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The following summaries are provided as fulfillment of milestone M4FT-14SN0811031 and represent international collaboration activities in disposal research funded by the US DOE Used Fuel Disposition (UFD) Campaign during Fiscal Year 2014.

UFD funded international interactions with the Germany

There are ongoing collaborative efforts between salt repository research scientists from US and Germany. In FY2014, these collaborative efforts focused on: 1) selected aspects of the safety case for salt disposal of high-level waste; 2) plugging and sealing of a salt repository; 3) salt mechanics modeling; 4) repository design including potential uses of an underground research laboratory (URL) at the Waste Isolation Pilot Plant (WIPP); and (5) geochemistry and hydrogeology modeling. In FY2014 these collaborations included one-on-one interactions, approximately quarterly videoconferences, and the 4th US/German Salt Workshop (Hansen et al. 2013), held September 16-17 in Berlin, Germany. Details of the collaborations in each of these five areas are described in Hansen et al. (2013) and summarized below:

Safety Case for Heat-Generating Waste Disposal in Salt

- 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).
- SNL is beginning to develop 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.

Plugging and Sealing

- Sealing capability for both shafts drifts has to be demonstrated in the laboratory and at full-scale in situ.
- Real-time and full-scale drift seal demonstrations are ongoing in the Morsleben repository, in the European project full-scale Demonstration of Plugs and Seals (DOPAS), and in the BMWi research and development (R&D) project, "Shaft seals for repositories for high-level radioactive waste" Schachtverschlüsse für Endlager für hochaktive Abfälle (ELSA). The ELSA project is developing concepts for shaft seals and demonstrating functional elements using laboratory and medium scale tests. One of the key overarching research areas pertaining to plugging, sealing, testing, and modeling involves reconsolidation of granular salt, particularly in the horizontal orientation.

Salt Mechanics Modeling

- The Joint Project has been officially extended to include two additional benchmarking problems based on in situ full-scale tests conducted in the early 1980's at WIPP. Modeling will compare an isothermal mining development test (WIPP Room D) to a heated "overtest" for simulated defense high-level waste (WIPP Room B).
- In concert with benchmark modeling of the full-scale field tests, German research groups are conducting approximately 140 laboratory experiments on WIPP salt. Back-calculations of the various lab tests with different boundary conditions demonstrate the ability of the models to describe different phenomena and their dependencies under different and well-controlled conditions. Back-calculations of these lab tests are not only performed for the parameter determination, but also as a check of model capability to describe the deformation behavior of bedded WIPP salt.

Repository Design and Use of the Underground Research Laboratory (URL)

- The international salt repository community has significant participation in collaborative monitoring projects, which were revisited in this workshop. With this experience in mind, workshop participants examined possible uses of the new URL in the WIPP underground setting. The URL provides a unique opportunity to advance the scientific basis for heat-generating waste disposal in salt. With this opportunity comes a significant responsibility to use this space as intelligently and cost-effectively as possible. Several potential activities were discussed in break-out sessions and feedback included a sense of duration, cost, and merit among the many potential uses. A more formal and rigorous review process of URL activities would be expected in order to guide development of the URL.

Geochemistry and Hydrogeology

- Issues from the Actinide and Brine Chemistry (ABC) Workshop held in Santa Fe were discussed.
- Contributions of anoxic corrosion and microbial consumption of cellulosics, plastic, and rubber to gas generation were quantified from the work supporting the WIPP compliance certification.
- Hydrogeologic modeling was put forward as a new area for collaboration. Powerful tools are able to meet the needs of far-field modeling, with applicable porous and fractured media flow.

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

UFD funded international interactions with Japan

A new international collaboration is being developed with Japan Atomic Energy Agency (JAEA) regarding the geologic disposal of used fuel. The SNL researcher is working with Masahiro Shibata of the Performance Assessment Research Group within the Geological Isolation Research and Development Directorate of JAEA to construct the collaboration scope and schedule. The JAEA has begun a mulit-year plan to develop the technical bases and safety case for direct disposal of used fuel that will be documented in a series of progress reports, with the final report including international peer review. The program would include modeling of used fuel degradation performance and experimental work to further the technical basis for the fundamental understanding of these processes and to improve the technical bases of the performance assessments. There are a number of parallel and complimentary tasks to the JAEA work covering used fuel degradation and those within the UFD Campaign. These include (a) the radionuclide instantaneous release fractions from used fuel; (b) dissolution of used fuel matrix grains, (c) radiolytic effects. Additional planned JAEA activities related to performance assessment or waste package behavior may offer additional areas for UFD Campaign collaboration. For used fuel degradation, the general approach is that the UFD Campaign would supply annual reports on the modeling advances on used fuel degradation to the JAEA program. The UFD Campaign input would facilitate the JAEA modeling program and contribute to planning experimental work. In return, the JAEA program would provide UFD Campaign access to define some of the experimental conditions and direct access to results of their experimental program.

