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US/German Collaboration in Salt Repository Research, Design and Operation

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ABSTRACT

Recent developments in the US and Germany [1-3] have precipitated renewed efforts in salt repository investigations and related studies. Both the German rock salt repository activities and the US waste management programs currently face challenges that may adversely affect their respective current and future state-of-the-art core capabilities in rock salt repository science and technology. The research agenda being pursued by our respective countries leverages collective efforts for the benefit of both programs.

The topics addressed by the US/German salt repository collaborations align well with the findings and recommendations summarized in the January 2012 US Blue Ribbon Commission on America's Nuclear Future (BRC) report [4] and are consistent with the aspirations of the key topics of the Strategic Research Agenda of the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP) [5].

Against this background, a revival of joint efforts in salt repository investigations after some years of hibernation has been undertaken to leverage collective efforts in salt repository research, design, operations, and related issues for the benefit of respective programs and to form a basis for providing an attractive, cost-effective insurance against the premature loss of virtually irreplaceable scientific expertise and institutional memory. A brief overview of ongoing activities, achievements, and prognostications are given in the paper.

INTRODUCTION

The scientific understanding of rock salt advanced greatly in the latter half of the 20th century from cogent and systematic research on salt formations as promising and suitable geologic media for disposal of radioactive wastes. Salt research was promoted by the National Academy of Sciences [6] in 1957, when they stated that their collective and favorable opinions regarding salt disposal would be predicated on "the research (being) done before any final conclusion is reached on any type of waste disposal."

Predictable geology and a number of inherent characteristics such as low permeability, high thermal conductivity, and self-healing underlie the technical foundation supporting salt formations as a suitable repository host. The salt disposal concept is bolstered by successfully operat-

ing deep geological repositories for chemical-toxic wastes in Germany and the WIPP in the US, which is the first geologic repository for transuranic waste. German and the US therefore possess knowledge and sound expertise to apply to the special issue of disposal of heat-generating waste in salt. From a practical viewpoint, salt repository design has a great advantage over other geologic formations because approximately 150 years of conventionally mining salt has shown that salt mining is safe, easy, inexpensive, and applies qualified technologies.

During the last 40-50 years extensive research, development and demonstration (RD&D) activities have been conducted and contributed to the profound knowledge available concerning rock salt. These achievements were manifested in laboratory and in situ experiments, as well as in large-scale demonstration activities [e.g., 7-11]. In recent years noteworthy progress was made in the US and Germany on safety assessment exercises, geomechanical benchmark modeling, and technological developments, such as emplacement techniques [12-13]. Because of this work, comprehensive knowledge and sound expertise in various fields of salt repository science and engineering have been acquired over the years. Therefore, German and US financial and intellectual investments in salt repositories are unique and represent state-of-the-art global assets.

It is acknowledged, that the enormous prospect of building a salt repository and the scientific-technological challenges connected can be tackled much more efficiently by an international job-sharing effort. Such collaboration certainly holds the potential to reduce risk and cost while strengthening the scientific basis. Furthermore, international collaboration provides and offers the opportunity for education, training, and the exchange of scientists to promote development of the requisite human capital needed over repository lifetimes. The importance and the potential of the collaboration has been acknowledged by the responsible ministries and departments and underscored in 2011 by the signing of a Memorandum of Understanding (MoU) between DOE´s offices of Environmental Management and Nuclear Energy and the German Ministry of Economics and Technology, which is responsible for site-independent RD&D in Germany.

Long-lasting international cooperative efforts unambiguously showed that the fruitful and successful cooperative work has contributed significantly to each national knowledge base. It has also fostered exchange between researchers in scientific and technological areas. Very positive outcomes arise when common purpose can be defined in overlapping projects, particularly when collaboration adds to multidisciplinary and multinational networks. It is accepted that it becomes more and more valuable to cooperate in joint international projects 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. Moreover, the benefits of international cooperation can be communicated to the public, thereby demonstrating common understanding in the world-wide scientific community to solve the task of waste disposal together in a multinational, safety-oriented, and responsible effort.

Recent developments in both countries have given rise to renewed collaborations in salt repository investigations and related studies. Both the German rock salt repository program and the U.S. waste management program grapple with challenges in terms of maintaining and honing their respective current state-of-the-art core capabilities in rock salt repository science and technology. The following sections describe several venues of constructive international collaborations being pursued by US and German salt repository researchers.

