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The following summaries are provided as fulfillment of milestone M4FT-15SN0811021 and represent international collaboration activities in disposal research funded by the US DOE Used Fuel Disposition (UFD) Campaign during Fiscal Year 2015.

UFD funded international interactions with the Germany

There are ongoing collaborative efforts between salt repository research scientists from US and Germany. These collaborative efforts focus on fundamental topics such as thermomechanical behavior of salt, plugging and sealing, the safety case, and performance assessment, and are aimed at advancing the basis for disposal of heat-generating nuclear waste in salt formations. In FY2015 these collaborations included: one-on-one interactions; approximately quarterly videoconferences; the 5th US/German Salt Workshop (Hansen et al. 2015), held September 8-10, 2014 in Santa Fe, New Mexico; and the 4th Nuclear Energy Agency (NEA) Salt Club Meeting, held February 25, 2015 in Paris, France. In addition, the topic of operational safety was introduced as a new collaborative topic in FY15. Details of the collaborations in several areas are summarized below, based on descriptions provided in Hansen et al. (2015):

Design and Operational Safety

The serious operational events at WIPP in 2014 provided sharp focus and tangible reality to the topic of operational safety. Workshop participants gained deeper appreciation for the seriousness of operational safety and the complexity involved with recovery from off-normal events. Design of a salt repository for high-level waste and spent nuclear fuel takes into account retrievability and safety requirements. Examples provided at the 5th US/German Workshop included:

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- In 2010, the Bundesministerium für Umwelt (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) [BMU 2010] issued the new *Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste*. The safety requirements focus on retrievability and make it a strict licensing requirement. According to the safety requirements, retrievability is considered as the planned technical option.
- A very recent and important development is the increasing relevance of probabilistic approaches in the regulation of geologic repositories. The shift from deterministic to probabilistic approaches is clearly exemplified in the US DOE nuclear facility safety analysis (WIPP Documented Safety Analysis) and the Yucca Mountain License Application. For the Yucca Mountain Project probabilistic requirements have even been formalized in the U.S. safety regulation (10 CFR Part 63). It can be seen that operational safety analysis is changing, at the same time that safety experience is accumulating at existing facilities. Especially for new systems and technologies, probabilistic approaches provide important supplements for safety demonstration. Nevertheless, since probabilistic approaches for large-scale systems are yet under development it is of vital importance to facilitate an international exchange in order to avoid diverging methodologies, respectively to build up confidence in probabilistic approaches.
- Keynote speaker, Dr. Steve Rottler, highlighted examples spanning a variety of research, design, development, prototype, qualification and production activities, where the breadth of work encompasses micro- to macro-scale efforts with varying levels of complexity. For the 2718 labs located within Sandia National Laboratories, multiple hazards in combination typically have to be considered. To ensure safety in this highly complex environment the approach of Engineered Safety had been developed and introduced at SNL. How the approach is implemented in reality was explained by Dr. Rottler by means of the examples of a bioremediation project, a polymer R&D laboratory, and the Z-Machine accelerator containment system. A very important basis for gaining safety is implementing a Critical Thinking Mindset which means to encourage critical thinking in daily life.

Geomechanical Issues

Ongoing collaborations between US and German salt researchers include testing on all scales, advanced thermal-mechanical modeling and benchmarking, and seal system performance, to name a few. Decades of R&D have rendered a mature understanding of salt formation behavior as well as interactions between the salt and engineered and geotechnical barriers. Specific collaborations in FY15 included:

- Investigations of the mechanical response and evolution of the salt underground initiated by excavation, including ongoing geomechanics matters pertaining to room closure.
- Code benchmarking of salt constitutive modeling and implementation using large, modern computational capacity.
- Continued collaboration in laboratory and field testing and geomechanical modeling as part of Joint Project III [Hampel et al. 2012; 2013]. This work has ensured validated and verified computational capabilities for both bedded and domal salt are being developed and parameterized.
- Lessons learned from the Gorleben site (Vorläufige Sicherheitsanalyse Gorleben or VSG)
- Plugging and sealing studies
- Preparation of an invited, external publication on salt geomechanics [Hansen and Popp 2015].

