

## **R&D INTO HLW DISPOSAL IN GERMANY – ACHIEVEMENTS AND PERSPECTIVES**

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### **ABSTRACT**

The paper gives a brief overview on the status of nuclear waste management in Germany especially concerning R&D issues. Topics shortly addressed are the current waste disposal policy, responsibilities and objectives of R&D related to high-level waste disposal. Selected achieved results of R&D projects are also addressed to show the state of knowledge in waste disposal in rock salt. The importance of international cooperation will be shown by addressing briefly the R&D activities in international programs and projects.

### **INTRODUCTION**

In 2004, in Germany 18 reactors at 13 nuclear power plants with a total output of about 22 GW are in operation, and 19 reactors, research reactors included, were decommissioned.

The output power corresponds to about 30 % of total electricity production [1]. The average age of all reactors is about 23 years.

Phase-out of nuclear energy is the objective of the Federal government. Since the General Elections in 1998 this objective has been consequently pursued. In June 2001 the agreement on nuclear phase-out was signed between government and electric utility companies. Basically, this had no legally binding consequences, but was a sort of gentlemen's agreement on an orderly termination of nuclear energy production. Nevertheless, it was the basis for the amendment of the Atomic Energy Act which came into force in 2002.

### **CURRENT NUCLEAR WASTE POLICY**

The current nuclear waste policy which is a consequence of the agreement and the amendment of the Atomic Energy Act concerns issues like existing reactor lifetime, reprocessing, waste transportation, interim storage, and, of course, the disposal of radioactive waste, esp. the repository projects Gorleben and Konrad.

### **Limited Operation Lifetime of Reactors**

Concerning reactor lifetime there is no agreement on a fixed date. Operation lifetime is determined by the limited electrical output. Assuming a mean total operation time for all reactors of 32 years and starting in the year 2000 the last reactor will be shut down when all reactors will

have generated about 2000 TWh of electrical energy. It can be concluded that the last reactor will go off line in 2022. No new nuclear power plant will be constructed. [2]

## **Reprocessing**

Starting on July 1<sup>st</sup> 2005, further reprocessing of spent fuel elements in France (La Hague) and in the UK (Sellafield) is inadmissible. Direct disposal will be the only way to dispose of spent fuel elements. Vitrified waste which is still in France and UK will be taken back according to agreements concluded with the United Kingdom and France under public international law. It will be disposed of in Germany after an interim storage time of about 30 years.

## **Transportation**

Spent fuel elements are still shipped from the nuclear power plants to be reprocessed in France or UK or to the central interim storage facilities at Ahaus and Gorleben, Germany. After the expiration of the reprocessing contracts and with the commissioning of the decentralized interim storage facilities, i.e. at the sites of the nuclear power plants, transportation will be terminated. After 2005, only the high-level reprocessing waste will be shipped from La Hague and Sellafield to Germany. As soon as a repository is in operation, spent fuel or vitrified high-level waste will be transported from the interim storage facilities to the conditioning plant where the spent fuel is reloaded into disposal casks and finally transported to the repository.

## **Interim Storage**

The interim storage concept is based on the storage of spent fuel elements and vitrified wastes in CASTOR-type transportation containers.

Central interim storage facilities at Ahaus and Gorleben are operational. The Ahaus facility is used for containers with thorium high-temperature reactor (THTR) fuel elements and spent fuel elements. The Gorleben facility has the license to store, besides spent fuel elements, the reprocessed vitrified wastes from France and UK.

Two decentralized interim storage facilities for spent fuel elements at the sites of two decommissioned reactors are in operation. To avoid future transportation decentralized storage facilities at nuclear power plant sites shall be operational in 2005 and are designed for a storage period of 40 years. [3]

For 13 nuclear power plants on-site spent fuel storage facilities are licensed by the Federal Office for Radiation Protection (BfS).

