CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Annual Meeting of the American Association of Petroleum Geologists (20.01402.861)

DATE/PLACE: March 10–13, 2002; Houston, Texas

AUTHOR: C. Dinwiddie

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PERSONS PRESENT:

Cynthia Dinwiddie of the Center for Nuclear Waste Regulatory Analyses (CNWRA) participated in the annual meeting of the American Association of Petroleum Geologists held in Houston, Texas, March 10–13, 2002. Nearly eight thousand geologists and engineers from the fields of petroleum, natural gas, uranium mining, environmental remediation, methane hydrates, and CO_2 sequestration attended the meeting, including many representatives from the private sector, universities, DOE national laboratories, and the U.S. Geological Survey.

BACKGROUND AND PURPOSES OF TRIP:

The purposes of this trip were to present CNWRA and NRC research to the scientific community that may potentially be used to evaluate DOE estimates of matrix permeability and the extent of construction disturbance in drift walls at Yucca Mountain, and to assess methods, tools, and conclusions presented by other researchers that could be useful in meeting the objectives of the NRC. The American Association of Petroleum Geologists annual meeting is also an excellent forum for meeting prospective candidates for hydrology and geology positions at CNWRA.

MEETING SUMMARY:

<u>Presentations and Posters</u>

Selected topics pertinent to evaluating DOE characterization of Yucca Mountain and the NRC role as a regulator are discussed in the following paragraphs, including an oral technical session on uranium energy: source, to power, to repository, which was sponsored by the Energy and Minerals Division of the American Association of Petroleum Geologists.

The International Atomic Energy Agency has recently published the report *Analysis of Uranium Supply to 2050*. D. Underhill (consultant, Vienna, Austria) presented a talk by the same title, wherein he evaluates the role of 125 known uranium deposits supplying Market Based Production (i.e., uranium produced at or below the price set by the market, in order to satisfy demand that is not met by other energy sources). He concludes that known uranium resources will meet projected requirements to a great degree (see the aforementioned report), but at a very high cost unless future exploration efforts find substantial lower-cost deposits.

R. Maxwell (International Nuclear, Inc., Casper, Wyoming) presented a talk on domestic uranium resources (670,000 MTU [1,500,000,000 lbs U_3O_8]) and their availability. He reported that 2,000 MTU [4,000,000 lbs. of uranium] was produced in the USA during 2001, that production has been declining, and that nuclear power plants now account for about eight percent of total domestic energy demand. Resources appear to be sufficient for the next 20 to 30 years of operation, given the number of currently operating reactors. However, negligible new resources have been added to the domestic uranium portfolio during the past two decades, the blame for which he places squarely on low prices and an unstable market. Regarding availability of uranium resources, environmental and political concerns were said to play a substantive role, the numbers of experienced miners and extraction companies are on the decline, and the remaining large number of small deposits requires a paradigm shift, including consolidation with the goal of forming economically viable mining units. Data collected early-on has frequently been lost or discarded, which will inevitably lead to redundant mining of old prospects. Maxwell concludes by stating that in situ leaching technology may potentially accelerate production, increase the resource base, and decrease environmental impact, but only if the "regulatory regimes involved do not continue on the current path toward increasingly arbitrary and expensive controls."

V. McLemore (New Mexico Tech) spoke about the abundant uranium resources in New Mexico (37,500 MTU [84,000,000 lbs. U_3O_8]) and the two factors that are stalling current and future development. One company (Quivira Mining Company, owned by Rio Algom Ltd.) has produced uranium in New Mexico by mine-water recovery during the period 1984-2000. Other than that, Hydro Resources, Inc. (Churchrock) and NZU, Inc. (Crownpoint) have each put their in situ leaching plans on hold. Rio Grande Resources Company maintains its closed facilities at the flooded Cibola County Mt. Taylor underground mine. Anaconda Uranium purchased the Cibola County La Jara Mesa deposit from Homestake Mining Company in 1997, but the deposit will not be developed until production costs are lowered (e.g. through in situ leaching technology), and/or uranium prices increase.