Underground Research Laboratory (URL)

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In collaboration, US and German researchers have reviewed and evaluated thermally driven processes in salt disposal and identified key technical areas in which to prioritize resources. The goal for disposal research in salt is to provide sufficient technical information to license a repository successfully. The necessity or utility of a salt underground laboratory is to be evaluated in the context of an overall research agenda that supports a license application. In both advanced programs and also in the less advanced ones URLs are considered to be indispensable especially to perform experiments and demonstration activities under repository like conditions. Specific activities in FY15 included:

- The need for a salt URL (including bedded and/or domal salt)
- Identification of a generic research strategy and proposed testing activities for a salt URL.
- Discussion of the use of a URL or other mined salt formation for experimental activities that could capture the early evolution of a salt excavation (e.g., examine the initial, undisturbed conditions, the evolutionary changes imparted by excavation, and the boundary conditions extant when field activities are undertaken).

Safety Case for Heat-Generating Waste Disposal in Salt

Specific collaborations in FY15 included:

- Subject matter experts from the US and Germany are in the process of compiling a comprehensive Features, Events, and Processes (FEPs) catalogue for disposal of heat-generating waste in salt (Freeze et al. 2014; Sevougian et al. 2015).
- SNL has developed a generic safety case for disposal of heat-generating waste in bedded salt. Collaborators discussed elements of the safety case including handling uncertainties and the qualitative contribution of analogues. This progress along with Germany's preliminary safety analysis for the Gorleben site (Vorläufige Sicherheitsanalyse Gorleben or VSG) provide a strong technical basis for a safety case for salt disposal of heat-generating nuclear waste.
- SNL has developed a salt knowledge archive.
- Far-field hydrogeologic modeling, with applicable porous and fractured media flow.
- Exploring public outreach initiatives implemented successfully in other countries to help frame a societal strategy.

The overriding premise for these US/German collaborations is to advance the scientific bases for salt repositories.

UFD funded international interactions with the Republic of Korea

Korea Atomic Energy Research Underground Research Tunnel (KURT)

Deliverable M4FT-15SN0807082, "Report on international collaboration on fluid flows in fractured crystalline rocks," (Y. Wang) will contain the discussion of interactions with KURT

Fuel Cycle Alternative Working Group (FCAWG) under the Joint Fuel Cycle (JFCS) US-ROK Bi-lateral agreement

The Fuel Cycle Alternative Working Group under the Joint Fuel Cycle Studies bilateral between the Republic of Korea (ROK) and the United States (US) Department of Energy (DOE) held meetings on Jeju Island in the Republic of Korea. The meetings began on Tuesday, April 28, 2015 and concluded on Thursday, April 30.

Each of the subgroups within the FCAWG met together, then separately. The three subgroups are shown below with summaries of bi-lateral collaborations.

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USED FUEL DISPOSITION SUBGROUP

1. Progress of Geo-environmental DB for Geological Disposal: [KORAD](#) Integrated Natural Barrier DB System (KOINS)
 - ROK will finalize project at end of July, 2015
 - Freeze requested to see demo of this DB from ROK...maybe at next FCAWG UFD WG meeting [DELIVERABLE FROM ROK TO US]
 - US wants design document info on ROK DB. Needs to be translated from Korean to English. [DELIVERABLE FROM ROK TO US end of Dec 2015]
 - US interested in structure of FEPs database being used in KOINS [DELIVERABLE FROM ROK TO US include with demo deliverable]
2. A Preliminary Applicability of Deep Borehole Disposal for High Level Waste in Korea:
 - Clarification of DBH use for CANDU [feasibility study for pyro process CANDU;
 - US would like more information about the drilling done at the sites in ROK
 - US interested in SiC materials being used for disposal canisters
3. Deep Borehole Disposal:
 - Preliminary information on DBFT was presented and explanation as to why M2 deliverable from the US will not become available until after RFP final process is completed.
4. Unsaturated Zone Modeling Concept and Plan:
 - Sharing experiences: not only the data of UZ modeling but also trial and error using TOUGH on YMP
 - Review the modeling report from KORAD: in part of the suitability and the reliability
5. ROK discussed concrete degradation experimental work at Wolsong site.
6. Experimental Program for Used Fuel Disposition in Crystalline rocks
7. UFDC Generic Disposal System Analysis (PPTX). Geoff Freeze
 - ROK interested in PFLOTTRAN. ROK looking at choosing a PA system and would like info from US on "why PFLOTTRAN"

