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MEMORANDUM FOR: Margaret V. Federline, Chief
Hydrology and Systems Performance Branch

THRU: David J. Brooks, Section Leader
Hydrologic Transport Section
Hydrology and Systems Performance Branch

FROM: John W. Bradbury, Geochemist
Hydrologic Transport Section
Hydrology and Systems Performance Branch

SUBJECT: TRIP REPORT ON THE USGS COMMITTEE FOR THE ADVANCEMENT OF SCIENCE IN THE YUCCA MOUNTAIN PROJECT, CASY SYMPOSIUM

The USGS sponsored a symposium on the effects of repository thermal loading on fluid movement and geochemistry at Yucca Mountain on March 24 and 25, 1993. This meeting was held in Denver, and involved investigators from the USGS, LANL, LLNL, SNL, and LBL and representatives from DOE, NRC, CNWRA and the State of Nevada. Enclosure 1 is the agenda. Highlights of the meeting are described below:

- R. Morisette provided an historical perspective on the design basis of the repository as presented in the SCP. At 48-60KW/acre, temperatures in the farfield would not exceed 75°C; temperatures greater than 50 m from the repository horizon would not exceed 100°C. Zeolites would not be exposed to temperatures greater than 60°C, and consequently would remain stable. No new fractures would be generated and the change in temperature at the ground surface would be less than 6°C.

- L. Ramspott compared the SCP design to the "cool" design to the "extended dry" design. The SCP design was formulated in 1983 when D. Vieth sequestered a number of people in a hotel in Las Vegas for 22 days and told them to design the repository site. At that time the primary barrier to radionuclide release was the Calico Hills formation. Dryness of the site was considered secondary.

  - An earlier design consideration was that the repository would contain spent fuel that was on the average 5 years out of the core (YOC). As the program slipped schedules, that concept has progressively changed such that in 1990 the YOC was 29. The effect is that the thermal load per cansiter is less. However, as more spent fuel is generated the size of the repository must increase. The "Yucca duck" design as presented in the SCP is no longer being considered. A larger repository is now required to contain the larger quantity of waste.

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- At one time in the past, the question was asked, "Can you cool the repository with ventilation?" A viewgraph was shown in which the heat from the repository could be used to drive a convection cell where cool air from the surface could be drawn into the repository, warmed by the hot canisters, and vented out a chimney. This conceptualization predated the carbon-14 issue.

• T. Buschek presented recent modelling work on the thermal effects of the repository on the temperature and moisture contents of the geologic setting. This two-hour talk was the focus of the meeting. The modelling involved two-dimensional two-phase flow and heat transfer in an equivalent porous medium. The hydrostratigraphic units are all horizontal. He varied permeabilities of these units over many orders of magnitude to bound all the possible permeabilities likely to be encountered in the fractured unsaturated medium of Yucca Mountain. Enclosure 2 is a description of the current modeling effort from the January 1993 Lawrence Livermore Progress Report on the Yucca Mountain Project.

- The modelling showed that significant redistribution of moisture will occur in the repository. If this moisture is concentrated above the repository horizon and then drains back through the repository, the flux of water would greatly exceed any fluxes conceivable by increased infiltration due to changes in the climate. The repository could drip for 600 to 1000 years.

- The modelling effort showed that at low permeabilities, the repository-driven heat flow will be dominated by heat conduction. At permeabilities above 1 darcy, a buoyant convective system can be developed and will dominate the system after 1000 years. For comparison, the permeability at the repository horizon described in the SCP was 18 millidarcy.

- The modeling showed that the most significant drying effects occur at the repository edges where moisture is moved in the vapor phase to regions high above the repository horizon. Less movement of moisture through the center of the repository is due to extensive boiling there, which increases the pressure and reduces mass transfer.

- Convection does not affect the temperature distribution around the repository. Tight impermeable zones above the repository could make convective cells more likely. Even a non-connected system could develop remote convective cells.

- The repository heat can drive thermal mixing in the saturated zone. This is the first time I have seen consideration of thermal effects in the saturated zone.