R. Vance (Natural Resources Canada, Ottawa, Ontario) presented a talk on uranium resources in Canada–the world leader in uranium production, exhibiting the largest established production capacity (10,683 MTU [24,000,000 lbs. of uranium] in 2000, up 30 percent from 1999 due to the new McClean Lake and McArthur River mines). Some of the world's largest known high-grade uranium deposits are located in Canada, and this country ranks fourth in the world for total uranium resources (437,000 MTU [980,000,000 lbs. of uranium]). Vance reports that sustainable development is an important factor in the development of mining projects, and that native inhabitants of the Athabasca Basin, northern Saskatchewan profit from the projects. Canadian uranium production will continue expanding in the Saskatchewan province, in spite of low prices (e.g., a new mine at Cigar Lake is expected to begin producing in 2005). Other Canadian resources of current economic interest are located in the Thelon Basin of Nunavut, and the future discovery of previously unknown resources is anticipated.

R. Grubbs (Garb, Grubbs, Harris & Associates, Dallas, Texas) spoke on Australian uranium deposits, which are the largest in the world. Rivaling Canada, Australia hosts the world's largest high-grade uranium deposits, located in the Alligator River Basin. The Ranger Project, which is a three-decade old open pit mine, is Australia's largest uranium mine and is now in the final stage of operation. The Olympic Dam multi-metal deposit also produces significant amounts of uranium. The Australian government has been primarily concerned about nuclear proliferation, but also has environmental and cultural concerns with respect to uranium mining (e.g., the Alligator River Basin is partially comprised of Aboriginal Sacred Lands). These concerns are reflected in the government's ambivalent attitude toward nuclear power.

C. Stewart and L. Reimann (Power Resources, Inc., Glenrock, Wyoming) presented a talk on the use of mineralogy for enhancement of mining and restoration. Examination of uranium roll front mineralogy, which includes speciation, access, and other reactive phases (e.g., pyrite and clays) provides: (i) an improved assessment of lixiviant effects on uranium ore bodies, and (ii) an improved plan for uranium ore body restoration. Predictive geochemical modeling of post-closure mine waters is also based upon the dual consideration of mineralogy and water chemistry.

R. Smith (R.B. Smith & Associates, Inc., Wimberly, Texas) discussed the ways in which the modern uranium explorationist must differ from those of the past. Past explorationists found and delineated more than 89,000 MTU [200,000,000 lbs. of U_3O_8] that has been either never or only partially mined. The original exploration companies who did this work are for the most part gone, and ownership has generally gone back to the original owner or to the U.S. Government. The modern explorationist will have to be adept at researching old data: from the literature, government agencies, and past uranium resource exploration data that may be forgotten, lost and deteriorating in an old warehouse, or even destroyed. The modern and future explorationist will need to track down retired geologists, chase company records that have passed through many mergers, quit false trails, find new leads, and when the data are finally in hand, the explorationist must be able to interpret data generated as long ago as four decades.

R. Finch (Argonne National Laboratory) discussed the precipitation of neptunium solids during the aqueous corrosion of neptunium-doped uranium oxides. In the corrosion experiment that he describes, the starting solids were exposed to water-saturated air for a period of several weeks in sealed stainless steel containers. In the end, he demonstrated that uranyl oxyhydroxides incorporate small amounts of neptunium, and that crystalline NpO_2 will precipitate at 150 and 90 °C [302 and 194 °F]. The co-existence of neptunium-bearing uranyl compounds with pure neptunium oxides aids definition of the neptunium solubility limit (given the experimental conditions) of uranyl compound structures. When these experimental results were applied to a recently-developed model for predicting dissolved neptunium concentrations in uranium-saturated groundwaters, they resulted in reasonable agreement with experimentally-measured neptunium concentrations from studies on the aqueous corrosion of spent nuclear fuels. The presence and state of neptunium in oxidizing groundwaters continues to be an element of particular significance as DOE develops plans for the proposed high-level nuclear waste repository at Yucca Mountain, Nevada.