## **Disposal**

In Germany deep disposal for all types of radioactive waste is obligatory. Based upon the geologic situation and scientific consensus rock salt was the preferred option to dispose of heat producing radioactive waste. One of the essentials of the new nuclear waste policy is that further sites in different host rock formations shall be explored and decisions will be made after

comparing the alternatives. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) demands one single repository for all kinds of radioactive waste.

The waste is to be disposed of in a national repository, i.e., no export or import of radioactive waste is allowed. The target for repository start-up still is the year 2030. The site selection procedure is based upon the recommendation of the Committee on a Site Selection Procedure for Repository Sites (AkEnd) [4]. A five-step procedure – combining scientific and social criteria – for the implementation processes was proposed that will be finished with having a repository ready for operation. BMU intends to amend the Atomic Energy Act accordingly within this legislature period.

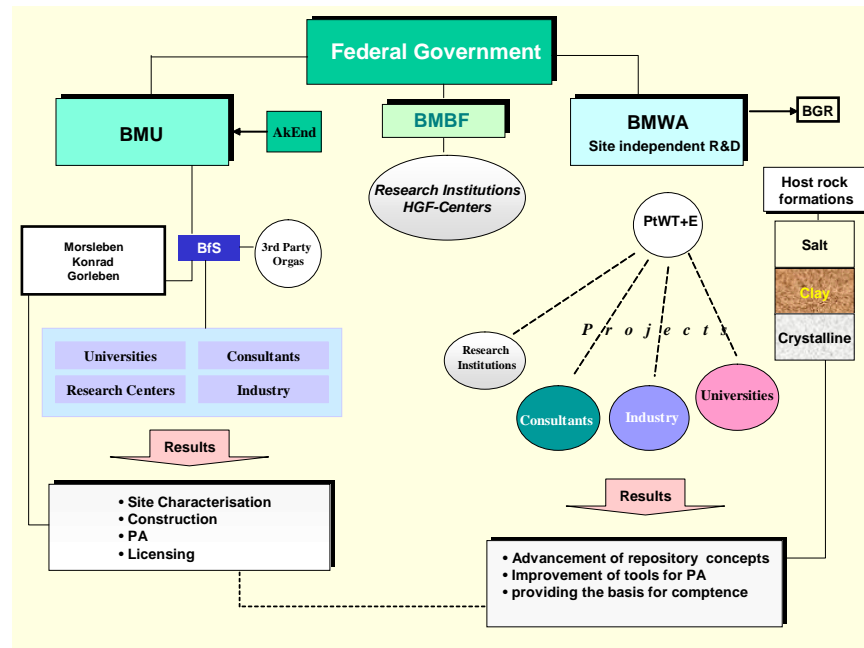
From 1979 till 2000 the Gorleben salt dome was explored with regard to its suitability as a repository for spent fuel and vitrified high-level waste. Although Gorleben did not prove to be unsuitable, it is the government's view that further exploration of the Gorleben salt dome cannot contribute to clarify questions related to conceptual and safety-related issues, e.g. gas, criticality, retrievability, suitability of other host rock formations than rock salt, etc. [5]. Therefore, a moratorium of 3 to 10 years was imposed to clarify these questions. During the moratorium the necessary measures will be taken to maintain the Gorleben site. This will also include the necessary legal steps to secure the position of the Federal government and to make the project secure from interventions of third parties. In 2005, the above mentioned questions are supposed to be answered.

The Konrad mine, a former iron ore mine, is intended to be used as a repository for intermediate and low-level waste. The licensing procedure is completed. The license, however, has not become effective immediately, thereby delaying further on-site construction due to appeals in court.

In 1998, in Morsleben the stop of short-lived L/ILW waste emplacement was decreed. At present, among others things, main activities comprise the work to provide all the documents necessary for licensing. It is intended to close the mine and the repository areas safely and securely starting in 2008.

