CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Annual Meeting of the Geological Society of America (20.06002.01.241/261)

DATE/PLACE: November 6–11, 2004; Denver, Colorado

AUTHOR: M. Juckett and C. Dinwiddie

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PERSONS PRESENT:

Miriam Juckett and Cynthia Dinwiddie of the Center for Nuclear Waste Regulatory Analyses (CNWRA) participated in the annual meeting of the Geological Society of America held in Denver, Colorado, November 6–11, 2004. Several thousand geoscientists attended the meeting, including many representatives from the private sector, universities, U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Energy (DOE), and the U.S. Geological Survey.

BACKGROUND AND PURPOSES OF TRIP:

The purposes of this trip were to present CNWRA technical work to the scientific community and to assess methods, tools, and conclusions presented by other researchers that could be useful to meet the objectives of various NRC programs. Additionally, Miriam Juckett attended the short course *Hydrogeologic Field Methods* before the meeting, and Cynthia Dinwiddie attended the field trip *Ancient Depositional Environments Control Modern Aquifer Quality: Stratigraphy of Groundwater Resources in the Denver Area* following the meeting.

MEETING SUMMARY:

Short Course:

John Moore (United States Geological Survey, retired) and Mike Wireman [U.S. Environmental Protection Agency (EPA)] taught a short course on hydrogeologic field methods. Dr. Moore's sessions included primarily managerial and well-drilling information. His course material included project management discussions, such as planning an investigation, proper record keeping, preparation and review of reports, and management steps. The discussions on wells and well drilling included topics such as sources of water to a well, well monitoring, water level measurements, coring methods, and well sampling. He also included information on aquifer tests, groundwater movement, rock porosity, and stream flow measurements. Mr. Wireman taught an informative session on Dense Non-Aqueous Phase Liquids including chemical and physical properties, fate and transport in the subsurface, monitoring and remediation of Dense Non-Aqueous Phase Liquid-contaminated sites. Dense Non-Aqueous Phase Liquid-contaminated sites are a fairly common environmental problem in the United States and require complicated monitoring techniques and often remediation. He also taught a

session on tracer tests, which included discussions on various types of tracers, stream tracing, groundwater tracing, vadose zone tracing, mine tunnel tracing, and examples from real-life tracer tests. The information obtained from this short course will be useful for a better understanding of the Nye County Early Warning Drilling Program and related programs in which the CNWRA participates.

Presentations and Posters

Selected topics pertinent to the NRC role as a regulator and to evaluating the potential DOE license application for Yucca Mountain are discussed in the following paragraphs. This information was presented in an oral technical session titled Geologic Disposal of Radioactive Waste: Rising to the Challenge of Regulatory Requirements and Environmental Protection at the Waste Isolation Pilot Plant Near Carlsbad, New Mexico, and the Yucca Mountain Site, Southern Nevada, which was sponsored by the Geologic Society of America Hydrogeology Division, DOE, and the Geologic Society of America Geology and Public Policy Committee.

Russell L. Patterson (DOE, Carlsbad Field Office) gave an overview of the Waste Isolation Pilot Plant repository. DOE responded to a congressional directive (The DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980) to provide safe and permanent isolation of long-lived radioactive wastes by seeking to construct and operate a Waste Isolation Pilot Plant as a geologic repository. EPA was designated the primary regulator for the Waste Isolation Pilot Plant 12 years later through the Land Withdrawal Act of 1992. EPA established radiation protection standards for the facility and certified in May 1998 that the Waste Isolation Plant Plant met these standards. The first shipment of transuranic waste was received in March 1999. DOE submitted the required documentation to re-certify the facility. The DOE compliance re-certification application included information and analysis from the original Waste Isolation Pilot Plant Compliance Certification Application, reflected developments occurring over the last five years of operations, and was accompanied by an updated performance assessment supported by new data from continuing scientific studies and performance confirmation monitoring.

