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Salt Disposal of HLW: Path Forward for US and German Collaboration

F. D. Hansen
Sandia National Laboratories, Albuquerque NM 87185 fdhanse@sandia.gov

INTRODUCTION

Recent developments in Germany and the United States have renewed efforts in salt repository investigations. Representatives of institutions in both countries conducted a workshop in Canton Mississippi USA. The workshop was hosted by Mississippi State University and Sandia National Laboratories (1). The purposes of the workshop were to coordinate a potential research agenda of mutual interest and to leverage collective efforts for the benefit of their respective programs. The following article summarizes the findings of the workshop and describes a series of investigations to advance the state-of-the art.

DESCRIPTION OF THE WORK

Invited key investigators in salt repository science and engineering presented past, present and future directions in salt research applied to heat-generating waste disposal to identify a coordinated research agenda that participants can agree in principle to pursue, with the intent of maximizing individual resources for the mutual benefit of each program. By conducting this workshop, participants intend to reinitiate collaborative research activities and bring them to the level of cooperation enjoyed in the past, create a potential joint research agenda, and renew working relationships among institutions and individuals.

Predicated on the workshop presentations (posted on the website) and other material, participants identified several potential coordinated research areas. As the German/USA salt repository programs move forward in their respective countries, the intent is to maximize individual resources for the mutual benefit of each program. This workshop basically reinitiated previous collaborative research activities that had been waning for about ten years.

An abbreviated list of research topics derived from the German/USA workshop is given in this section. A more comprehensive summary of the workshop will be published in proceedings. In some cases, the collaboration topic is less *research* than a recognition that salt repository sciences are encumbered with some lingering issues, which need to be reviewed and summarized before embarking upon a research agenda. In several instances, clear research topics for collaboration are identified.

Many of the primary attributes of salt disposal are known and have been demonstrated at an operational scale over significant periods of years. However, there remain pesky issues that perhaps have either not been substantially investigated or reviewed to the point of objective reconciliation. Some of the *issues* identified at the workshop may represent convictions or perceptions in the absence of supporting scientific evidence. The following list identifies phenomena or processes, which might be incorporated into a performance assessment model, if warranted.

Brine Migration. Brine exists in bedded salt in three forms: fluid inclusions, hydrous minerals and grain boundary water. Owing to the characteristics and environments of the brine in salt, its transport or migration occurs via three primary mechanisms: motion of the brine inclusions in a temperature gradient, vapor-phase transport along connected porosity and liquid transport driven by the stress gradient.

Vapor Transport. One of the most important issues in a high-level-waste repository is the presence of and the fate of any brine that may be present. Schlich (2) modeled water inflow of the heater experiments conducted at the Asse mine. It appears that vapor transport processes account for moisture movement, and the often mentioned brine inclusion migration is less important.

Gas Generation and Pressure Buildup. Hydrogen gas generation from anaerobic corrosion of steel container materials might inhibit rock convergence and consolidation of crushed rock backfill. The associated hydrogen volumes and rates require further quantification.

Buoyancy. The movement of canisters containing heat-generating nuclear wastes buried in a salt formation has been questioned. The existence of buoyant forces due to thermally-produced density differences suggests the possibility of initiating convection cells in a plastic medium like salt.

Heat Effects. It is widely held that the heat load from high-level waste is detrimental to operations and long-term isolation in salt. This perception may be balanced by accounting for heat effects that are favorable to operations and long-term safety.

Hydrofracture and Dilatancy Boundary. Mechanically or hydraulically induced permeability is based on the same microphysical process of percolation flow along grain boundaries after exceeding a threshold. In both cases the induced permeability is created by removal of intergranular cohesion.

Consolidation of Hot Granular Salt. Crushed salt used as backfill may be an important element in a potential high-level-waste repository. Relatively little elevated temperature mechanical testing has been conducted for crushed salt. The accelerating effect of moisture on consolidation needs further investigation. Modeling concerned with long-term, low-porosity, two-phase flow is likely required.

Solubility and Transport. The salt repository community continues to research radionuclide solubility as if there is ample brine available within the salt to dissolve and transport the waste. There are at least two parts to this important issue: one concerns brine sources and volume and the other concerns existence of a pressure gradient capable of driving the soluble radionuclides to the biosphere.

Degradation. This research area addresses the underlying hypothesis that waste forms placed in salt will degrade sufficiently that the residue can be removed readily by a human drilling intrusion.

Radiolysis. Radiation is known to liberate hydrogen but further data are needed on the effect of combining radiation and temperature on the waste materials, waste packages, and the salt.

To be comprehensive in the pursuit of high-level waste salt repositories it is incumbent upon the salt repository advocates to objectively evaluate these issues.

FUTURE DIRECTION

Topics given above pertain to specific phenomena, several of which would be incorporated into the next generation of modeling. Thus, the future directions are likely to include evaluations of fundamental processes in the laboratory, exploration of the enormous promise of new computational tools, and possible large-scale experiments for scale effects appraisal.

Stone and coworkers (3) have taken a leading role in developing coupled process models. Recent investments in the Sandia SIERRA Mechanics code suite have supplied the basic building blocks for realizing a multi-physics capability for repository systems engineering. Several discriminating features of this highly nonlinear, thermal-mechanical analysis are being developed. Past analyses of salt creep and room closure have been constrained by the computational complexity of simulating coupled processes. Models for simulating the disposal concept have been run using the advanced code suite of SIERRA Mechanics, developed at Sandia to run on massively parallel computing hardware.

Hampel and coworkers (4) recently summarized numerical simulations for the design and stability analysis of underground openings in rock salt. Between 2004 and 2010, six project partners compared their constitutive models for rock salt. The results of specific benchmark calculations demonstrate that the models describe correctly the relevant deformation phenomena in rock salt under various influences. Their benchmark calculations and comparisons of isothermal results in joint projects showed that the constitutive models captured deformational phenomena in rock salt below and above the dilatancy boundary.

Based on the developments at Sandia Labs with SIERRA Mechanics and the developments described by several German salt researchers, it would appear that different teams have collected a comprehensive experimental data base and theoretical knowledge base for the mechanical deformation of rock salt. Several advanced constitutive models have also been developed and applied. However, the strong temperature dependence on the mechanical deformation of rock salt needs to be reevaluated today if the salt disposal option is selected. For the calculation and assessment of the tightness of the geological barrier rock salt around a repository, further effort is also to be made in the investigation and modeling of salt damage healing and the corresponding reduction of permeability.

Coupled thermo-mechanical benchmark 3-D simulations could be performed to evaluate intact salt in order to calculate the evolution of stresses, strains, dilatant volumetric strains, and damage around a potential repository for heat-generating radioactive wastes in rock salt.

The outcome of the geochemistry workshop should attempt to integrate respective research goals with those described in this paper. The ideal future would include advancing the technical baseline regarding the processes described in the German/USA salt repository workshop, and performing appropriate code benchmark calculations, ultimately leading to a reliable in situ test for model validation.

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