HLW DISPOSAL IN GERMANY – R&D ACHIEVEMENTS AND OUTLOOK

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ABSTRACT

The paper gives a brief overview of the status of R&D on HLW disposal. Shortly addressed is the current nuclear policy. After describing the responsibilities regarding R&D for disposing of heat-generating high-level (HLW) waste (vitrified waste and spent fuel), selected projects are mentioned to illustrate the state of knowledge in disposing of waste in rock salt. Participation in international projects and programs is described to illustrate the value for the German concepts and ideas for HLW disposal in different rock types. Finally, a condensed outlook on future activities is given.

1. Introduction

In Germany in 2006, 17 reactors at 12 nuclear power plants (NPP) are in operation. In the first six months the total output power was about 86 TWh, about 5 % more than during the same time period in 2005. Still about 30 % of the total electricity production is contributed by the German NPP. To date 19 reactors (power reactors and prototype facilities) are in the decommissioning phase or have been decommissioned.
Nuclear matters were discussed during the coalition negotiation talks end of last year. It was decided to maintain the status-quo because of opposing views with respect to the use of nuclear energy and to keep up decisions made in the consensus agreement of 2001, which was the basis for the nuclear phase-out. It was agreed upon, however, to continue and expand safety research on NPP. The coalition parties also confirmed that it is acknowledged that the safe disposal of radioactive waste has to be ensured and the Government will *"tackle this issue in a speedy and result oriented manner. We intend to solve this question by the end of the current electoral term*." (1) In April 2006, the Government's new energy concept lasting to 2010 was discussed by high-ranking politicians and experts from electric utilities at the first national energy summit. Working groups were established to prepare documents for the next meeting in fall 2006. (2)

2. Current nuclear waste policy

Reprocessing of spent fuel (SF) elements in France and in the UK has been terminated. The vitrified waste, still in France and in the UK, will be taken back in due time according to existing international agreements. Shipment of the reprocessed waste from France and the UK to the central interim storage facilities is allowed. The shipments to the reprocessing plants in France and the UK were discontinued. Shipment of HLW and spent fuel (SF) from the interim storage facilities or the on-site storage facilities to the repository site will not be allowed before a deep geological repository is in operation.
Two central interim storage facilities are operational. At Ahaus (North Rhine-Westphalia) the BZA (Brennelement-Zwischenlager Ahaus) facility is used to store both SF elements and thorium high-temperature reactor (THTR) fuel elements. At Gorleben (Lower Saxony) the BLG (Brennelement-Lager Gorleben) facility is used to store SF elements and the reprocessed vitrified waste. Two de-centralized interim storage facilities for spent fuel elements at the sites of two decommissioned reactors are in

operation, too. At each NPP an on-site storage facility will be operated to store the SF for a period of 40 years. All facilities are licensed by the Federal Office for Radiation Protection (BfS). (3)
The lifetime of existing nuclear reactors is determined by the limited electrical output (Atomic Energy Act (AEA), 2002) Preliminary calculations, based upon the AEA, show that energy production will stop in the year 2022. Especially this issue still is a matter controversial national discussion against the background of international developments and initiatives.
There is consensus to dispose of all types of wastes in deep underground repositories in Germany, i.e., neither export nor import of radioactive waste is allowed. A decision about the rock type that will finally host the repository for heat generating waste is still pending. There are some discussions of having a sort of site selection process using some of the ideas of the AkEnd (4). However, this might postpone the target of the Government to start the operation of a repository in 2030.
In Germany, rock salt was the favourite host rock for a deep underground repository for vitrified waste and SF. R&D that was performed for years has lead to a sound base of knowledge. However, based upon a governmental decree in connection with the phase-out decision, the investigation of other favourable host rocks became also subject to R&D activities.
Moreover, the idea to have only one single repository for all kinds of radioactive waste still is under discussion.
The year 2000-moratorium that halts the exploration of the Gorleben salt dome still is effective. Only on-site maintenance measures are permitted. A crucial point connected with the moratorium was to clarify questions related to conceptual and safety-related issues for all suitable host rock types. The Federal Office for Radiation Protection (BfS) awarded contracts to national and international groups to work at these questions. The reports were reviewed, presented and discussed during an internal workshop one year ago (3). At present the synthesis report, its conclusions and the consequences for the Gorleben moratorium are being reviewed by GRS, the main German TSO. Presently, there is no indication that the moratorium would be finished prematurely.
For Schacht Konrad, planned as a repository for non-heat generating intermediate and low-level waste, the licensing procedure is completed after more than two decades. However, law suits delayed the immediate implementation. On March 8, 2006, the complaints were rejected by a high administrative court because they were irrelevant. There was no appeal possible. Yet, the complainants will go to the higher administrative court to appeal against this decision. Hopefully, after the decreed license and the Federal Government's decision that Konrad is to be operated as a repository, the start of operation might be around the year 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.