UFD funded international interactions with the Republic of Korea

Deep Borehole Disposal (DBD):

Mr. Jong Youl Lee and Dr. Heui Joo Choi from KAERI were hosted by Bill Arnold at Sandia National Laboratories during the week of January 6-10, 2014. Technical discussions were held on the deep borehole disposal research programs in Korea and by DOE. Mr. Lee described the preliminary results of the Korean deep borehole disposal technical assessment and recent results from two deep drilling projects in Korea were also presented. Presentations were made by a number of Sandia staff members on technical capabilities potentially relevant to deep borehole disposal research, including groundwater environmental tracers, geochemistry of borehole seals, deep borehole drilling, numerical modeling, and performance assessment. Mr. Lee and Dr. Choi also attended a meeting of the deep borehole disposal industrial consortium as observers.

Korea Atomic Energy Research Underground Research Tunnel (KURT)

Collaborative Research (as opposed to information sharing at technical exchanges) occurs only in disposal research, and is funded by the US through the UFD. Collaborative research activities include:

- Tests of various methods of measuring streaming potential (SP) to characterize in-situ geology and hydrology. Experimental approach has been designed by US and ROK researchers and is currently implemented at lab scale in ROK. The approach will be tested in the field in KURT (KAERI Underground Research Tunnel) in FY15, following an ongoing expansion of the underground facility.
- Joint development of in-situ hydrologic and geochemical measurements in boreholes in crystalline rocks: In FY14, KAERI has provided a draft of R&D roadmap for the activity. Testing may be done in boreholes at KURT.

- UFD staff will visit KURT in October to discuss additional collaborations in the underground facility.

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 at the Pacific Northwest National Laboratory in Richland, Washington. The meetings began on Monday, June 23 and concluded on Wednesday, June 25.

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

1. Used Fuel Disposition Subgroup
    a. ***Deep Borehole Disposal***: ROK to send canister work reports to US as well as a series of reports resulting from ROK borehole work (2015). US to re-send 5 reports from US to ROK, and EOFY 14 DBH MS report to ROK. .
    b. ***Evaluation Tools for Repository Decisions***: ROK to send updated crystalline data and p arameters for PA modeling. US to send EOFY MS report for GDSA, and the SRS FCRD I nventory Report to the ROK.
    c. ***Crystalline Disposal Systems, Robust Materials for Disposal***: ROK will (1) provide to th e US fracture properties on two ROK research sites, (2) continue work at KAERI and KU RT through the contract funded by the US DOE UFDC through SNL, (3) provide a report on properties of buffer material from KAERI based research in the ROK, (4) provide top ographic data and crystalline parameters (hydrologic, geochemical). US will (1) provid e information on SNL's work on iodide sorption and transport, (2) provide the Discrete Fracture Model (DFM) tool that is being developed in the UFDC, as well as the continu um model, (3) provide a report on experimental and modeling tasks on the thermal li mits of bentonite (Ca and Na) clays used in engineered barrier systems, (4) provide the EOFY14 MS report on natural systems, engineered barriers and reference case determ ination for crystalline disposal.
2. System Evaluation Subgroup:
    a. ROK discussed The Public and Engagement Commission on Spent Nuclear Fuel Manag ement, and several national decisions of the Atomic Energy Commission about interim storage, pyroprocessing and sodium-cooled fast reactors. ROK recommended to exch ange the cost basis of pyroprocessing between the Korea Atomic Energy Research Inst itute and the DOE Fuel Cycle Technology Program. ROK indicated information contain ed in DOE's Fuel Cycle Evaluation and Screening report may be useful in further analys es using the nuclear fuel cycle evaluation code, NUCYCLE, an integrated dynamic analy sis code for nuclear energy systems being developed in ROK.
    b. US summarized the status of interim storage and transportation activities underway in the U.S. The information and data used in these analyses may be of use in the econo mic feasibility study on pyroprocessing.
3. Storage and Transportation Subgroup. US presented UFDC R&D in Experiments, Analysis, Tran sportation, and Field Demonstration and discussed the progress on the High Burnup Fuel Dry C ask Storage Demonstration Project. ROK gave a presentation on the KORAD 21 and 21C storag e systems that will hold 21 low burnup (<45 GWd/MT) PWR assemblies with a total maximum

heat load of 16.8 kW. An identified area of interest to ROK and US is to determine the effect o f screen mesh size (and removal of the screen) from the inlet and outlet vents. The subgroup will work to have a good exchange of information and ideas between the work KAERI is doing and what PNNL is doing to support UFDC in thermal and structural analyses. With the ROK de sire to have construction of an interim storage site completed by 2024, a similar timeframe to the US desire, there is a great need for enhanced collaboration between the two countries to f acilitate this goal.