DISCUSSION

With regard to the Government's obligation to provide repositories for high-level radioactive waste (HLW) (spent fuel and vitrified high-activity waste), basic and applied R&D is needed in order to make adequate knowledge available to implementers, decision makers and stakeholders in general. In Germany the 6th Energy Research Program of the Federal Government is the general framework for RD&D activities in radioactive waste disposal [14]. The Ministry of Economics and Technology (BMWi), 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. Non-site specific R&D projects are funded by BMWi on the basis of its current Research Concept [15]. It is recognized that international cooperation has been and will be an indispensable part in RD&D on radioactive waste disposal, because it is valuable and practical to cooperate in joint international projects, not only to distribute the financial burden, i.e. by operating underground research laboratories (URL), but to use the distributed and sound expertise for solving common national and international problems. Significant support for international activities is funded or co-funded by BMWi, on the one hand because of its responsibility for this research, but, on the other hand, as a sign for the importance attached to international cooperation. These activities are based on agreements between Governments, scientific institutes, universities or national research centers, and the European Commission.

The importance of the collaboration between US and Germany was recently re-emphasized by the responsible ministries and departments in the respective countries. Collaboration protocol was underlined in 2011 by the signature of a MoU between DOE´s offices for Environmental Management (EM) and Nuclear Energy (NE) and the Ministry of Economy and Technology and now provides the basis for joint activities addressing RD&D topics on radioactive waste (radwaste) disposal. It is recognized that international scientific cooperation serves mutual benefit in assuring progress in science through shared research and development. All prominent scientific research institutions working in the field of radwaste disposal are involved, including national research centers and universities. The MoU also delineates the over-arching expectations of the types of cooperation and collaboration.

After changes and new developments in radwaste policy and dormancy of international cooperation for some time, it was decided to revive US/German collaborations. With this new beginning, the 1st US/German Workshop on Salt Repository Research, Design and Operation was organized in Canton MS in 2010. Of course this was not the first such workshop, but rather the *first of a new era*. The first joint workshop mapped out a potential research agenda and renewed working relationships at the institutional and individual levels. The workshop brought together key investigators in salt repository science and engineering [16]. The workshop basically reinitiated previous collaborative research activities that had been waning for about ten years. As the German and US salt repository programs move forward in their respective countries, the intent is to maximize individual resources for the mutual benefit of each program.

In 2011, the 2nd workshop was organized in Peine, Germany, to intensify the cooperation, to coordinate a potential research program which meets mutual interests, and to increase the collec-

tive efforts for the benefits of the respective programs and RD&D initiatives. During the 2nd workshop, the current status of repository research in salt formations in Germany and the US was outlined. In five sessions, safety analyses, sealing concepts for repositories in salt, strategies for the backfilling of mine openings, deformation and healing of rock salt, and natural analogues for the final disposal in salt were presented and discussed. The progress is documented in the proceedings document [17], which provides a discussion as well as direction for future common activities.

In 2012, the 3rd workshop of this series was organized by Sandia National Laboratories (SNL) in Albuquerque, NM on October 8-11. More than 60 participants were present, including thirty salt research scientists from Germany and an approximately equal number from the US (including representation from DOE/NE and DOE/EM). As these collaborations proceed, the scientists and engineers have sharpened the focus on certain key areas. In this particular workshop, the US/German salt researchers considered the state-of-the art in three main salt repository topics:

1. The Safety Case for HLW disposal in salt. The 2.5 day technical exchange by the international salt research community illustrated the solid foundation for supporting a safety case and performance assessment of HLW repositories in salt. Germany's recently issued preliminary safety analysis for Gorleben (Vorläufige Sicherheitsanalyse Gorleben or VSG) [1] was discussed extensively from the domal salt perspective, in addition to the review of the US ability to support a safety case from a bedded salt perspective.
2. Benchmark modeling. Based on an initiative a few years ago, German salt modeling researchers and Sandia signed an MoU for a Joint Project to formulate a strategy for generic modeling of thermomechanical field-scale tests. German researchers have projected the possibility to undertake testing of WIPP salt to adapt their constitutive models for (bedded salt) analysis.
3. Reconsolidation of granular salt. Reconsolidation of granular salt is a key technical issue for German repositories, WIPP (i.e., panel closure options), and design and performance of salt repositories for heat-generating waste in the US. It was evident from the workshop that the international database of salt reconsolidation research is extensive and continues to deepen.