3. Responsibilities for R&D

The 5th Energy Research Program of the Federal Government "Innovation and New Technology" is the framework for R&D activities. The Ministry of Economics and Technology (BMWi) is the ministry in charge. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Ministry of Education and Research (BMBF) are involved, as well. Besides the main topics "Renewable energies" and "Energy efficiency" nuclear safety research and waste disposal are parts of the program. (2)

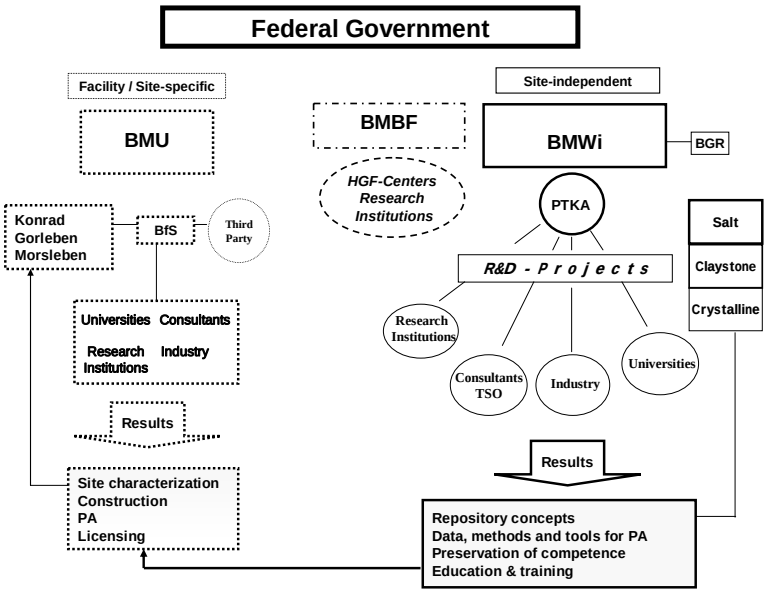

Fig.1. Responsibilities for R&D

Activities related to HLW disposal are basically the responsibility of BMU, the BMWi, and BMBF.
Leading principles are safety and responsibility for present and future generations, thus being in line with international conventions. Subsumed under this is the Government's legal obligation to provide repositories for radioactive waste. Basis for funding site-independent research by projects is the Research Concept of BMWi. (5) In the beginning it focused on R&D activities related to disposal in rock salt. After the changes in politics and the new nuclear policy streamlining became necessary in some areas to prioritize R&D and to put emphasize on other host rock types than rock salt. The R&D projects funded by BMWi (Fig. 1, right) can be assigned to applied basic research, defined as basic research being conducted with the prospect to create a sound basic knowledge in a long perspective helping to solve foreseen, consisting or future problems. The Project Management Agency Forschungszentrum Karlsruhe (PTKA) acting on behalf of BMWi is the managing and supervising unit. It helps to transfer programmatic contents into projects, provides support with regard to conceptual work, controlling, evaluation, and general management tasks. This respective research is carried out by industrial companies, consultants, technical support organizations (TSO), universities, and research institutions. The results can principally be used by legal bodies, authorities, reviewers, operators, private industry, and other stakeholders.
BMBF is funding primarily basic research conducted by the national research scientific-technical and biological-medical centres that constitute the Helmholtz-Association. Research on waste disposal is carried out in the national research centres Karlsruhe and Jülich. BMBF is also responsible for funding R&D on underground disposal of chemotoxic waste. The respective projects are also coordinated and supervised by PTKA.
BMU, the German regulatory body, is responsible for the disposal projects and the related facility- / site-specific R&D. On behalf of BMU, BfS initiates and coordinates this R&D. BfS is in charge of activities regarding construction and operation of facilities for disposing of radioactive waste using the expertise of third-party organizations. Project-specific activities are performed mainly by research centres, consultants, universities, and industrial companies. The results are directly used by BfS for site characterization, performance assessment, and license application.
By law, the costs for facility-specific R&D are paid according to the “polluter-pays-principle“, e.g., regarding Gorleben, the electric utility industry.