John S. Stuckless (U.S. Geological Survey, Denver) gave an historical overview of the U.S. Geological Survey activities pertaining to the Yucca Mountain Project. U.S. Geological Survey Director, Dr. V.E. McKelvey, suggested to DOE in 1976 that the Nevada Test Site be considered as a potential host area for a deep geologic repository because more than 900 person-years of investigation and interpretation of several potential on-site geologic environments had already occurred. The U.S. Geological Survey further proposed to DOE in the early 1980s that the unsaturated zone be considered for a repository host horizon, naming Yucca Mountain in particular. DOE requested the U.S. Geological Survey to actively advocate Yucca Mountain as a potential repository site in 1987, but U.S. Geological Survey Director Dr. D.L. Peck declined, citing the need for the Survey to provide unbiased scientific data and interpretations as part of its obligation to the Nation under its charter from Congress. A committee of U.S. Geological Survey scientists, assembled to review DOE Viability Assessment of a Repository at Yucca Mountain, published their review in 1999, agreeing with the general DOE conclusion that the site remains promising, but noted several areas of inquiry where more work was needed. DOE requested the U.S. Geological Survey provide an opinion on the Site Recommendation in 2001. U.S. Geological Survey Director Dr. C.G. Groat wrote a letter identifying several favorable and unfavorable earth science related aspects of the Yucca Mountain site, as well as areas of inquiry where additional study would be needed prior to

permanent closure of a potential repository. Dr. Groat further noted in this letter that in 20 years of careful study, no demonstrable unfavorable conditions had been identified, and that no obvious areas where such unfavorable conditions might exist were foreseen. In conclusion, the U.S. Geological Survey supported, from an earth science perspective, DOE recommendation of the Yucca Mountain site to the President of the United States.

David C. Buesch (U.S. Geological Survey, Las Vegas) presented a paper on geologic and rock mechanics limits on maximum potential strain in the 12.8-million year history of the Topopah Spring Tuff. Crystallization along 3,835 fractures observed in borehole cores and along the detailed line survey in the Enhanced Characterization of Repository Block leads to the conclusion that most fractures formed during cooling. Some fractures are of indeterminate age and origin, yet can be attributed to late-stage cooling, but there is an absence of mechanical damage related to seismic shaking in observed fractures.

Jerry L. King (Bechtel SAIC Co., Las Vegas) presented a paper on realistic peak ground velocities for seismic events at Yucca Mountain. His thesis was that while regulations require low probability events ($P = 10^{-6}$/yr) to be considered, the velocities and accelerations associated with such low probability events are not physically realistic. Estimates of shear strains required for failure of lithophysal host rock were determined from rock mechanics tests and computer models (0.09–0.35 percent), and were then used to calculate the required peak ground velocities {153–451 cm/s [60.24–177.56 in/s]} for such failure. Ground motions of this amplitude are associated with probabilities on the order of 10^{-5}/yr, and King concluded that this range of peak ground velocities is a reasonable upper bound for consideration within Yucca Mountain performance assessments.

Joseph Whelan (U.S. Geological Survey, Denver) presented a post-analysis audit of secondary calcite and opal occurrence within the context of probabilistic seismic hazard analyses for Yucca Mountain. The premise of this audit was that the preservation of delicate textures observed in the repository host horizon is inconsistent with estimates of large peak ground velocities. Fracture coating and crust samples were originally collected without regard to a search for seismic-related damage, so this post-analysis audit is limited to researchers' memories and records of samples collected for other purposes. Ongoing work includes analyses for estimating velocities required to break thin calcite blades, which are often found intact.

Frank V. Perry (Los Alamos National Laboratory) presented a paper on the 2004 high-resolution aeromagnetic survey, which was conducted to detect buried basaltic volcanoes in the alluvium-filled basins surrounding Yucca Mountain. If buried basalt is determined to be present below Jackass Flat, mean estimates of volcanic hazard could increase significantly. The completed helicopter-borne aeromagnetic survey will be followed by drilling of anomalies in five Jackass Flat locales to better understand any buried volcanoes, and, finally, by an update to the 1996 expert elicitation to reassess the hazard estimate. Jackass Flat anomalies are probably Miocene-age basalt, but some anomalies are likely faulted tuff, rather than basalt.

Schon Levy (Los Alamos National Laboratory) presented a paper on the occurrence of erionite at Yucca Mountain. Erionite, a fibrous mineral, is found in the rocks in the Yucca Mountain vicinity. While most areas have occurrences of less than 1 percent erionite, a few locations have been found with up to 45 percent occurrence. Most occurrences of erionite are in the Topopah Spring Tuff in transition zones. Characterization studies on the rocks in which erionite

occurs included secondary-mineral assemblages, including some in the Topopah Spring tuff that were highly potassium-enriched. Slides with Scanning Electron Microscopy photos of the erionite and secondary minerals were shown. Erionite is a concern due to its association with mesothelioma, a lung disease caused by the fibers lodging in and inflaming the lungs.