Though not explicitly a presentation topic, much effort was placed on building new collaborations and researcher-to-researcher relationships among the many newer and younger members of the research community to aid in knowledge transfer and succession planning. In addition, there were renewed discussions about other possible field-scale collaborations to exploit our respective URL resources.

As with previous US/German salt repository workshops, these proceedings will be prepared and posted on our Salt Repository Website [18]. (http://www.sandia.gov/SALT/SALT_Home.html). The 4th US/German salt repository workshop is planned for Berlin Germany in September 2013. The main topics will include geomechanical issues such as reconsolidation of salt, the safety case for HLW in salt, confidence and data supporting plugging/sealing/barriers, and an introduction of hydrology collaborations.

Within barely three years of this newly restarted US/German endeavor excellent results have been reached, which are perfectly in accord with the aims of the MoU:

- Exchange of general technical and scientific information, organization of meetings, seminars and workshops;
- Joint participation in research and development programs of the European Commission;
- Observation of, and participation in, studies carried out at locations appropriate for the participants;
- Exchange of staff between the sending and receiving organizations;
- Exchange of academic/university personnel for education and training, all pursuant to appropriate written agreements.

Moreover:

- Many participants in the US/German workshops also contribute substantially to the conferences of the Solution Mining Research Institute (www.solutionmining.org) and the Mechanical Behavior of Salt Symposia (www.saltmech7.com).
- The Institute of Nuclear Waste Disposal of the Karlsruhe Institute of Technology and Los Alamos National Laboratory jointly organized a workshop on Actinide Brine Chemistry in a Salt-Based Repository [18-Altmaier]. This will be continued with future meetings, workshops and other types of scientific exchange.
- Collaboration is also performed in EC-funded projects on monitoring repositories and the investigation of radionuclide behavior [19-MoDeRn]
- Collaboration in the area of safety assessment aspects (handling of uncertainties) was strengthened between US and German safety analysts.
- Collaboration in engineering of machinery for repository operation including demonstration activities is being discussed.

A very important joint project is addressing the benchmarking of constitutive models for rock salt. This project was running for some time on a national (Germany only) basis. The focus is on modeling the temperature influence on salt deformation and modeling sealing and healing of damaged rock salt [20]. When SNL joined the project as the seventh partner it was a potent addition because of their recognized expertise and tools in salt repository thermomechanical analysis.

The present project phase comprises performance and back-calculations of specific laboratory tests as well as simulations of the in situ structures, such as a heated borehole of an experiment performed in the former Asse mine. The results are being compared with each other and with former in situ measurements. The modeling of healing of pre-damaged rock salt is studied with simulations of a drift in the Asse II salt mine that was excavated in 1911, and of which a 25 m long section was lined after 3 years with a cast-steel tube and concrete. The simulation results will be compared with each other and with in situ permeability measurements that were made behind the liner 85 years after the installation. In the future it is intended to perform benchmark simulations with the considered models of two identical rooms at the WIPP—one room was ambient and the other heated to conditions simulating high-level waste disposal. The study is planned to be accompanied by an extensive laboratory test program using WIPP salt to generate data for the parameter determination of Permian bedded salt.

One of the most important issues in any nuclear waste repository program is to build a safety case that provides the entire scientific-technical basis. In the US, for example, the Safe-

ty/Performance Assessments (SA/PA) was conducted for and in conjunction with the 1996 Waste Isolation Pilot Plant (WIPP) Compliance Certification Application (CCA) to demonstrate the long-term performance (10,000 years). The application was intensely scrutinized by many diverse stakeholders, including an international peer review group coordinated jointly be the Organization for Economic Cooperation and Development Nuclear Energy Agency (OECD-NEA) and the International Atomic Energy Agency (IAEA), and ultimately approved by the U.S. Environmental Protection Agency (EPA).

In Germany, currently a multi-organizational project, funded by the Ministry of the Environment, is currently making for the first time a preliminary safety analysis for a possible HLW-repository in a domal salt structure [1]. A comprehensive approach addressing all issues necessary (e.g. features, events and process (FEP)-catalogue, safety concept, repository concepts, inventory, geology, and retrievability) has been developed. A *safety case* is a formal compilation of evidence, analyses, and arguments that quantify and substantiate the safety of a repository. The safety case could be initiated in the US by using the extensive technical basis already available for radioactive waste disposal in Germany as well as the experience and technical basis supporting the WIPP certification and operation [21]. Because of the importance of these issues for the respective programs and for the scientific relevance of these topics, it was agreed to intensify the dialogue and information exchange between US and German scientists.