4. Achievements

During the last decades a lot of R&D on HLW disposal in rock salt was performed. One of the most important achievements was the development of the Direct Disposal concept. Starting in 1985, after having performed some preliminary studies, this ambitious R&D program was successfully finished officially in 1995. The goals of the four subprograms, a) spent fuel conditioning and cask development (POLLUX casks and canisters), b) demonstration tests (emplacement and handling technologies for heavy payloads, THM behaviour of crushed salt backfill), c) conceptual design of the disposal systems (System analyses), and d) laboratory tests were achieved. All large-scale tests were successfully executed and could be concluded according to schedule. (6) For scientific reasons, the last test within this program, the TSDE (Thermal Simulation of Drift Emplacement) or EC-co funded BAMBUS experiment was prolonged and was finished in 2004 (7). It was the last it-situ test performed in the Asse salt mine. As a consequence of this program direct disposal of spent fuel became a disposal option legally equivalent to reprocessing. Now it is the only legally accepted way to dispose of spent fuel and vitrified waste.
Lessons learnt from all these experiments were that validation of function and reliability of large technical equipment is feasible, that material behaviour can be described adequately by experiments and modelling and that legal requirements can be fulfilled. Moreover, it is commonly acknowledged that the use of large-scale or full-scale in-situ demonstration experiments, also performed in underground research laboratories, is indispensable. This is not only essential for scientific reasons but also because of its importance to get public acceptance for safe and secure handling of technology.
Besides the engineering work and large-scale experiments, laboratory experiments and research focused on contributions for performance assessment has been performed to improve the knowledge. Especially the tools and instruments to be used in modelling and performance assessment were further developed substantially and tested in several national and international projects.

An important experiment, coordinated by PTKA and managed by the Kali und Salz (K+S) company, was the BMBF-funded large-scale shaft sealing experiment carried out with regard to the underground disposal of chemotoxic waste. (8) This joint project aimed at planning, constructing, and testing of a long-term stable sealing system. The investigations were accompanied by laboratory experiments and numerical modelling. It could be shown that the experiment can be considered to be representative for sealing elements to be used in real shafts. The project results are used by K+S in the closing activities of three shafts of a salt mine. Although the results were not intended to be used for radioactive waste disposal a lot of expertise was gained that can be used in a synergistic way.
The knowledge gained about disposing of heat-generating waste in rock salt during the past decades has reached a certain status of maturity. It was shown that technological problems can principally be tackled. Techniques for the emplacement of spent fuel and vitrified waste are at hand. A lot of knowledge has been accumulated about the behaviour of rock salt and crushed salt backfill. Databases and models were permanently improved. Instruments to be applied in safety assessments exercises are available. Yet, there are some open questions left that could be answered in the years to come. Moreover, up to now there are no indications that rock salt is not suitable to accommodate a repository for heat generating waste.
The Government decided that other host rock types should be investigated. To reach an adequate level of knowledge and expertise as compared to rock salt in due time is a challenge. Therefore, R&D activities were intensified. The respective projects are focused mainly on argillaceous rock and comprise feasibility studies (9), laboratory experiments and modelling. The results achieved to date have contributed to a certain level of knowledge and expertise. (e.g., 10, 11).

5. International cooperation

A lot of these activities are integrated in international programs and activities in underground research laboratories. There are various reasons for that approach. Experience showed that the fruitful and successful cooperative work has both contributed a lot to the national knowledge and fostered the exchange between researchers in scientific and technological areas. Problems connected with large R&D projects can be tackled much more efficiently by an international “job-sharing” effort, both to reduce risks and costs. An additional important aspect surely is the positive effects on education and training on human capital involved in all the activities. International cooperation is mainly based on agreements between Governments, scientific institutes, universities or national research centres, and on agreements with the European Commission. Very positive outcomes arise by the overlapping of projects in these areas resulting in building up multidisciplinary and multinational networks. It is acknowledged that it becomes more and more valuable to cooperate in joint international projects, e.g. in URLs, both to share the financial burden but also to use the combined and sound expertise of national and international experts to solve common research tasks. Against the background of these positive aspects and because of its responsibility for R&D as well as a sign for the importance attached to international cooperation, international activities are directly funded or co-funded by the German government, respectively BMWi. Moreover, the benefits of international cooperation can be communicated to the public showing that there is a common understanding in the world-wide scientific community to solve the task of waste disposal together in a multinational effort, safety-oriented and responsible in due time.
When rock salt was the favoured material to host a repository in Germany, and the Asse mine was used as sort of URL, a series of projects were carried out in cooperation with institutions from countries then also interested in rock salt (e.g., France, the Netherlands, Spain, US). Most of these experiments were co-funded by the European Commission in the respective Framework Programs. (e.g. 12)
Yet, German research institutions have participated in foreign projects and programs related to other host rock formations, because it was important to understand possible other candidate host rock formations and to get information and knowledge for evaluating the pros and cons.

A lot of projects were and still are performed in underground laboratories. During the last years the participation focused on topics like development of techniques and technologies for site characterization, for repository construction and operation, and performance assessment. In the meantime the knowledge in some areas has become quite advanced. Therefore, future work will increasingly focus on specific problems.