Saxon E. Sharpe (Desert Research Institute, Reno) presented a paper on quality-assured Yucca Mountain climate data products available from Desert Research Institute websites: www.ymp.dri.edu and www.nts.dri.edu. Sixteen years of climate summaries are currently available, and more will be added in the future. Tabular and graphical data products include air temperature, humidity, wind speed and direction, wind gusts, precipitation, solar radiation, barometric pressure, dew point, wet bulb temperature, evapotranspiration, and atmospheric stability data. The end-user may compile subsets of available data or may extrapolate climate data beyond that currently available. Climate and Infiltration and Preclosure Safety Integrated Subissue staff may find these sites of use during review of the potential Yucca Mountain license application.

Zell Peterman (U.S. Geological Survey) presented a paper on the geochemistry of the dust found at and in Yucca Mountain. Dust may play an important role in the potential corrosion of waste packages due to deliquescence of salts and dust on the surface of the waste packages. In preparation for experiments to investigate that potential, dust was collected from the walls of the Yucca Mountain tunnels and crossdrifts using a vacuum. Samples were characterized using x-ray diffractometry, inductively coupled plasma/mass spectrometry, gravimetric methods, titration, and combustion. Soluble salts were found to compose less than 1 percent of the in-drift dust, averaging approximately 0.37 percent in the main tunnel and 0.17 percent in the cross drift. Major components of the soluble fraction of dust were calcium, magnesium, sodium, potassium, ammonia, chloride, bromide, fluoride, bicarbonate, nitrate, sulfate, and phosphate. Mean nitrate and chloride ratios of soluble salts from various size fractions of dust range from 1.0 ± 0.2 to 1.8 ± 0.5. No calcium chloride was found in the dust, but ammonium compounds were present. For corrosion mitigation, the nitrate and chloride ratio must be at least 0.9; the soluble salts in the dust had a ratio greater than 0.9. Conversely, pore waters have a nitrate and chloride ratio less than 0.9. Interactions between the dust and the pore waters are expected to create a noncorrosive combination.

Russel Jarek (Sandia National Laboratory) presented a paper on in-drift chemical modeling of the Yucca Mountain environment. Multiscale thermal, physical, and chemical environmental models were developed. Activities included acquiring data representative of the proposed repository environment and surrounding areas, development of an aqueous Pitzer database, modeling coupled thermal-hydrological-chemical processes, and application of results to total system performance assessment. Five pore waters were chosen for thermal-hydrological-chemical analyses, with a range of chemistries for upper and lower lithophysical brines, including sodium, potassium, chloride, and nitrate. Three temperatures {40, 70, and 100 °C [104, 158, and 212 °F]} and three partial pressures of carbon dioxide were used for the simulations. No calcium chloride was predicted in any of the 11 bins of seepage composition, and one ends with calcium nitrate brine.

Yingqi Zhang (Lawrence Berkeley National Laboratory) presented a paper about her TOUGH2 thermo-hydrologic simulations of a bench-scale heater experiment conducted by Ronald Green and James Prikryl of CNWRA, approximately 10 years ago. A dual-permeability model and an active-fracture model were each used to estimate the evolution of temperature and saturation at

the crown of the bench-scale drift, as well as the potential for thermal seepage. The author reported that different approaches were used for implementing fracture and matrix interactions, and that preliminary results are consistent with temperature profiles and seepage obtained from lab experiments.

James B. Paces and Brian D. Marshall (both of the U.S. Geological Survey, Denver) presented papers suggesting that calcite and opal deposits at Yucca Mountain may be used to estimate the temporal and spatial distribution of water seeping into the repository. Temporal studies are accomplished using ion microprobe U-series dating and cathodoluminescence of opals. Variations in uranium concentration are most likely due to climate-induced variations in percolation flux. Light-dark microbanding pairs within Yucca Mountain opals have an approximate 100-thousand year periodicity. The historical spatial distribution of water seeping into a portion of the repository horizon was determined within a 60-cm-wide band observed along 1,350 m [4,429 ft] of the Enhanced Characterization of Repository Block and from acid extraction of 500 m [1,640 ft] of cuttings from vertical Borehole USW SD–6. The average spacing between successive mineral deposits in the Enhanced Characterization of Repository Block increases from 0.8 to 4 m [2.6 to 13.1 ft] as the tunnel penetrates deeper rock units of the potential repository horizon. Potential hypotheses to explain this result include (i) percolation is focused into a smaller number of flow paths with depth, (ii) water imbibes into the rock matrix with depth, or (iii) water evaporates with depth. The smallest abundances of secondary minerals were noted to occur beneath Yucca Mountain crest, even though infiltration models estimate that the largest infiltration fluxes occur there. Marshall attributed this incongruity to redistribution of flow within the Paintbrush nonwelded hydrogeologic unit, which he mistakenly asserted is completely unfractured. These mineral abundance maps should prove useful in refining unsaturated zone flow models.