UFD funded international interactions with Taiwan

TECRO-AIT Joint Standing Committee Meeting on Civil Nuclear Cooperation, Taipei, Taiwan, ROC. December 10 - December 12, 2013

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:

- Spent fuel performance assessment in crystalline media,
- Deep borehole disposal,
- Nuclear fuel 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 November in Washington, DC.

International Exchanges at SNL through the Repository Lecture Series

SNL hosts a series of planned monthly Repository Science Lectures. Topics of the lectures are associated with storage, transportation and disposal of used nuclear fuel and the lecturers come from varied backgrounds and experience. Information is exchanged at each lecture. Two of the lectures in FY14 were specific to international topics. They were:

Nuclear Waste Management in Korea: The tail wagging the dog? July 17, 2014, Dr. Jooho Whang, Department of Nuclear Engineering, Kyung Hee University, ROK

Korea is the 9th large energy consuming country in the world, which accounts for 2.1% of the global energy consumption. Korea depends heavily on energy import over 95%. Portion of nuclear power in primary energy supply has decreased from 16% to 12% during the last 10 years. Yet, dependence of Korean economy on heavy chemical industry will require for the coming decades inexpensive electricity provided by nuclear power. One third of electricity is being supplied by nuclear power and the government announced in the second energy basic plan that nuclear power will take 29% of generation capacity, which is 42.3 GWe, in 2035.

It is a great challenge that Korea Hydro and Nuclear Power Company (KHNP) has to provide information on SNF for dry storage licensing in and on time. 18 kinds of PWR fuels have been used in 19 reactors. To assure retrievability and structural integrity of SNF after many years of dry storage, many degradation mechanisms SNF under normal and accident conditions have to

be investigated. This topic is in Korea-USA new agreement agenda for technical cooperation encompassing storage, transportation and disposal of SNF.

Radioactive Waste Management Disposal in Germany and Europe, July 23, 2014, Dr. Thilo v. Berlepsch, Head of International Cooperation Department, DBE Technology

The requirements of the European Commission imposed by the radioactive waste directive from 2011 led to the development of a new site selection process. A central part of the process is a new site selection act, which - for High Level Waste only - introduces a regulator who is independent from the licensee and new bodies to ensure transparency and a social agreement on all issues concerning disposal of radioactive waste. The new process comes at the same time as the re-evaluation of all German nuclear waste repository projects.

Additional European projects at varying stages of their programs were presented. In the Netherlands a small nuclear program allows to store the radioactive waste until a final solution is found. France prepares the licensing documents for its geologic repository. The most advanced project in Europe is Finland, where the disposal level of the future repository is already reached and the current progress of the project suggests also no substantial delay in the future

Selected Conference Participation by SNL Researchers

Fast / Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel (*FIRST-Nuclides*): Antwerp, Belgium, December, 2013

SNL researcher participated in the FIRST-nuclides collaborative project. FIRST-nuclides provides technical data directly relevant to the activities within the US DOE NE Used Fuel Disposition Campaign regarding Used Fuel Degradation and Radionuclide Mobilization for which I am the technical lead. The results presented at this 2nd Annual Workshop of FIRST Nuclides aid our current project for constraining instant release fractions of radionuclides from used fuel, as well as our future objectives for high-burnup used fuels. Presentations were made by the participating European experts covering sample preparation and experiment control protocols, fission gas releases, radionuclide release in leaching experiments, modeling synthesis of the data, and training activities within the collaborative project. Additionally, presentations covered investigating geologic disposal systems for high-level radioactive wastes based on the accepted methods, data sets, and models for safety assessments of geologic repository programs.

International Conference on the Performance of Engineered Barriers (PEBS): Backfill, Plugs & Seals. Hannover, Germany, February 6-7, 2014

SNL researcher attended this, the final event in a multi-year project with European Union support (www.pebs-eu.de) that was hosted by the German institute BGR (Federal Institute for Geosciences and Natural Resources) in Hannover. The multi-year budget was 130M EUR of which about half was provided by the EU and the rest by participants. Accordingly, the research was strongly focused on questions related to the waste disposal concepts being pursued by the EU member states. Thus, the meeting was focused on behavior of clay buffer materials, clay-based backfill, and argillaceous host rock.

The current European Community/Euratom R&D context (FP-7) was described. Approximately 17M EUR will be available in 2014-15, the call was in January, and proposals are due 17April14. Participation will likely be limited to European states, although investigators from elsewhere may collaborate, and outstanding proposals from organizations in other countries may be entertained.

Presentations were of high caliber. Investigators from Canada, China, Czech Republic, Finland, France, Germany, Great Britain, Japan, Spain, Sweden, Switzerland and the U.S. were present, including representatives from development companies Andra, Posiva, SKB and Nagra.