SYSTEMS EVALUATION SUBGROUP

William Boyle, US DOE, and Dr. Won Il Ko (KAERI) held discussions that were follow on to discussions between Dr. Ko and Dan Vega (joint meeting of SSWG/ERWG) of DOE HQ. Dr. Ko discussed the economics of pyro-processing.

STORAGE & TRANSPORTATION SUBGROUP

1. R&D Status of SNF Transport and Storage System in Korea, Tae-Chul Moon
This presentation provided an overview of the KORAD R&D Project, design and analysis of SNF transport and storage casks, and system operating procedures.
2. FY15 Focus for the Used Fuel Disposition (UFD) Campaign – Storage and Transportation Research & Development, Ken Sorenson
This presentation provided an overview of the DOE/EPRI High Burn-up Spent Fuel Data project, closing the gaps on for spent fuel cladding, and stress corrosion cracking for stainless steel canisters used to dry store spent fuel.
3. Safety Tests of Spent Nuclear Fuel Storage Casks, Sanghoon Lee
This presentation covered the experimental work on-going at KAERI on scale=--model storage cask analysis and testing. In particular, data is being collected for a tip-over 1/3-scale event.

USED FUEL DISPOSITION SUBGROUP– APRIL 29

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FCAWG UFD subgroup meeting (9am – 6 pm)

STORAGE & TRANSPORTATION SUBGROUP – APRIL 29

The Storage/Transportation Subgroup met separately and three presentations were given.

1. Spent Fuel Integrity R&D Status in Korea:
Discussion provided a comparison between the Korea and U.S. R&D situation and then provided a detailed overview of a multi-year experimental and code development effort to assess spent fuel cladding characteristics subjected to storage conditions. Specific items were identified for potential collaborations between KAERI and the US.
2. High Burnup Spent Fuel Data Project:
Discussion provided a programmatic overview of the DOE/EPRI dry storage data project.
3. Spent Fuel Characterization Tests:
Discussion provided a detailed overview of how the DOE/EPRI dry storage data project sister pins were selected, what types of non-destructive and destructive tests were being considered, and what specific tests are being considered for each individual fuel rod.

UFD funded international interactions with Taiwan

TECRO-AIT Joint Standing Committee Meeting on Civil Nuclear Cooperation, Argonne National Laboratory. November 3 – November 7, 2014

SNL researcher attended this meeting on behalf of both SNL and DOE. William Boyle (DOE NE 53) was unable to attend. The SNL researcher participated in information exchanges and identification of mutual areas of interest within Working Group #2, Nuclear Science, Technologies and Safeguards. Multiple areas of mutual interest were identified for activities in the back end of the commercial nuclear fuel cycle. Specific areas of mutual interest included ROC interest in sharing experiences and exchange of information with the US DOE on:

- Public participation in siting of nuclear facilities,
- Geological repository sciences,
- Technology transfer for radioactive waste disposal,
- Nuclear fuel extended storage and transportation projects and
- The UFD campaign progress in general.

SNL researcher committed to and provided multiple milestone reports on these topics. The next AIT-TECRO meeting will be in December, 2015, in Taiwan.

UFD funded international interactions with the United Kingdom

1. SNL is negotiating with Univ. of Sheffield/UK to assist SNL in R&D for deep disposal borehole sealing.
2. SNL has planned a joint peer review (October) with RWM/NDA in the UK whereby SNL will review 2 of their major reports (thermal and MPC related), and they will review SNL's latest report on DPC direct disposal and supporting documents as needed.