- Four characteristics that could make the results of this modeling effort invalid or inaccurate are 1) the effects of thermal buoyancy, 2) condensate drainage, 3) nonequilibrium fracture flow, and 4) spatial variability.

• S. Levy described petrologic features in Harper Valley that could have been formed by the near syngenetic hydrothermal alteration of the still warm tuff units. Possibly, meteoric water could have percolated into the units. The interior of the units might have been hot enough to flash the water to steam. Brecciation of the rock could have resulted.

• D. Bish described mineral stability of the zeolites and clays as a function of temperature. The parameter used to record their stability was the molar volume. The zeolites decreased in volume on heating to 300°C but rebounded on cooling to room temperature. On heating, the zeolites lost between 8 and 10 weight percent attributed to dehydration. The molar volume of smectite clay decreased by a factor of two and the collapse was partially irreversible. Finally, it is interesting to note that quartz has a higher K_d than clinoptilolite for Np.

• B. Glassley discussed geochemical modelling in a nonisothermal flowing system. He is studying the dimensionless Damkohler number which relates kinetics of a chemical reaction to flow velocity. Large Damkohler numbers suggest local equilibrium will be attained. Small Damkohler numbers suggest reactions may not have a chance to take place in a fast flowing system. He suggests that the work of Buschek now allows a framework in which geochemistry modelling can be included. It should be noted, however, that only limited data exist on the rates of chemical reactions expected to occur at Yucca Mountain.

• B. Ross listed reasons why the temperature could be higher than predicted by modelling assuming an equivalent porous medium (ECM). These include 1) water for heat pipe could run down through pillars or cold spots, 2) down fractures too fast for evaporation, or 3) water could be removed by ventilation. He also listed reasons why the temperatures could be less than predicted. These include 1) the requirement that the system get very wet before fracture flow can occur, 2) heat is removed by ventilation, or 3) instability phenomena tend to amplify small scale variability. Heat transfer is sensitive to 1) bulk permeability, and 2) water mobility in unsaturated fractures.

Panel Discussion

• The panel discussion highlighted the differences between the engineers and the scientists. The engineers want a repository that stays dry for a long time so they can have confidence in their corrosion models. The scientists prefer a cold repository to minimize the effect on the geologic setting. Then they will be confident about the future of the repository. The modelling effort by T. Buschek shows that the temperatures may not be greater in a repository with a higher thermal load, depending on bulk permeability.

• An engineer pointed out that a 5% defect rate is the common industrial standard. The goal of the project is a 1% defect rate.

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B. Bodvarsson suggested the possibility of phreatic eruptions if the system is sealed such that the pressure can exceed the lithostatic load. P. Bethke supported the idea by mentioning that many epithermal systems experience phreatic eruptions.

- Consensus of all those present was that the modeling exercises are interesting and illustrate that even simple systems are not always predictable. All agreed the most important characterization activity is to begin the large block heater test to supply physical backing to the theoretical models.

/s/

John W. Bradbury, Geochemist
Hydrologic Transport Section
Hydrology and Systems Performance Branch

Enclosure:
As stated

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USGS COMMITTEE FOR THE ADVANCEMENT OF SCIENCE
IN THE YUCCA MOUNTAIN PROJECT

CASY SYMPOSIUM
March 24-25, 1993
Holiday Inn West
14707 West Colfax Avenue
Golden, Colorado
(303) 279-7611

EFFECTS OF REPOSITORY THERMAL LOADING ON FLUID MOVEMENT
AND GEOCHEMISTRY AT YUCCA MOUNTAIN

Wednesday, March 24

MORNING CHAIR - Bill Dudley (USGS)

8:30 *WELCOME AND INTRODUCTION - Larry Hayes and Bill Dudley (USGS)*

8:45 HISTORICAL PERSPECTIVE ON THERMAL LOADING CONSIDERATIONS - Mike Voegele (SAIC)