The German regulatory framework requires using state-of-the-art technology in any radioactive waste repository. Therefore, significant effort has been invested in developing the technological ways and means for safely hoisting heavy waste packages containing either spent fuel or vitrified HLW, handling and transporting them underground, and disposing of the packages at their final position. These operations involve among others safely hoisting payloads of up to more than 160 tons, well beyond the state-of-the practice in conventional mining. The German design and demonstration work on a 1:1 scale can provide a valuable resource for the currently envisaged demonstration tests in the WIPP URL research work in the US [22]. A preliminary discussion on the use of the new underground space being created at WIPP was held at the 3rd US/German workshop in Albuquerque.

One of the most essential outcomes of the collaboration up to now was the creation of the so called Salt Club. It was acknowledged that countries such as the US, Poland, the Netherlands, and Germany have or still consider salt formations as highly favorable rock types to host a deep geological repository for high-level radioactive waste. Considering this and discussions during the first workshop and preparatory activities of workshop participants a proposal was made to have a co-operative project – the Salt Club - under the aegis of the Nuclear Energy Agency. The Salt Club was officially acknowledged by NEA in spring 2012. During the workshop a preliminary list of activities was formulated as bases for future Salt Club activities. Potential topics included a compendium of salt deposits, natural analogues applied to a rock salt repository, creating a consolidated FEP-catalogue for rock salt, and knowledge base on rock salt. The first topic addressed was natural analogues. A successful international workshop was organized in Germany in September 2012 with a large number of participants from industry and scientific institutions. The presentations will be published by NEA.

CONCLUSION

The ongoing cooperative effort of the United States and Germany is a vivid example of the benefits of international cooperation between peers and for mutual advantage. A most obvious benefit is the optimization of scarce human resources use, which is of paramount importance in societies where know-how in the nuclear field is becoming a rare commodity. But also the economic gains of avoiding duplication of efforts and of adding national capabilities to jointly achieve common objectives is most significant.

Intermittent collaboration and cooperation between Germany and the US on repository sciences has been ongoing since the 1960s. These collaborations were particularly productive in the period of time leading up to the certification of WIPP. The corpus of information available today provides a firm foundation for a HLW salt repository safety case, both in Germany and the US.

Yet, perhaps the most imperative outcome of the re-strengthened cooperation is knowledge preservation. For a variety of reasons repository projects in both countries have proven to require much more time than initially anticipated. Widespread skepticism about nuclear power use has rendered the waste management field uninviting for young scientists and engineers. Attracting qualified staff and transmitting the accumulated know-how to the next generation is therefore a major challenge. International cooperation is an excellent vehicle to awaken the enthusiasm of young people and motivate them to join the long-term effort required for safe waste disposal. Joint work in international cooperation opens also the minds to new thinking, different perspectives, and diverse perception of identical issues. Correspondingly, activities in this particular field, as the exchange of experts for limited period of time, which is being discussed between some of the cooperation partners, is expected to render major benefits.

As these collaborations move forward and deepen, the authors of this paper put forward a shopping list of potential goals.

- Develop and exchange rock salt information among nations currently pursuing or considering rock salt as a candidate deep geological repository medium.
- Collaborate with international peers and stimulate interest in salt as a viable repository host medium.
- Identify and perform fundamental joint research into areas where understanding is incomplete.
- Exchange and transfer advanced methods and tools developed for salt disposal to industry.
- Characterize and qualify the information available.
- Promote information exchange on approaches, methods, methodologies, and technologies
- Outreach to other salt related applications.
- Afford technical experts access to and interchanges with the latest international developments in salt mechanics sciences.
- Inform and provide advice on conceptual topics, performance descriptions and modeling.
- Publish results, models, reliability, data quality, and evaluate national and international RD&D activities.
- Develop a central library of acquired salt data, information, and knowledge with broad access provided via the Internet.

- Address the fundamental issue of knowledge management.
- Reinvigorate the science (chemistry and physics) of rock salt through education, training development of new researchers and students.
- Perform fundamental research.

Recent progress, motivated leadership, and focused workshops allow the authors of this paper to express an optimistic view for salt repository future.

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