## RESPONSIBILITIES AND OBJECTIVES FOR R&D

In general, the German Federal government has to ensure the safe disposal of radioactive waste by providing repositories. R&D and funding, however, are different from that in other countries.



**Fig. 1. Responsibilities for R&D**

R&D is in the responsibility of BMU and the Federal Ministry of Economics and Labor (BMWA) and is funded by BMWA and the Federal Ministry for Education and Research (BMBF). BMU is the regulator for disposal projects and is responsible for related site-specific R&D. (Fig. 1)

On behalf of BMU, the Federal Office for Radiation Protection (BfS) initiates and co-ordinates site specific R&D and uses the expertise of third-party organizations. BfS is responsible for construction and operation of plants and installations for disposing of radioactive waste. Special R&D tasks are carried out mainly by research centers, 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 site-specific R&D are paid by the electric utility industry according to the “polluter-pays-principle“. The future procedure is currently under discussion. [6]

Non site-specific R&D is funded by BMBF and by BMWA (Fig. 1, right). The general aim of this R&D is to provide the scientific and technical basis to help protect man and the environment against hazards that could originate from disposal facilities, therefore being an essential part of the Federal government’s precautionary research measures.

On behalf of BMWA and BMBF, the management group PtWT+E at Forschungszentrum Karlsruhe co-ordinates the ensuing R&D. Basis for this non-site specific R&D is the Research concept of BMWA [7] whose objectives are threefold, namely, advancement of repository concepts, improvement of tools to evaluate and assess long-term safety, and, on a minor scale, adoption and further development of nuclear material safeguards.

The R&D-projects are carried out by industrial companies, consultants, universities, and research institutions. Principally, any legal bodies, authorities, reviewers, operators, private industry, and other stakeholders can use the results.

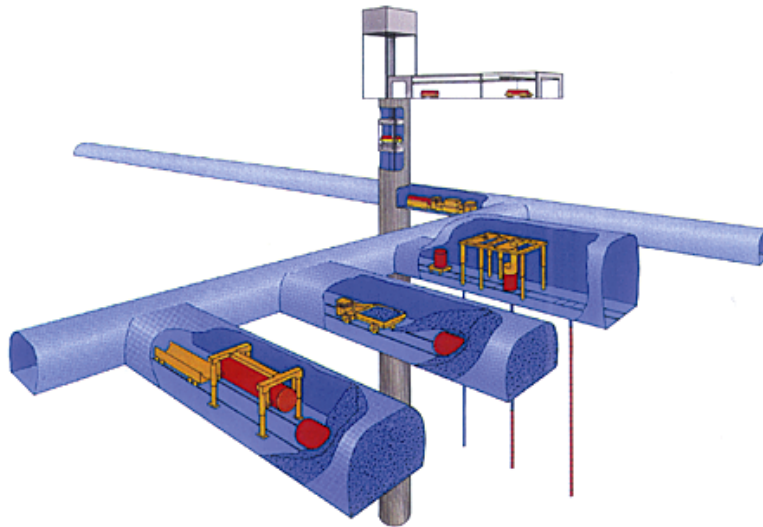
Because of the decision of the Federal government to investigate other host rocks beside rock salt, it became necessary to streamline the Research concept in some areas and to prioritize R&D also with regard to other host rocks.

Underground disposal of chemotoxic waste is meanwhile a well established industrial option to dispose of these types of waste. The accompanying R&D activities are also coordinated by PtWT+E.

## ACHIEVEMENTS

In Germany it is agreed upon that deep underground disposal of hazardous waste – both radioactive and chemotoxic waste – is the selected option. Since the early days of R&D for disposal, rock salt has been considered as the preferred host rock because of its well known positive features. According to the German reference concept to dispose of high-level waste and spent fuel in a salt repository was developed.

