept is available. Fundamental problems don't exist anymore. The open scientific questions could be answered in the years to come and should not impede any political decision pertaining to a German deep geologic repository for HLW in rock salt.

KEY PROJECTS

First steps to identify open questions have been made by initiating key projects being currently carried out. Their results may substantially contribute to decision making or foster future decisions to be made in Germany with respect to HLW disposal in a deep geological repository.

The first key project deals with the development of an advanced safety concept for a HLW waste repository in rock salt.

It was felt necessary to initiate such a project to take stock of R&D achievements made during the past 15 years. Since the mid-nineties remarkable developments in R&D improved the basis both for the development of a safety strategy and also for the compilation of the most important elements of an advanced safety case. This project is a joint activity between DBE Technology, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), and the BGR, the German Geological Survey, combining the particular scientific-technological expertise of these institutions (17)

Although there were some safety assessment exercises performed in Germany an exercise or task comparable to the modern form of a safety case has never been made. One of the basic ideas of

this project is to work on a sort of holistic approach that combines the repository concept with all available scientific-technological information and safety analysis. There is neither the intention to make a safety case nor any sort of safety analysis but to check completeness of instruments and methodologies and to identify deficits also with regard to future R&D.

Presently the safety criteria are under revision and are being further developed referring to the international state-of-the-art. Important to stress is a new approach to categorize scenarios by using probability aspects. This distinction is of high importance for HLW disposal in rock salt because the most probable scenario is the normal evolution scenario, i.e. the complete enclosure of the waste. Disturbed evolution scenarios are of "second" priority. This approach means a paradigm change because it reversed the former way of addressing the importance or priorities of scenarios. On the other hand it is of high importance and a challenging task to proof total inclusion against the background of meeting the protection objectives.

There are some requirements concerning the instruments and methodologies to deal with these tasks and may lead to some necessary future activities (i.e. siting or safety analysis). Against this background the project is conceptually divided into several work packages. The combination of the outcome will result in a concept to proof safety. Topics that will be addressed are building a reference concept (based upon a geological model, and the German disposal concept) and evaluating the operational safety. A very important topic is the very first systematic development of a FEP catalogue for rock salt, and to perform a scenario development.

Furthermore, emphasis is put on proving both the integrity of the geological barrier and the technical barriers against the background of complete enclosure. Finally, the development and evaluation of release scenarios, and evaluation of non-radiological impacts in the post-operational phase will be addressed. Based upon the results gained open questions and deficits concerning safety and realization are to be identified and recommendations for future R&D will be given. These are especially concerning the effectiveness of the technical barriers and the geologic barriers.

The second key project aims at completing and optimizing the direct disposal concept of spent fuel by a full-scale demonstration of technology for the emplacement in vertical boreholes. Main objective of this project performed by DBE Technology is the development and the full-scale test of an emplacement technology for spent fuel casks. The technical feasibility will be proved, the demonstration of safety in the operation phase will be shown by an adequate number of tests, conclusions for the post-operational phase will be drawn, and, very important, investigations and preparations will be performed to have a basis for licensing this borehole emplacement concept.

To optimize the emplacement technology for spent fuel elements a so called fuel rod cask to host three PWR fuel elements was developed by the German nuclear industry. By using only one emplacement system advantages with regard to time management and financial aspects are expected. New requirements for the techniques are based upon the dimension and the size of the casks. Therefore, some parts have to be developed. These are the transfer cask, a transport vehicle, an emplacement device and a borehole lock. The experimental program will consist of several parts: besides a full-scale test of the emplacement device simulation experiments to handle operational breakdowns. The tests should give information on robustness and reliability of the systems. (18)

This project gets national funding by BMWi and industry, but is also co-funded by the EC in the 6th FP (ESDRED – Integrated Project) (19).

In summary: Considering the disposal of spent fuel in rock salt this project is a milestone because it will contribute to have a final view on the disposal options and emplacement technologies that are relevant for rock salt. This project will provide some more information and, as a result, may contribute in decisions on future disposal options.