Concerning crystalline rock, the ongoing R&D activities focus on experiments performed in the URLs in the Swiss Grimsel Test Site (GTS) and in the Swedish HRL Äspö. On a minor scale, there is collaboration with Russian institutions.
The activities in the GTS started about two decades ago. Close collaboration with international partners took place in a series of projects during the six investigation phases of the GTS. (13) The investigations comprised host rock characterization, considering the hydrogeological, petrophysical, and mechanical properties, projects, the study of the EBS behaviour (i.e. FEBEX, GMT),and the study of colloid and radionuclide migration. A lot of basic knowledge was gained, a detailed system understanding was created, sophisticated computer codes, measuring devices and methods, and state-of-the-art analytical tools, were developed.
In 1995 cooperation in the HRL Äspö started because it was deemed necessary to extend the knowledge on types of crystalline rock other than those of the Grimsel granite. Cooperation started in projects focusing on developing and testing of instrumentation and methods for underground rock characterization, studying the behaviour of the EBS, development of numerical flow and transport models as well as studying radionuclide migration (in particular actinides), and the impacts of colloids and microbes. Tools, measuring devices, sophisticated analytical instruments and method used in GTS were transferred and very successively used in the HRL Äspö. (14) At present German scientists participate in six projects in the HRL. (15)
Since 2001, there has been a cooperation agreement between BMWi and ROSATOM (the former MINATOM). The very first project within the collaboration aims at developing a proposal for a site investigation and selection program for a generic repository in crystalline rock. German and Russian experts in geology, technology and safety assessment are working on a concept for borehole disposal of vitrified waste in granite in the area of Krasnoyarsk. (11, 16)
R&D in argillaceous rocks started late compared to the activities in crystalline rock. Initially it was mainly focused on plastic clay, and on minor scale, on indurated clay. Now emphasise is put on indurated clay. Because there is no URL in Germany it is appropriate to participate in the Swiss Mont Terri URL and the French URL in Bure. In the Mont Terri URL projects related to all clay-relevant issues are performed. German scientists are involved in several projects. (17) At the URL at Bure activities focus on issues that are comparable to and complementing the Mont Terri activities. Topics are the study of THM-properties of the clay, the characterization of this material, and participation in selected in-situ tests. The entire work in the URLs is accompanied by laboratory experiments and modelling.

5.1 Framework Programs of the European Commission

The participation in the Framework Program of the European Commission still is an essential part of the national research policy and is considered as crucial and necessary for reasons like to gain expertise, to transfer experience, to exchange knowledge, to increase excellence, support mobility and scientific exchange. In the 6th Framework Program German research institutions participate in nearly all projects/initiatives either as coordinator or as member of the scientific body. Participation takes place in the projects NF-PRO (Understanding and Physical and Numerical Modelling of the Key Processes in the Near-Field and their Coupling for Different Host Rocks and Repository Strategies), ESDRED (Engineering Studies and Demonstrations of Repository Designs), FUNMIG (Fundamental Processes of Radionuclide Migration), PAMINA (Performance Assessment Methodologies in Application to Guide the Development of the Safety Case, under negotiation), the Network for Actinides Sciences ACTINET, and the Project “Co-ordination of research, development and demonstration (RD&D) priorities and strategies for geological disposal”(CARD). (18)
Because of the benefits resulting from past Programs, the participation is justified also in the 7th EC-Framework (EURATOM) Program currently being prepared.

6. Outlook

With regard to HLW disposal in rock salt the status of knowledge is well advanced. Some key projects being carried out will have an important impact on the salt concept. Their results will be a milestone for future decision making. The first one, being part of the EC-ESDRED project aims at completing and optimizing the Direct Disposal concept by full-scale demonstrating the emplacement of SF in vertical boreholes. The second project deals with the development of an advanced safety concept for a

HLW waste repository. Performance Assessment exercises were performed within the framework of German R&D projects at the end of the 1980s and in the first half of the 1990s. Since then remarkable developments improved the basis for developing an advanced safety case. A joint R&D project is being performed to identify major needs for further R&D. Moreover, using the approach of proving the safe enclosure without release for the expected evolution of the repository is considered to be more appropriate for a rock salt repository and takes advantage of its specific properties.
During the last few years in Germany the knowledge concerning indurated clay increased. The project results achieved so far, including the Clay study (19) of BGR, the German Geological Survey, allow a better and more qualified estimation and evaluation of the pros and cons of HLW disposal in clay. However, to reach a state-of-the art like in rock salt, there are R&D efforts by projects pursued addressing e.g., conceptual and safety related questions or all problems connected to host rock characterization.
The Research Concept of BMWi 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 both concerning budget constraints and adaptation to future demands, priorities and perspectives.

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