It includes drift emplacement of spent fuel casks and emplacement of high-level waste in vertical boreholes. Crushed salt is used as backfill material. [8]



**Fig. 2. The German reference concept for high-level waste disposal**

The drift emplacement concept was primarily developed to dispose of spent fuel assemblies. It can also be employed to dispose of vitrified high-level waste if the canisters are packed into self shielded casks. The fuel assemblies are packed in self shielded casks, so called POLLUX casks, weighing about 65 t. The casks are emplaced on the floor of horizontal drifts. The maximum temperature at the disposal cask surface is 200°C. After emplacement of a cask the remaining volume in the drift is backfilled with crushed salt.

In the borehole emplacement concept high-level waste canisters are piled upon each other in vertical boreholes, 300 m in depth and 60 cm in diameter. Each canister contains the vitrified high-level waste originating from reprocessing. Also in this concept the maximum canister surface temperature must not exceed 200°C. Horizontal emplacement in drifts is a possible alternative for high-level-waste disposal. Backfill will be emplaced around the canisters to distribute the stacking load of the canisters to the surrounding rock.

The backfilled drifts will be sealed. After closing the repository the shaft will be sealed, too.

Starting in 1981 and finishing in 2004 a R&D program focusing on drift emplacement was conducted. The main goal was to develop and to demonstrate the disposal technology for 65 t-cast iron casks for spent fuel. A stepwise procedure was chosen: feasibility studies, conceptual design and a full-scale demonstration test. Especially the last step was very ambitious because it had to be shown that waste casks could be safely and reliably lowered through the shaft and emplaced. The full-scale demonstration program consisted of an experiment to show the feasibility of lowering heavy loads (85 t payload), of remotely controlled cask emplacement, of backfilling techniques, and, finally, of an in heater test in the Asse salt mine. All the large-scale tests were successfully performed and could be concluded according to schedule. [9] In 1994, as a consequence of this success, the Atomic Energy Act was amended and direct disposal of spent fuel became a disposal option legally equal to reprocessing. Today, direct disposal is the only legally accepted way to dispose of spent fuel and high-level waste.

Another path to technology development, testing and demonstration, was to carry out in-situ experiments. These experiments were conducted in the Asse salt mine. Its availability was extremely valuable, because for more than two decades it served as an underground laboratory and accommodated important - partly large-scale - in-situ experiments that were carried out in collaboration with international partners. The "Brine Migration Test" was performed in cooperation with the US Department of Energy. Co-60 sources and electrical heaters were used to study the influence of radiation and heat on rock salt and proved the suitability of rock salt as host rock for waste. [10] Within the "HAW-project" the technology for vitrified high-level waste canister transportation and emplacement was developed and tested. [11] Unfortunately, the active in-situ test had to be given up due to licensing problems and funding uncertainties.

Despite some drawbacks quite a lot of successful international research projects were performed in the Asse mine: The „Active Handling Experiment with Neutron Sources" (AHE) which was carried out from 1991 to 1995. This experiment had the goal to investigate the effects of neutron backscattering from the surface of the narrow drifts in a repository on the occupational dose burden during underground waste handling [12]. The DEBORA-experiments (Development of Borehole Seals for Radioactive Waste) simulated the borehole emplacement of steel canisters containing vitrified waste originating from reprocessing of spent fuel. [13] The TSDE

experiment (Thermal Simulation of Drift Emplacement) simulating the drift emplacement of heavy self-shielding casks for spent fuel was the most important experiment performed in the Asse. It was designed in 1985 as a full-scale experiment. Six heater casks were emplaced in two drifts. After installing a lot of measuring devices the drifts were backfilled with crushed salt. Heating started in 1990 and was finished in 2003. With a 10-year heating period it was the longest-running in-situ heater experiment worldwide. Excellent data concerning the mechanical behavior of the surrounding rock salt, the crushed salt backfill, the EDZ behavior, the corrosion behavior of container materials, and instrument performance were collected. Post-test drift excavation and analysis gave valuable additional information and confirmed measurement results. Modeling tools to be used for describing the THM-behavior were further developed substantially during the experiment. Collaborators from European countries and the US participated in these so called BAMBUS I and II-experiments within the 4<sup>th</sup> and 5<sup>th</sup> Framework Program of the EC. [14], [15].

