CONF-971241--2

ISOTOPIC DATA OF PORE WATER EXTRACTED FROM UNSATURATED-ZONE CORES AT YUCCA MOUNTAIN, NEVADA.

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Lakewood, Colorado 80225. USA

Isotopic compositions of unsaturated-zone (UZ) ground water ($\delta^{18}O$, δD, $\delta^{13}C$ and ^{14}C) at Yucca Mountain, Nevada, the site of a potential permanent national nuclear waste repository, can be used to infer the origins of water, residence times of the water, water flux, climatic and evaporative history of water, flow paths and velocities. These data can also be used as indicators of transport properties or water-rock interaction. The lack of long-term direct measurements of infiltration requires proxy indicators of water movement through the unsaturated zone to extend the record into the past. This report will discuss δD and $\delta^{18}O$ data obtained from pore water, along with the $\delta^{13}C$ and ^{14}C data of gas and water obtained from four boreholes dry-drilled through all UZ lithologic units to infer the existence of nonvertical flowpaths through the mountain and residence times of pore water.

Stable isotope compositions of pore-water samples from SD-7, -9, –12 and UZ-14 boreholes indicated that little evaporation occurred before infiltration. Furthermore, the top two-thirds of Topopah Spring Tuff in the SD-boreholes are similar to those values of Paintbrush nonwelded unit in UZ-14 ($\delta D > -100‰$). Also these data display a trend toward more negative values as the depth increases. SD-9 data are slightly scatterred, but mostly greater than -100‰. If mixing of a significant amount of the last ice-age water (more depleted in δD due to cold climate) occurred in the matrix water of the Topopah Spring Tuff, the pore water δD values would be shifted to more negative values; this were not observed. However, in the basal vitrophyre near the bottom of the Topopah Spring Tuff, δD values in boreholes (SD-7, -9, and -12) are consistently shifted to more negative values, implying that pore water probably contains a component of the last ice-age water. Previous study (Pei Yu, 1996) indicated that vacuum distillation of pore waters for stable isotope analysis produced unreliable results from tuffs containing zeolite minerals. However, mineralogical analyses of these cores in the basal vitrophyre indicated no presence of zeolite. The stable isotope compositions of pore water in the Calico Hills Formation in all boreholes are greater than in the immediately overlying Topopah Spring Tuff, similar to the values above the basal vitrophyre. Therefore, the pore water above the vitrophyre zone in the Topopah Spring Tuff and in the Calico Hills Formation is likely to be Holocene water, but in the basal vitrophyre the pore water is likely a mixture of ice-age water with the Holocene water. These hypotheses will be further tested by the ^{14}C data in the next section.

Gas-phase ^{14}C data from UZ-1 should be representative of UZ-14 because these two boreholes are only 30 m apart. The ^{14}C activities of gas-phase CO_2 in UZ-14 decrease steadily from surface to depth of about 366 m (where ^{14}C activity is about 25 pmc, equivalent to corrected ^{14}C age of about 13,000 years) and increase near the top of the Calico Hills Formation with some irregularly large activities of about 100 pmc for three samples. $\delta^{13}C$ values of two of these samples are about –9 ‰, indicating a larger component of atmospheric CO_2 gas possibly introduced during drilling (atmospheric CO_2 has $\delta^{13}C$ = -7 to -8 ‰). The third sample has a $\delta^{13}C$ value of –15.3 ‰. The other gas samples in the Calico Hills Formation have ^{14}C activities which increase with depth and range from 48 to 80 pmc. The ^{14}C activities of gas-phase CO_2 in instrumented borehole of SD-12 decrease from surface to depth similar to the trend observed in UZ-14 with two anomalously large ^{14}C

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activities: one near the lower part of the Topopah Spring Tuff (386 m or 1,266 ft); and the other near the upper part of the Calico Hills Formation (436 m or 1,430 ft). In any case, the majority of ^{14}C activities in gas-phase CO_2 in the Topopah Spring Tuff of SD-12 are consistent with the data in UZ-14. However, the change in gas-phase ^{14}C activities at the Calico Hills Formation is due to equilibration of CO_2 gas and bicarbonate ion in liquid phase which was probably transported water through fractures by fast pathways. The modification of ^{14}C activities in the gas phase will be greater because the liquid phase contains an order of magnitude more carbon than the gas phase (most pore spaces in the Calico Hills Formation are occupied by water which has a large concentration of bicarbonate ion, i.e. the dominant carbon-bearing species). Therefore, gas-phase ^{14}C activities should be representative of the pore-water ^{14}C activities.