J. Stuckless (USGS) gave a presentation titled "The Yucca Mountain Project: A Major Earth Science Investigation." A synopsis of his presentation follows: Studies of the site began in the late 1970s. Millions of person-hours have been spent in the ensuing investigation, and in every field of geoscience. The mountain lies in a region of tectonic extension, with currently active seismicity and volcanism (at this point he provided an anecdotal story of the incredulous reaction he received from a local woman when he openly admitted these two points). A system of normal faults with Pleistocene slip cut and bound the mountain, but tectonic hazards are demonstrably low. The mountain consists of late Tertiary silicic pyroclastic rocks, and the Paintbrush Group has been the primary focus of study. The regional climate is semi-arid with only ephemeral stream flow, and water within the unsaturated zone (up to 500-m [1600-ft] thick) flows through both fractures and the rock matrix. Complete turnover of air within the unsaturated zone takes no more than two years (at this point he discussed pre-historic cave paintings as analogs for the circumvention of water around underground openings, as well as the fact that calcite silica veins and opals appear from isotopic data to simply be remobilized caliche instead of generated from upwelling water). The surface of the water table beneath Yucca Mountain is relatively flat (the concentrations of naturally-occurring chloride were used to identify flow paths, and water movement is slow (seven- to ten-thousand year retention time), thus enhancing the potential for dispersion of any radionuclides that reach this saturated zone. Geochemical retardation by exchange with minerals like zeolites provides the final natural barrier supporting long-term waste isolation. He concluded with a discussion of anomalous isotopic uranium compositions, and stated that while the citizens of Carson City and Las Vegas are opposed to the designation of Yucca Mountain as a geologic repository of high-level nuclear waste, the citizens of Amargosa Valley, near the compliance boundary, are not. Stuckless was asked the following question: Could Yucca Mountain be a repository for Class C and Class B low-level wastes, considering the specific problems that are associated with these wastes? Stuckless replied first that there was simply not enough room out there [Yucca Mountain], and then rephrased his answer thus: If we wanted to expand the site, it would require an act of Congress; space is limited by Congress.

R. Levich (DOE, Las Vegas, NV), R. Patterson (DOE, Carlsbad, New Mexico), and R. Linden (Golder Associates, Inc., Las Vegas, Nevada) prepared the following presentation (presented by Levich): Closing the Uranium Fuel Cycle: Deep Geologic Disposal at Yucca Mountain and WIPP. A synopsis of their presentation follows. With the goal of safely disposing of spent nuclear fuel and long-lived radioactive waste, thus closing the nuclear fuel cycle, the DOE developed the Waste Isolation Pilot Plant in Carlsbad, New Mexico. The Waste Isolation Pilot Plant was specifically developed for disposal of transuranic waste, contaminated sludge, and refuse from nuclear weapons production containing alpha-emitting radionuclides with atomic numbers above 92 and half-lives greater than 20 years. Mixed and pure transuranic wastes are each disposed of in the geologic disposal facility. Waste is packaged in TRUPACT II containers, and is then emplaced in rooms or tunnels, which are excavated from Permian-age bedded salt formations that are 650 m [2150 ft] below the land surface. The salt beds will eventually flow into the unoccupied space that surrounds each container, completely entombing the waste. The first disposal room was filled to capacity during August, 2001, and was then sealed with negative pressure from repository airflow. Ten years passed between the time when the facility was ready for operation (1988) and the EPA certified the facility for operation (1998). In the future, the facility expects to receive waste from both large and small generators, and a particle physics laboratory may potentially be developed, as well.

Levich concluded his presentation with the following discussion of Yucca Mountain. Through characterization efforts, the DOE made the determination that Yucca Mountain, Nevada is suitable for the development of a deep geologic repository for the disposal of spent nuclear fuel and high-level nuclear waste. The waste is to be emplaced within robust bimetallic canisters, inside tunnels excavated from welded tuffs, which lie 300 m [1000 ft] below the mountain's crest, and 300 m [1000 ft] above the water table. Studies have indicated that the natural system in union with the supporting engineered barriers provide a safe environment for the isolation of waste. Levich stated there are currently 45,000 metric tons [100,800,000 lbs.] of spent nuclear fuel needing disposal, and predicts that this will increase to 105,000 metric tons [240,000,000 lbs.] by 2035. He also briefly mentioned the fact that DOE originally researched sites in many states, but that through the 1987 amendment to the Nuclear Waste Policy Act, Congress limited future site characterization to Yucca Mountain. Due to a less than complete response by Stuckless to a question asked from the audience during the previous presentation (i.e., due to specific problems associated with disposal of low-level nuclear waste, would it be, or could it be disposed of at Yucca Mountain?), Levich concluded by responding that there was no intent to dispose of low-level waste at Yucca Mountain, regardless of the presence or absence of space limitations.