Lessons learnt from all these experiments are that legal requirements can be fulfilled, comparison and validation of material behavior with measurements is possible, validation of function and reliability of large technical equipment is feasible. Today it is commonly acknowledged that the use of large-scale or full-scale in-situ demonstration experiments is indispensable. This is of special importance to get public acceptance for safe and secure handling of emplacement technology.

Presently, the Asse mine is in the closing phase and no further experiments will be possible. In Germany, an underground laboratory in rock salt is no more available.

Another example for important R&D coordinated by PtWT+E was a large-scale experiment investigating the possibility of shaft sealing (Fig. 3).

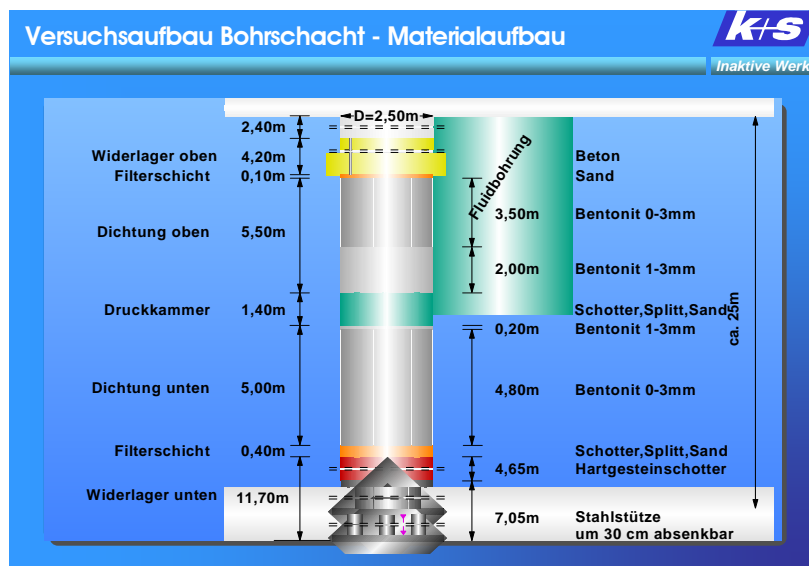


Fig. 3. The large-scale shaft seal experiment

This joint project was conducted and managed by the Kali und Salz (K+S) company, Kassel, which is not only the leading salt and potash producing company in Germany but also an internationally well known company in this business.

The project was funded by BMBF and belongs to R&D activities carried out with regard to the underground disposal of chemotoxic waste. Although the results are not intended to be used for HLW disposal, a lot of expertise was gained.

In a synergistic way the experiences gained may be of great use also for other disposal options when dealing with shaft sealing problems. The two-phase project was launched in 1994 and ended in 2002. The goal was to plan, construct and test a long-term stable shaft sealing system. The project was successfully finished and showed that gravel columns with a height of several hundreds of meters can be realized showing nearly no measurable subsidence after the construction phase. It could further be shown that the column was stable after flooding. The measured subsidence of the basaltic gravel was in the mm-range. Sealing elements based on specifically designed and manufactured bentonite material were tested in a number of medium-scale tests. A final large-scale experiment with a bore shaft of 2.5 m in diameter, simulating real shafts with diameters of 5 to 7 m, was performed. A brine pressure of up to 7 MPa was applied to the bentonite seals of the bore shaft-experiment for several hundreds of days. The experiment was partly decommissioned to get detailed information on the system behavior and the surrounding rock salt during the lifetime of the experiment. It was shown that the sealing element is stable and technically tight (permeability lower than  $10^{-18}$  m<sup>2</sup>). Therefore, it is representative for future sealing elements to be used in real shafts. [16], [17] The large-scale tests were accompanied by numerous laboratory experiments and numerical modeling.