Pore-water ^{14}C values in the upper 91m of UZ-14 and SD-12 are in general agreement with the gas phase data, indicating equilibration between the liquid and gas phases. However, in the Calico Hills Formation of UZ-14, some data are about 30 pmc off from the gas ^{14}C data. The reason for the nonequilibrium condition in these samples is likely due to core samples that were contaminated with drilling air. Gas samples were pumped overnight to remove any atmospheric gas before sample collection. Thus the collected gas samples were probably equilibrated with the pore water and are representative of pore-water ^{14}C ages.

The fact that ^{14}C activities in the gas phase did not continue to decrease from Topopah Spring Tuff to the Calico Hills Formation (the trend is increasing instead) indicates that simplistic one-dimensional downward flow through the Calico Hills Formation is inadequate to explain these ^{14}C data. The probable explanation is that pore water in the Calico Hills Formation were partly derived from lateral flow of water which recharged through fractures or faults along the west side of Yucca Mountain, possibly in Solitario Canyon.

In conclusion, the unsaturated-zone pore-water (and perched-water) stable-isotope values at Yucca Mountain, Nevada, are generally larger than the measured lowest value of -99.8 permil in δD, indicating water of Holocene age. However, in the basal vitrophyre zone near the bottom of the Topopah Spring Tuff the δD values, in three of four boreholes examined (SD-7, -9, and -12), are consistently shifted to more negative values, implying that waters were infiltrated during the colder climate of the last ice-age. The δD values in the Calico Hills Formation in all three boreholes are larger than those of the basal vitrophyre zone and similar to those values above the basal vitrophyre zone, indicating post-ice age water.

The gas-phase ^{14}C profiles show a general increase in age downward with depth in the Topopah Spring Tuff to 13,000 years around the vitrophyre zone. The gas-phase ^{14}C ages in the Calico Hills Formation below the vitrophyre zone are younger, ranging from 1,000 to 6,000 years. This age inversion is consistent with the interpretation of the δD values. This age inversion could be attributed to mixing of vertically percolating pore water with younger water derived from a different flow path, such as lateral flow from the Calico Hills Formation recharged through the west side of Yucca Mountain in the Solitario Canyon.

Reference:

Yu, Pei, 1996, The isotopic chemical characterization of the unsaturated zone at Yucca Mountain, Ph. D. thesis, Dept. of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, Colorado. 206p.

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Field Testing and Associated Modeling of Potential High-Level Nuclear Waste Geologic Disposal Sites
December 15 and 16, 1997, Nuclear Waste Department, Lawrence Berkeley National Laboratory, Berkeley California

Underground Testing and Modeling At Yucca Mountain

- **Monday, December 15, 1997, 8:00am-5:00pm, Building 66, Auditorium, LBNL**

Session I: Yucca Mountain Field Testing
Session Chair: William Boyle, DOE/YMSCO
8:00am-8:20am: Welcome Bo Bodvarsson / Maryann Villavert, LBNL

8:20am-8:50am: Invited speaker

Progress in Field Testing and Modeling Activities at the Yucca Mountain Site,
J. R. Dyer DOE/YMSCP, 1180 Town Center Drive, Las Vegas, NV 89134, USA MS 523/HL-523

8:50am-10:30am

Flow Tests to Quantify Seepage into Drifts,
J. S. Y. Wang, P.J. Cook, R.C. Trautz, and G. S. Bodvarsson, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

A Sensitivity Study on the Probability of Seepage Into Drifts at Yucca Mountain,
J. Birkholzer, G. Li, C-F. Tsang, Y. Tsang, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Analysis of Uncertainty for 2-D Fracture Flow and Seepage Into an Excavated Drift,
A. L. James, C. Oldenberg, and S. Finsterle, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

The Drift Scale Heater Test at Yucca Mountain, Nevada,
M. Peters, R. Datta, and R. Wagner, M&O; *W. Boyle and R. Yasck,* DOE/YMSCP, 1180 Town Center Drive, Las Vegas, NV 89134, USA, and *N. Elkins and D. Weaver,* Los Alamos National Laboratory, Los Alamos, NM 87545, USA.