Sharad Kelkar (Los Alamos National Laboratory) presented an informative paper on a series of alternative saturated zone flow models developed to incorporate the latest information available from a revised hydrogeologic framework model, new water-level data, a revised recharge distribution, revised boundary fluxes, and new hydraulic conductivity data. These alternative flow models have smaller residuals, but nevertheless, confirm the appropriateness of the basecase model. The flow paths of the alternative flow models move deeper into the aquifer and due south, in comparison to the shallower and east-southeast to southerly trajectory of flow paths resulting from the basecase model. Specific discharge values from the alternative flow models are significantly lower than those from the basecase model, and the ratio of flow path length in volcanics to that in alluvium is greater for the alternative flow models than for the basecase model. The alternative flow model median transport time for non-sorbing radionuclides to breakthrough at the compliance boundary ranges from 6,500 to 9,100 years, which is approximately 10 times slower than the transport time estimated by the basecase model. Finally, the matrix diffusion mechanism in volcanics, which significantly retards radionuclides, is more dominant at the low transport velocities estimated using the alternative flow models. Overall, the conclusion of the author is that while the basecase model is less realistic, it is more conservative, and therefore adequate for use in informing the total system performance assessment for Yucca Mountain.

Cynthia L. Dinwiddie (CNWRA) presented a paper summarizing the results of field and laboratory work from a Bishop Tuff, Bishop, California site that is considered a natural analog to the Paintbrush nonwelded hydrogeologic unit. Current DOE models predict large-scale lateral flow within the Paintbrush nonwelded hydrogeologic unit at Yucca Mountain, Nevada.

Deformation-induced secondary heterogeneities adjacent a near-vertical fault in the nonwelded Bishop Tuff (Bishop, California) were studied through *in-situ* gas permeability, structural mapping, and laboratory analyses as analogs for fault deformation features within the poorly exposed Paintbrush nonwelded hydrogeologic unit. Three features of fault zone deformation were identified that may act to constrain lateral flow in unsaturated nonwelded ignimbrites: (i) development of a fault gouge, with a decrease in grain size caused by grain deformation, leads to a marked decrease in permeability over that of host rock, (ii) long open fractures paralleling the fault will impede lateral flow, and (iii) small-scale fractures and grain rotation in adjacent matrix blocks induce an interconnected porosity not seen in host rock. A paper on this topic is in review at *Hydrogeology Journal*, and is also available on ADAMS.

Keni Zhang, et al. (Lawrence Berkeley National Laboratory) withdrew their paper on a modeling study of the temporal damping effect in the Paintbrush nonwelded hydrogeologic unit at Yucca Mountain. Their proposed paper was related to an open Unsaturated and Saturated Flow Under Isothermal Conditions related agreement item.

Teamrat A. Ghezzehei (Lawrence Berkeley National Laboratory) presented an interesting paper about the identification of flow regimes in unsaturated fractures. Flow visualization experiments were used to develop a self-consistent conceptual model for flow through a relatively smooth-walled single fracture. The flow regimes considered, in the order of increasing flow rate, are: flow of adsorbed film, sliding drops, rivulet flow, stable film flow, and wavy film flow. When asked by G.S. Bodvarsson (Lawrence Berkeley National Laboratory) what flow regime in smooth-walled fractures is expected at Yucca Mountain with an infiltration rate of 5 mm/yr [.2 in/yr], the author responded that the likely flow regime is either sliding drops or rivulet flow.

Jörn Hoffmann (German Aerospace Center) prepared an informative paper on the present and future role of remote sensing in hydrogeological studies. Many parameters and processes of hydrogeological interest can be related to those observable by satellite sensors. For example, water content may be computed given albedo contrasts in day and night infrared images of a region. Interferometric synthetic aperture radar may be used to detect moisture changes, but work must be done to differentiate this signal from displacement or other signals. Some surface displacements are caused by stress associated with storage changes. Interferometric synthetic aperture radar may be used to detect seasonal subsidence and uplift. Furthermore, changes in storage affect changes in Earth's gravity field; these changes can be measured with the GRACE satellite instrument. Three near-future satellite missions offer potential hydrogeological applications: (i) the Japanese Advanced Land Observing Satellite, including the Phased Array type L-band Synthetic Aperture Radar instrument, launch planned for 2005, (ii) the European Space Agency's Soil Moisture and Ocean Salinity 2007 mission, and (iii) the NASA Hydros 2009 mission.