The project results are presently used by K+S in the closing activities of three shafts of a salt mine. This mine has to be kept dry over long time because of the highly soluble potash minerals found in the vicinity of the underground openings. By this measure a subsidence of the area above the mine could be avoided, which would not be the case if the mine would be flooded and dissolution of the underground openings would occur.

Engineering work and large-scale experiments are only one side of the medal. The other side comprises the wide field of laboratory experiments, the study and modeling of increasingly complex systems, aiming at assessing the performance of the total repository system. During the last years a lot of R&D had been performed to improve the knowledge in these fields. Especially the tools and instruments to be used in modeling and performance assessment were substantially improved and tested in several national and international projects. [18]

Within a performance analysis, the simulation of both groundwater movement and radionuclide transport is of great importance. For a repository in rock salt this is of special concern because the variable salinity of the groundwater must be considered. During the last few years very sophisticated and outstanding tools had been developed that allow to perform 3d modeling of the groundwater flow which occurs in the overburden of a salt repository [19]. It is now possible to simulate groundwater movement for large (km<sup>2</sup>) and complex hydrogeologic and geologic areas



in calculation times of hours using highly sophisticated numerical methods and using parallel computers. In particular, this program can also be applied for problems that are not related to radioactive waste disposal, e.g. simulating the spatial and temporal evolution of mining regions or problems related to coastal aquifer management.

Based upon the same numerical methods, a fast 3d-transport code to model pollutant migration through porous and equivalent-porous media for large and complex areas was developed including all retention and interaction processes relevant for long-term safety assessment requirements. [20]

## **INTERNATIONAL COOPERATION**

International cooperation still is and will be an indispensable part in R&D on radioactive waste disposal. For decades German scientists have participated actively in R&D projects performed in foreign URLs. The advantages of these collaborations are to gain experience in techniques relevant for site characterization and for repository construction and operation, and to develop and improve the understanding of models for performance assessment. International co-operation in URLs is necessary to better understand the pros and cons of possible candidate formations, especially if, as in the German case, the government decides to halt the underground exploration at Gorleben and to investigate other rock formations. Then the participation in R&D projects in foreign URLs becomes of paramount importance because Germany has no underground laboratory, neither in hard rock nor in clay. In order to be prepared for site selection process in other formations co-operation in foreign URLs is the only way for German scientists to gain experience in other host rocks.

German scientists are involved in projects in the Swiss Grimsel test site (GTS) and the rock laboratory in Mont Terri, in the Swedish Äspö Hard Rock Laboratory (HRL), and in the currently constructed underground laboratory in Bure, France.

The investigations in granitic rock being performed in the GTS are mainly dealing with topics related to colloid and radionuclide migration, gas migration in the engineered barrier system and the interface to the geosphere, and investigations with regard to the behavior of the engineered barrier system.

Comparable topics are dealt with in the HRL Äspö. The host rock is a saturated fractured rock in contrary to the Grimsel granite which is a relatively dry. Main objects of interest are developing and testing of instrumentation and methods for underground rock characterization, behavior of the engineered barrier system and the Prototype Repository project, the development of numerical models for the calculation of flow and transport processes in natural and technical barriers as well as on studies of radionuclide migration (in particular actinides) and impacts of colloids and microbes.

In Germany R&D concerning argillaceous rocks started relatively late and was performed on a much smaller scale compared to research activities in granitic rock which started two decades ago in the GTS. The work on argillaceous rocks was intensified after the political decisions to phase-out nuclear energy and to investigate other potential host rock formations because of the doubts concerning the salt option.

In the Mont Terri rock laboratory, which is constructed in opalinus clay, a consortium of international organizations - among others from Switzerland, Germany, France, Belgium, Japan, and Spain - has been carrying out several projects related to issues like rock characterization, the development of instruments for rock characterization, study of the THM- behavior, modeling of processes that are expected to occur in the rock as a consequence of the storage of radioactive waste, etc.