9:15 OVERVIEW OF THERMAL LOADING OPTIONS AND THE EXTENDED DRY CONCEPT - Larry Ramspott (LLNL)

9:45 ***BREAK***

10:00 IMPACT OF REPOSITORY THERMAL LOAD ON HYDROTHERMAL FLOW - Tom Buscheck (LLNL)

12:00 ***LUNCH***

AFTERNOON CHAIR - Zell Peterman (USGS)

1:30 HISTORICAL DEVELOPMENT OF THE EXTENDED DRY CONCEPT - Dale Wilder (LLNL)

1:45 TRADITIONAL AND PERSISTENT FACTORS FAVORING LOW THERMAL LOADING - Gene Roseboom (USGS)

2:15 HYDROTHERMAL ANALOGS AT YUCCA MOUNTAIN - Schon Levy (LANL)

2:45 ***BREAK***

3:00 EFFECTS OF HEATING ON ZEOLITES AND SMECTITES - David Bish (LANL)

3:30 EFFECTS OF HEAT ON HYDROLOGIC PROPERTIES - Alan Flint (USGS)

4:00 CONSIDERATIONS OF GEOCHEMICAL AND PHYSICAL EFFECTS - Bill Glassley (LLNL)

4:30 Announcements and discussion of Day 1

Thursday, March 25

MORNING CHAIR - Dick Luckey (USGS)

8:00 GEOMECHANICAL *EFFECTS OF HEAT ON FRACTURE SYSTEMS - Larry Costin* (SNL)

8:30 PHYSICAL PROCESSES AFFECTING TEMPERATURES AT YUCCA MOUNTAIN - Ben Ro... (Disposal Safety, Inc.)

9:00 COMPARISON OF DUAL-POROSITY AND EFFECTIVE-CONTINUUM APPROACHES TO THERMAL MODELING - Ed Kwicklees (USGS) and Bo Bodvarsson (LBL)

9:30 ***BREAK***

10:00 PERFORMANCE ASSESSMENT PERSPECTIVE - George Barr (SNL)

10:30 POSSIBLE IMPACTS ON NATURAL BARRIER SYSTEM - Dwight Hoxie (USGS)

11:30 ***LUNCH***

AFTERNOON CHAIR - Bill Dudley (USGS)

1:00 PANEL DISCUSSION - Panelists: Bo Bodvarsson (LBL)
Phil Bethke (USGS)
John Bredehoeft (USGS)
Clarence Duffy (LANL)
Eric Ryder (SNL)
Ed Taylor (M&O/TRW)
Dale Wilder (LLNL)
Ike Winograd (USGS)

Charge to the Panel: By personal observations on the symposium and related topics and by questions directed to the speakers or others in the audience, lead the group in examining such questions as:

- strengths and weaknesses of models and concepts presented, particularly as to thoroughness in representing the important processes and hydrogeologic and mineralogic frameworks

- possible beneficial and adverse mineralogic changes resulting from a large heat load

- effects of thermal loading on difficulty of predicting flow and transport in both liquid and gaseous states

- ramifications of thermal loading scenarios from warm to very hot

3:00 Adjourn

ATTACHMENT 1
MEETING AGENDA

The paper by W. Glassley entitled "Validation of Hydrogeochemical Codes Using the New Zealand Geothermal System" was approved by YMPO. It will be published in the proceedings of the CEC Natural Analog Working Group meeting that was held in Toledo, Spain on October 5-9, 1992 and will also be published as an LLNL preprint.

Discussions were held regarding PACS workscope statements.

1.2.2.2.2 Hydrologic Properties of the Waste Package Environment

The first draft of the Study Plan for the Near Field Environment Hydrology Task is in the internal technical review process.