Literature advertised at this technical session on uranium included the Environmental Activities in Uranium Mining and Milling report: a joint National Energy Agency/International Atomic Energy Agency report. This book provides survey responses from 29 countries regarding their environmental activities that are related to the production of uranium. It also discusses environmental and safety activities related to closure and remediation of production sites; the operation, monitoring, and control of active sites; and the planning, licensing, and authorization of new production facilities. An overview is provided of specific related interests, such as: ecosystem sensitivity, environmental impact assessments, air and water emissions, work environment, radiation safety, waste handling and disposal, mine/mill decomissioning, site restoration, and regulation of such activities. Finally, the International Atomic Energy Agency is also offering a geological map of the world's uranium deposits at a scale of 1:30,000,000. A guide book is provided as a companion document to this map.

The American Geological Institute staffed a booth in the exhibit hall, where they provided the most recent issue of their publication *Geotimes* (March 2002). The cover story is our nuclear legacy, including Yucca Mountain, Amichitka Island, and the Nevada Test Site. Interested parties will find some of the featured articles at the American Geological Institute website: www.agiweb.org/. These articles include (i) a one-page comment "Yucca Mountain: politics over sound science" by U.S. Senator Harry Reid; (ii) the article "In search of water: an update on Yucca Mountain studies" by R. Dyer, A. van Luik, R. Linden, and R. Salness (DOE and consultants); (iii) the article "A global snapshot [of the ways other countries handle their nuclear waste]" by K. Bartlett; (iv) the article "Nuclear stewardship: lessons from a not-so-remote island" by J. Eichelberger, J. Freymueller, G. Hill, and M. Patrick (U. of Alaska, Fairbanks, Alaska); (v) the photo essay "Nevada's legacy of nuclear testing" by G. van der Vink (IRIS consortium) and D. Graham (University of the Arts, Philadelphia, Pennsylvania); and (vi) the article "After the cleanup: isolating waste for the long term" by S. Mockler (prior research associate of the National Research Council's Board on Radioactive Waste Management).

F. Molz (Clemson University), C. Dinwiddie (CNWRA), A. Elci (Clemson University), and J. Castle (Clemson University) presented a poster paper about the role that instrument spatial weighting functions play with respect to geophysical measurements made on outcrops. When an instrument-based measurement is made of a physical property, such as permeability or electrical resistivity, not all portions of the medium being interrogated by the instrument are weighted equally. In general, each instrument will have some averaging volume, but the type of average that results in the reading displayed by the instrument or obtained through an appropriate calculation has only recently been studied. The averaging volume question is a difficult one, and it may not have a general answer for all types of heterogeneity. Nevertheless, insight may be gained by first considering an assumed homogeneous, or at least locally homogeneous, system. Current analytical techniques for measuring permeability with the gas minipermeameter or larger-scale pneumatic injection tests are based on the assumption of a homogeneous flow system. This presentation developed a theoretical basis for calculating instrument spatial weighting functions for both compressible and incompressible flows, and for voltage-driven systems in steady, homogeneous, and isotropic domains. A physical interpretation of instrument spatial weighting functions in terms of the ratio of steady-state energy dissipation rate per unit volume of porous medium at a local point, to the total energy dissipation rate over the entire flow domain was formulated. Thus, the instrument spatial weighting function defines the relative importance of various domain volumes to the overall measurement; stated another way, the numerical calculation of an instrument spatial weighting function yields a quantitative sensitivity map that is easily visualized. Thus, at least for the homogeneous case, end-users of instruments and sensors are now free to discover how measurement sensitivity varies within the "radius of investigation" of their instrument, rather than be misled by the unrealistic presumption that sensitivity is approximately uniform within a given averaging volume. The instrument spatial weighting function is a rather general concept, and measurement sensitivity maps were presented for both the conventional and the small drillhole gas minipermeameter probe, as well as for electrical resistivity measurements. Spatial weighting is demonstrably elevated in the immediate vicinity of minipermeameter tip seals and in the immediate vicinity of electrodes used to measure the electrical resistivity of the shallow crust. The physical interpretation of instrument spatial weighting functions determined through consideration of homogeneous media should form the basis for extending the concept to heterogeneous media.