German research institutions participate in the experimental R&D-program of ANDRA at the new underground rock laboratory being built at Bure in the Meuse/Haute-Marne district. Issues addressed are the study of thermo-hydraulic-mechanical properties of the clay, the characterization of this specific clay material, and participation in the design, execution and evaluation of the heater and ventilation tests. This collaboration will be a unique opportunity to be involved in such a project from its very beginning and will be a valuable source of information.

In general, the collaboration of German scientists in URLs in clay is a sort of preparation for possible future activities in German clay rock.

### **EC-Framework Programs**

Since 1975, German scientists have participated actively in R&D projects performed under the EU framework programs based on the EURATOM agreement. At the beginning, this participation was largely limited to R&D activities related to the disposal in rock salt. Substantial results have been achieved by collaboration with foreign partners in several projects. [21]

German research institutions currently participate within the current 6<sup>th</sup> Framework Program in the Integrated Projects (IPs) NF-PRO (Near field processes), ESDRED (Engineering Studies and Demonstration of Repository Designs) and FUNMIG (Fundamental Processes of Radionuclide Migration). IPs are new instruments within this framework program to “support objective-driven research, where the primary deliverable is new knowledge”. [22]

Main objective of the IP NF-PRO is the understanding and physical and numerical modeling of the dominant processes and process couplings in the near-field and their coupling for different host rocks and repository strategies. ESDRED is a joint research effort by national radioactive waste management agencies (or subsidiaries of agencies) and by research organizations to demonstrate the technical feasibility at an industrial scale for activities carried out to construct, operate and close a deep geological repository. FUNMIG is focusing on the radionuclide-host rock interactions providing a dominant barrier between radioactive waste and the biosphere.

### **PERSPECTIVES**

The knowledge on disposing of heat-generating waste in rock salt has gained a certain level of maturity. It could be shown that technological problems can be tackled. Techniques for the emplacement of spent fuel and vitrified high-level waste are at hand. A lot of knowledge has been gained about the material behavior of rock salt and crushed salt backfill, databases and models were permanently improved. However, some open questions still exist and must be answered. Especially, all aspects to be used for formulating the safety case have to be considered

and critically reviewed. This is of special concern for subjects like the compliance time of 1 million years with regard to geology and climatic changes, the role of safety indicators and of scenarios, the quality and the reliability of databases that must be scientifically approved, etc. A good approach in this way was suggested in the EC-NET-EXEL-project [23] by a group of international experts who collected topics to be worked on in future R&D projects on a national and European level.

For German scientists, the Government's decision to investigate other host rock types than rock salt as potential rock formations to host a repository is a challenging task, because it needs a lot of effort to reach the same level of maturity in knowledge and expertise as in salt in due time avoiding at the same time a tremendous loss of competence in salt related fields. Therefore, at present the focus lies on international cooperation and exchange of knowledge, because only through international and interdisciplinary cooperation, systems as complex as the one under scrutiny become amenable to solutions.

## CONCLUSION

BMWA and BMBF are funding non-site specific R&D for underground disposal of radioactive waste as a precautionary measure. This research is embedded in the EC's Framework program and international cooperation projects in foreign underground rock laboratories.

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. Yet, for several reasons, German scientists have participated and will participate in foreign R&D projects. The participation in foreign R&D projects takes place in European underground rock laboratories in different host rock formations (argillaceous rock, crystalline rock). The co-operation is of paramount importance because no German underground rock laboratory is available. Furthermore, it is important to get a better understanding concerning the pros and cons of the selected candidate formation in case the disposal in rock salt will be no future option in Germany. A further important point still is to strengthen the international co-operation and information exchange and to motivate the community to cooperate in several projects in the EC-Framework Programs.

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