Predicting Changes in Rock Mass Permeability Due to Thermal-Mechanical Effects,
S. C. Blair, P. A. Bergel, Lawrence Livermore National Laboratory, Livermore, CA 94551, and *H. F. Wang,* University of Wisconsin-Madison, Madison, WI 53706-1692

10:30am-10:45am Break

Session II: Yucca Mountain Laboratory Testing
Session Chair: William Boyle, DOE/YMSCO
10:45am-12:30am

Yucca Mountain Exploratory Studies Facility Thermal Tests,
Y. W. Tsang and J. T. Birkholzer, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Fast Flow in Unsaturated Fractures: Identification and Laboratory Quantification of Fracture Surface Flow Processes,
T. K. Tokunaga and J. Wan, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Experimental Studies of Vaporizing Flows in Unsaturated Fractures,
T. J. Kneafsey and K. Pruess, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Inconsistencies Between Laboratory-Determined Moisture Retention Characteristics and Observed Matrix Sorptivity,
J. R. Winterle, and S. Stothoff, Center for Nuclear Waste Regulatory Analyses Southwest Research Institute, San Antonio, TX, USA

Numerical Simulation of Water- and Air-Flow Experiments in a Block of Variably Saturated, Fractured Tuff,
E. Kwicklis, USGS, Box 25046, MS 421, Denver, CO 80225-0046, USA

12:30pm-1:45pm Lunch

Session III: WIPP and Other Sites
Session Chair: Ned Elkins, M&O/LANL

1:45pm-3:30pm

Hydraulic Characterization Activities in Support of the Shaft-Seals Fluid-Flow Modeling Integration Into the Waste Isolation Pilot Plant EPA Compliance Certification Application,
T. F. Dale, INTERA Inc., 9111 Research Blvd., Austin, TX 78758, USA; *L. D. Hurtado and M. K. Knowles*, Repository Systems Isolation Department, Sandia National Laboratories, Albuquerque, NM 87122, USA

Effects of Gas and Brine Flow on Repository Behavior in the 1996 Performance Assessment for the Waste Isolation Pilot Plant,
K. E. Economy, Palmer, Vaughn Applied Physics Inc., contractor to WIPP Performance Assessment Group, Albuquerque, NM, 87185,1328, and *J. Helton*, Department of Mathematics, Arizona State University, Tempe, AZ, 85287-1804, USA

Discrete-Feature Model for a Repository in Fractured Crystalline Rock,
J. E. Geier, R Haggerty, Clearwater Hardrock Consulting, Monmouth, OR 97361-9603, and *B. Dverstorp*, Swedish Nuclear Power Inspectorate, S-106 58 Stockholm

Measurement and Modeling of Two-Dimensional Unsaturated Zone Water Fluxes Near Buried Radioactive Waste at the Idaho National Engineering and Environmental Laboratory,

J. R. Nimmo, K. S. Perkins, M. A. Denton, S. M. Shakofsky, and J. F. Kaminsky, USGS, MS-421, 345 Middlefield Road, Menlo Park, CA 94025, USA

Time-Dependent Changes in the In Situ Hydrologic Properties of a Shear Zone,

P. Talwani, Department of Geological Sciences, University of South Carolina, 701 Sumter Street, Columbia, SC 29208, USA

3:30pm-3:45pm Break

Session IV: Yucca Mountain Hydrochemistry
Session Chair: Ned Elkins, M&O/LANL

3:45am-5:30pm

Use of Air-Flow and Rock-Gas Chemistry Data From Boreholes Open in the Unsaturated Zone to Estimate Permeability and Effective Air-Filled Porosity,

E. P. Weeks, G. L. Patterson, and D. C. Thorstenson. USGS, Box 25046, MS 413, Denver Federal Center, Lakewood, CO 80225, USA

Stable Isotope and Carbon-14 Data From Unsaturated-Zone Cores at Yucca Mountain, Title change m.m. 02/26/98

I.C. Yang, USGS, Box 25046, Federal Center, MS 421, Lakewood, CO 80225, USA

Evolution of Ground Water Chemistry in a Deep Vadose Zone in Silicic Volcanic Rocks in an Arid Environment,

A Meijer, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Hydraulic Inferences from Strontium Isotopes in Pore Water From the Unsaturated Zone at Yucca Mountain, Nevada,

B. D. Marshall, K. Futa, and Z. E. Peterman, USGS MS 963, Denver, CO 80225-0046, USA

Secondary Mineral Evidence of Large-Scale Water Table Fluctuations at Yucca Mountain, Nye County, Nevada,

J. F. Whelan and R. J. Moscati, USGS, PO Box 25046, MS 963, Denver Federal Center, Denver, CO 80225, USA

- **Tuesday, December 16, 1997, 8:00am-5:00pm, Building 66, Auditorium, LBNL**

Session V: International Papers
Session Chair: Paul Witherspoon, LBNL/UCB
8:20am-8:50am Invited Speaker:

From Field Data to the Evaluation of a Potential Site for Deep Geological Disposal: The Role of Groundwater Flow Models,