Instrument spatial weighting function analysis would be able to directly address the post-excavation pneumatic injection test data collected in the vicinity of Exploratory Studies Facility niches at Yucca Mountain. These data were collected from horizontal boreholes located parallel to the niche axes and at a distance of 0.6 m [2.0 ft] above the drift ceiling, yet the data were computed with the same infinite-boundary condition assumption as was used for the pre-excavation tests. Preliminary analyses by CNWRA staff suggest that this boundary condition is inappropriate, and that the degree of increased post-excavation permeability that the DOE attributes to excavation effects is overestimated by their neglect of a nearby infinite permeability zone (i.e. the niche opening), which is almost certainly a significant portion of the averaging volume being tested, given an injection interval 0.3 m [1.0 ft] in length.

S. Ahlgren and others (Midland Valley Exploration, Ltd. and Geo-Map, Inc) presented a poster on semi-automated fracture detection for three-dimensional stochastic fracture network generation and analysis that stood in stark contrast to the "randomly" distributed fracture networks generated by DOE and U.S. Geological Survey, which were presented at the ESF/ECRB UZ Testing Appendix 7 held in Las Vegas, Nevada, October 11, 2001. The Midland Valley method involves acquiring fracture data from analog outcrops with a long-range three-dimensional laser scanning system. Sub-planar regions are identified with automated and semi-automated feature extraction algorithms. Descriptive population and clustering statistics are automatically computed from the geometry of detected fractures, and are then used to stochastically populate a three-dimensional volume with synthetic fractures. The resulting fracture network may be analyzed topologically for definition of fracture connectivity, and used as a simulation resource for upscaling. Midland Valley reported on the application of these techniques to blasted outcrop faces in southern Arizona, with the result that fracture attributes were used to generate a three-dimensional fractured reservoir model, comprised of a synthetic fracture network.

R. Smallshire and others (Midland Valley Exploration, Ltd.) presented a poster on the determination of well connectivity through topological modeling of natural and synthetic fracture systems. The validation of synthetic Discrete Fracture Network models through topological analysis was discussed. This method decouples the topological characteristics of synthetic fractures from the actual fracture geometry, which facilitates illustration of two- or three-dimensional fractures and their intersections as vertices and edges in a graphical form. Geologically valid analyses which may then take place include (i) connected-component analysis for identifying mutually connected fractures; (ii) topological shortest path analysis; (iii) computation of fracture heirarchies; (iv) determination of mutual connectivity (topological distance), and (v) identification of the best-connected fractures in the newtwork. Incorporation of wells into the graph facilitates the determination of the degree of connectivity between them, without initiation of physical flow modeling.

IMPRESSIONS/CONCLUSIONS:

Technical sessions at the annual meeting of the American Association of Petroleum Geologists have traditionally been more poorly attended than at conferences such as the American Geophysical Union or the American Geological Society. This is due to the more competitive business-oriented nature of the exhibit hall, wherein there is abundant hawking of hardware, software, and services. However, the technical sessions have been improving in attendance during recent years, and the selection and approval of abstracts tends to be much more rigorous than at the meetings mentioned above. This annual meeting of the American Association of Petroleum Geologists was an important meeting to attend in order to meet the NRC objectives of DOE oversight because of the currently elevated visibility of nuclear waste disposal issues, which were featured in a special technical session.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

CNWRA staff are engaged in preparations for future field work, with the intention of matrix permeability data collection (using a small drillhole minipermeameter probe, originally developed at Clemson University) from nonwelded Yucca Mountain tuffs, as well as from nonwelded Bishop tuffs (Bishop, California)–a Yucca Mountain analog. Matrix permeability data collected in this manner would be compared to matrix permeability data provided by the DOE. Additionally, just as this probe could be successfully used in depth-of-weathering analyses on outcrops, it has similar potential for use in depth-of-construction disturbance analyses within drift walls.

RECOMMENDATIONS:

CNWRA staff recommend further investigation into the post-excavation niche permeabilities provided by DOE, congruent with the instrument spatial weighting function analyses discussed above, or similar analyses that could test DOE use of this permeability data.

SIGNATURES:

Cynthia L. Dinwiddie

Cynthia L. Dinwiddie
Research Engineer

03/27/02
Date

CONCURRENCE:

E. C. Pearcy

English C. Pearcy
Manager, Geohydrology and Geochemistry

3/25/2002
Date

for

Budhi Sagar
Technical Director

3/29/2002
Date