Gary L. Patterson (U.S. Geological Survey) presented a poster discussing minor and trace elements in the saturated zone area near Yucca Mountain, Nevada. Some patterns of occurrence are present among minor and trace elements which may help indicate groundwater flow patterns not readily seen with major ions. Groundwater from boreholes around Yucca Mountain demonstrates some chemical signatures, possibly indicating flow paths. Some of

these signatures extend from under Yucca Mountain down to the Fortymile Wash area or Amargosa Farms areas, while some are more local to the mountain itself. Ions noted as having patterns include barium, strontium, boron, uranium, lithium, iron, zinc, manganese, and aluminum.

Kiyoto Futa (U.S. Geological Survey) presented a poster on strontium isotopic compositions in groundwater from Nye County Early Warning Drilling Program wells. Strontium values in the wells (measured as compared to modern seawater) were examined for patterns that would indicate groundwater flow paths. The strontium chemistry of the water was compared to the strontium content of the surrounding tuffs, and a correlation was found that possibly indicates isolated groundwaters that have not mixed in the saturated zone. Other patterns that were found support the current flow models in which groundwater moves toward Fortymile Wash rather than directly south.

Bret Leslie (U.S. Nuclear Regulatory Commission) presented a poster on conducting the licence application review for the repository at Yucca Mountain, Nevada. NRC is under congressional mandate to determine the acceptability of the DOE application to build a high-level nuclear waste repository. The poster detailed the licencing proceeding rules, information architecture (including ADAMS, LSN, etc.), Yucca Mountain Review Plan, and licensing review plan. A risk informed approach will be used in evaluating the license, and an organized structure is in place to do so.

Field Trip: *Ancient Depositional Environments Control Modern Aquifer Quality: Stratigraphy of Groundwater Resources in the Denver Area*

Robert G. Raynolds (Denver Museum of Nature & Science, Department of Earth Sciences) led a group of 11 persons on a field trip to the proximal outcrop of the Wildcat Mountain distributary fan system. The sandstone-dominated fan formed during the Laramide orogeny, and covers an area greater than 1,000 square miles. Except for this outcrop, the mid- and distal portions of the alluvial fan system are buried up to depths of 457 m [1,500 ft]. These deposits lie on the western margin of the subsiding Denver Basin in rapidly urbanizing Douglas County. The outcrop is exposed as a small hill on the west side of the basin, and is the single recharge zone of the Arapaho aquifer. While the Arapaho aquifer is the most prolific aquifer south of Denver, it is essentially receiving no recharge from its small outcrop, as evidenced by the 30,000-year age of the produced water. The potentiometric surface is, thus, presently falling at the rate of 1 in/d. At this rate of decline, some communities in Douglas County will run out of well water within 5 years, while other communities will have up to an additional 8 years to react to the pending crisis. It is predicted that surface water from north of Denver will, in the short term, need to be trucked-in to Douglas County to meet water needs, and that in the longer-term (next 50 years), infrastructure for an aqueduct system will be developed. Real-estate values in Douglas County are anticipated to be impacted substantially over the short to mid term. The general populace of Douglas County has no appreciable understanding of the situation, and clear communication of the issue has proven to be a difficult challenge. The October 2004 issue of *The Mountain Geologist*, produced by the Rocky Mountain Association of Geologists, is devoted to this topic.

IMPRESSIONS/CONCLUSIONS:

The annual meeting of the Geological Society of America continues be a prime avenue for CNWRA staff to present their research results to the earth science community and to interact directly with national, and international scientists. Discussions with meeting participants consistently have resulted in useful insights into research topics and alternative modeling and approaches that aid staff in the review of a potential Yucca Mountain license application. This annual meeting was important to attend because of the elevated visibility of radioactive waste disposal issues, which were featured in a special technical session.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

None.

SIGNATURES:

Miriam R. Juckett — Date: 12/29/04
Research Scientist

Gordon Wittmeyer for C. Dinwiddie — Date: 12/29/04
Cynthia L. Dinwiddie
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