S. Vomvoris, P. Vinard and P. Marschall, Nagra, Hardstrasse 73, CH-5430, Wettingen, Switzerland

8:50am-10:30am

Hydrogeologic Experiment in Fractured Granite at the Kamaishi Mine, Japan.
T. Doe, M. Uchida, Sawada, Senba, Shimo, and Takahara, 1-9-13 Akasaka, Minato-ku, Tokyo, Japan

Geological Characteristics of Armenian NPP Region and Hydrological Criteria of a Medium For Nuclear Waste Isolation,
Y.G. Ghukasyan and R. T. Djrbashyan, Institute of Geological Sciences of National Academy of Sciences, #24a Marshal Baghramyan Avenue, Yerevan 375019, Republic of Armenia

Future of Geological Formation Usage for Radioactive Waste Isolation in Western Ukraine,
O. V. Shestopalova, Institute of Geological Sciences, 55b Gonchar Street, Kyiv, 252054, Ukraine

Velocity, Stress and Fracture Anisotropy; Seismic Measurements Around an Underground Opening,
R. P. Young and R. E. Murdie, Dept. of Earth Sciences, Keele University, Keele, Staffordshire ST5 5BG England, and *C. D. Martin,* Geomechanic Research Centre, Laurentian University, Sudbury, Canada

Three Dimensional Inverse Modeling of Multi-scale Hydraulic Test Data,
D. D. Walker, L. Eriksson, L. Lovius, and A. Strom, INTERA kb, Sollentunavagen 63, S-191 40 Sollentuna, Sweden

10:30am-10:45am Break

Session VI: Yucca Mountain Modeling A
Session Chair: Russell Patterson, DOE/YMSCO
10:45am-12:30pm

Alternative Approaches for Modeling Unsaturated Flow and Transport in Fractured Rocks,
D. A. Chesnut, University of California, Lawrence Livermore National Laboratory, c/o CRWMS M&O, 1180 Town Center Drive, MS423/624, Las Vegas, NV 90134, and *B. Faybishenko,* University of California, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Construction and Calibration of a Preliminary Three-Dimensional Finite-Element Ground-Water Flow Model of the Site Saturated Zone, Yucca Mountain, Nevada,
J. B. Czarnecki, C. C. Faunt, USGS, Box 25046, MS 421, Denver, CO 80225-0046, USA and *C. W. Gable, and G. A. Zyvoloski,* Los Alamos National Laboratory, EES-5, Los Alamos, NM 87545, USA

Effects of Faulted Stratigraphy on Saturated Zone Flow Beneath Yucca Mountain, Nevada,
A. J. B. Cohen and C. M. Oldenburg, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Saturated Zone Radionuclide Transport at Yucca Mountain, Nevada,
G. Zyvolski, B. Robinson, K. Birdsell, and J. Czarnecki, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Synthesis of Environmental Tracer Data and Numerical Simulations Test Models of Flow and Transport at Yucca Mountain,
A. Wolfsberg, J. Fabryka-Martin, G. Roemer, S. Levy, Los Alamos National Laboratory, Los Alamos, NM 87545, USA, and *D. Sweetkind*

12:30pm-1:45pm Lunch

Session VII: Yucca Mountain Modeling B
Session Chair: Russell Patterson, DOE/YMSCO
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A Site-Scale Model for Modeling Unsaturated Zone Processes at Yucca Mountain Nevada,
G. S. Bodvarsson, Y-S. Wu, E. L .Sonnenthal, M. Bandurraga, C. Ahlers, C. Haukwa, J. Fairley, J. Hinds, and A. Ritcey
Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

A modeling Study of Perched Water Phenomena in the Vadose Zone,
Y- S. Wu, A. C. Ritcey, G. S. Bodvarsson, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90-1116, Berkeley, CA 94720, USA

Integrated Radionuclide Transport Models for the Potential Repository at Yucca Mountain,
B. A. Robinson, K. H. Birdsell, C. W. Gable, A. V. Wolfsberg, G. A. Zyvoloski, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Unsaturated Zone and Groundwater and Groundwater Contamination at Two Western US Low-Level Radioactive Waste Disposal Sites: A Review,
H. G. Wilshire, 1348 Isabelle Avenue, Mountain View, CA 94040, USA, and *I. Friedman*, 2620 Vivian Street, Lakewood, CO 80215, USA

Numerical Simulations of Thermohydrological Process at YM.
T. Buscheck, Lawrence Livermore National Laboratory, Livermore, CA 94551, USA

3:30pm-3:45pm Break

3:45pm-5:30pm Round Table Discussion
Moderator: Paul Witherspoon

M98005649

Report Number (14) CONF-971241--2

Publ. Date (11) 199712

Sponsor Code (18) USGS, XF

UC Category (19) UC-000, DOE/ER

19980702 041

DOE