Mont Terri Technical Meeting TM-32. St. Ursanne, Switzerland, February 12-13, 2014

The technical meeting and underground visit lasted for 1.5 days during which 21 technical presentations were given and three new tests were proposed. Key contacts are Paul Bossart/Swisstopo (project leader), David Jaeggi/Swisstopo (runs key experiments) and Herwig Müller/Nagra (Nagra project lead). The following lists some of the topics from the conference of potential interest to UFD researchers. More details are available from the SNL researcher's trip report.

1. EB-Experiment Interpretation (E. Alonso/UPC Barcelona)
2. Survey of Bentonite Types (S. Kaufhold/BGR)
3. FE-Experiment Bentonite (H. Müller/Nagra)
4. FE-Experiment Scoping Calculations (B. Garitte/Nagra)
5. Microbial Consumption of H_2 Gas (R. Bernier-Latmani/EPFL)
6. Radionuclide Diffusion *In Situ* Test (O. Leupin/Nagra)
7. LP-Experiment (hydro-properties from earth tides) (J.-M. Matray/ISRN)
8. Deep Borehole Experiment (D. Jaeggi/Swisstopo).
9. Opalinus Spatial Variability (J. Becker/Nagra).
10. Wet Spots and the BBB-3 Borehole (T. Vogt/Nagra).
11. Suction, Strength and Anisotropy of the Opalinus (F. Amman/ETH).
12. Microseismicity from a Mont Terri Mine-By Experiment (Y. Le Gonidec/ Géosciences Rennes).
13. Geoelectric Surveys (M. Furche/BGR).
14. CO_2 Capture Project (H. Goodman/Chevron)
15. PS-Experiment (Opalinus Petrology) (B. Laurich/RWTH Aachen).
16. Characterization of Faults (Y. Guglielmi/Univ. of Aix-Marseille and C. Nussbaum/Swisstopo).
17. HG-A/HG-D Active/Passive Seismic (H. Maurer/ETH)
18. Mont Terri Geology and Seismology (P. Blaxcheck and C. Nussbaum/Swisstopo).
19. FE-Experiment Overview (T. Vogt/Nagra)
20. Fiber-Optic Measurements for Temperature Monitoring (F. Fischli/Marmota).
21. THM Simulation of Canister Movement (L. Laloui/EPFL)
22. Proposal: Modular Platform for μbio Studies "MA-A" (R. Bernier-Latmani/EPFL).
23. Proposal: Opalinus Palynology (D. Jaeggi/Swisstopo)
24. Proposal: Seismic Transmission "ST" (K. Schuster/BGR).

ETH (Zurich) Symposium on Rock Mechanics and Rock Engineering of Geological Repositories in Opalinus Clay and Similar Claystones. Zurich, Switzerland, February 14, 2014

This 1-day symposium was principally organized by Prof. Dr. Simon Löw of the Technical University – Zurich (ETH). The stated purpose was to help Nagra determine if enough is known about claystone mechanics for it to recommend that the siting process proceed past Stage 2 (a

process defined in the established Swiss siting protocol). There was extensive discussion of rock conditions at the Mont Terri URL, which is situated roughly 300 m below the surface (depth of potential repository sites could be 800 m or more). The symposium was conducted in three successive parts: 1) laboratory and *in situ* experiments, and models; 2) underground construction experience; and 3) proposed repository layouts and construction methods. The first part was presented by professors from academia, while underground construction experience was presented by investigators from Mont Terri and by Swiss tunneling engineers, and repository design information was discussed by staff from government agencies and R&D institutions. All presentations described below were specific to the Opalinus clay unless noted otherwise.

DECOVALEX Meeting. Avignon and Millau, France, April 4-12, 2014

Two SNL researchers attended this Development of Coupled Models and their Validation against Experiments in Nuclear Waste Isolation (DECOVALEX) meeting. The objective of trip was to ensure that the UFD work be appropriately represented at the workshop and the future work planned for DECOVALEX collaboration meet the UFD needs. At the workshop, the problem definition, modeling results as compared to experimental data, and the future work for each of five tasks were discussed in details. These tasks involve a broad specturm of modeling tools and codes of different maturity levels. Significant progress has been made since the last workshop. Payton Gardner presented his work on Task C2 – Modeling of Bedrichov Tunnel Test Case, Czech Republic. Yifeng Wang participated in the detailed discussion on Task C1 – Thermal-Hydrologic-Mechanical-Chemical (THMC) Modeling of Single Fractures. Given the significance of this task to nuclear waste disposal in crystalline rocks, Yifeng decided to join this task as an additional modeling team. Our general impression from this workshop is that a large body of data is available from the DECOVALEX project and DOE UFD should fully leverage these data for model development and validation. In some cases, for example, for Task C1, significant gaps still exist between model predictions and experimental data. So there is a great deal of interest in using DECOVALEX platform to better understand the underlying physical/chemical processes of experimental observations.