Some years ago the Federal Government decided to have other rock types (argillaceous rocks and crystalline rocks) investigated that may serve as potential host rocks for a deep geological repository for HLW in Germany. During the last years the activities were intensified. The R&D projects are focused mainly on argillaceous rock and comprise feasibility studies (20), laboratory experiments and modeling. A lot of these activities are integrated in international programs and activities in underground research laboratories in Switzerland (crystalline, argillaceous rocks), France (argillaceous rocks) or Sweden (crystalline rock). During the last years the emphasis was put on topics like development of techniques and technologies for site characterization, for repository construction and operation, and performance assessment.

Meanwhile more and more emphasis is put on investigating argillaceous rocks. In addition to the participation in international programs and projects with defined scientific topics some national projects were initiated and performed regarding conceptual (size, safety, costs, etc.) and feasibility issues (container, mining, etc.).

Moreover, some projects addressed technical issues (EBS, performance assessment). These projects were devoted to comparing national options to dispose of HLW in rock salt or clay stone (22) in order to provide basic understanding and to offer additional information for a scientific based discussion. Also a very preliminary conceptual design was made.

The third key project deals with the development of a reference concept for a German deep geological repository for HLW in an argillaceous host rock formation. The initiation of such a project was a consequence and continuation of the R&D activities connected to argillaceous host rocks. The project should provide fundamental ideas and proposals for a HLW repository in clay stone and intends to construct a reference concept for a repository. The concept is based upon generic siting information (Tonstudie made by BGR) and will consider all relevant information, i.e. thermo mechanical data, planning of mine openings, logistics, backfill, and closure concept and uses the international experiences of France and Switzerland. A rough estimation of the costs will also be made. Furthermore, questions are addresses concerning general mining issues like shaft sinking, drift cutting and borehole drilling, exploration methodologies, driving and support of cavern, emplacement techniques, container concepts, plugging and sealing, safeguards, and operational safety etc. and must be answered in detail.

In summary: For the first time a German reference concept for a HLW repository in clay will be developed. Estimations can be made concerning the technical feasibility, the safety relevant and economical consequences. A comparison with the HLW repository concept in rock salt can be made.

CONCLUSIONS

With regard to HLW disposal in rock salt the status of knowledge is well advanced. The expertise gained and the knowledge available concerning this concept shows that its implementation is technically feasible.

The key projects briefly reported of and the future R&D activities on the basis of the Research Concept of BMWi may contribute very much to further advancement in HLW disposal in rock salt.

The first one, being part of the EC-ESDRED project, will help to complete and optimize the direct disposal concept by providing an emplacement technology for spent fuel elements in vertical boreholes.

The second project deals with the development of an advanced safety concept for a HLW deep geological repository using the concept of complete enclosure. This is a sort of new safety philosophy being more appropriate for a rock salt repository because it takes advantage of the specific properties of rock salt. It will provide new methods and ideas to be used in a future safety case exercise. Furthermore it is a sort of management tool to identify open questions and problems to be solved in due time by respective R&D activities.

Rock salt used to be the candidate host rock for disposing of heat-generating nuclear waste in Germany. Up to now there are no indications that this material is not suitable to accommodate a repository for heat generating waste. These exemplary projects will have an important impact on the salt concept. Moreover, the results are of value for setting future R&D priorities in the Research Concept of BMWi.

During the last few years in Germany the knowledge concerning indurated clay increased. The project results achieved so far allow a better and more qualified estimation and evaluation of the pros and cons of HLW disposal in argillaceous rock. However, to reach a state-of-the art like in rock salt, there are R&D efforts needed. An important step forward is the development of a reference concept because of having the possibilities available for conceptual comparisons and future R&D priorities.

The results of these projects will be of high importance and may be a sound basis for general future decision making concerning HLW disposal.

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