Model Calculations

Work continued to analyze the preliminary scoping calculations of the hydrothermal performance of the repository, using the new model which represents hydrothermal flow in the upper 1000 m of the saturated zone (SZ) as well as within the unsaturated zone (UZ). With respect to both bulk permeability, k_b, and the impact of large-scale, buoyant gas-phase convection on thermal performance and moisture redistribution, past work has primarily focused on intermediate- to high-AML (Areal Mass Loading, expressed in metric tons of uranium per acre - MTU/acre) cases for which rock dry-out primarily occurs as a result of boiling. Permeability values considered range from 1.9×10^{-7} darcy (corresponding to no fractures) to 84 darcy (corresponding to one 1000-µm-fracture per meter). The reference-k_b case has a k_b of 0.28 darcy (corresponding to three 100-µm-fractures per meter). (One darcy is approximately 10^{-12} m^2). Current work is examining the impact of large-scale, buoyant gas-phase convection on thermal performance and moisture redistribution for low- to intermediate-AML (27.1 to 49.2 MTU/acre) cases for which dry-out primarily occurs under sub-boiling conditions.

Intermediate to High Thermal Loads

Before discussing the impact of buoyant gas-phase convection on sub-boiling performance, it is necessary to summarize what has been learned about the impact of buoyant gas-phase convection on boiling performance. In cases for which rock dry-out is primarily driven by boiling (intermediate- to high-AMLs), it was found that thermo-hydrological performance can be classified into three distinct categories with respect to k_b. The low-k_b category (k_b<0.01 darcy) corresponds to situations in which fracture density and connectivity throttle the rate of boiling and dry-out. Because heat flow is dominated by heat conduction, it is vertically symmetrical about the heater horizon. The low k_b results in large gas-phase pressure gradients that elevate the boiling temperature, thereby resulting in higher peak temperatures. The intermediate-k_b category 0.01 <k_b<10 darcy) corresponds to situations in which the fracture density and connectivity are sufficient to promote boiling that is not substantially throttled by flow resistance in the fractures. Because k_b is not sufficiently large to promote substantial large-scale buoyant gas-phase convection, local boiling pressure gradients dominate the large-scale, buoyant, gas-phase pressure gradients, resulting in steam flow and condensate generation that is vertically symmetrical about the repository horizon. The heat convective effects in the heat-pipe zone have a local, transient effect on the temperature distribution, but because convection does not significantly enhance the heat loss from the boiling zone to the far-field, the duration of boiling conditions is not significantly reduced.

The high-k_b category (k_b>10 darcy) corresponds to situations in which fracture density and connectivity are sufficiently large to allow large-scale, buoyant gas-phase gradients to dominate the local boiling pressure gradients, causing significant asymmetry in the vertical temperature distribution. For this category of thermo-hydrological performance, k_b = 84 darcy was considered. Although far-field convection completely dominates the direction of steam flow, causing all of the steam to be driven to the upper condensation zone, heat flow is still dominated by heat conduction, and the duration of the boiling period, t_b, is not substantially reduced (for high AMLs) relative to the intermediate-k_b case. Because large-scale buoyant convection enhances the heat loss for the boiling zone to the far-field, heat convection has a definite influence on heat flow (e.g., lowering peak temperatures), yet it accounts for less than 50% of the overall heat flow; therefore, this situation is referred to as convection-influenced heat flow. The term convection-dominated heat flow is reserved for cases in which convection accounts for more than 50% of overall heat flow.

Low to Intermediate Thermal Loads

For 27.1 MTU/acre (30-yr-old Spent Nuclear Fuel (SNF), and Areal Power Density (APD) of 20 kW/acre), bulk permeabilities of 0.28, 84, 168, 410 and 840 darcy were considered. It was realized that the average k_b in the UZ is not likely to approach the latter two values of k_b; however, calculations may be applicable to the local thermo-hydrological performance in highly fractured areas such as shear or fault zones. The primary purpose of this study was to identify the averaged conditions (thermal loading and k_b) required to result in heat flow being dominated by large-scale, buoyant gas-phase convection. Also considered were an intermediate and high bulk permeability for 49.2 MTU/acre (10-yr-old SNF and an APD of 57 kW/acre, corresponding to the reference SCP-CDR thermal loading); these values are 0.28 darcy and 84 darcy. Note that the high value is only a factor of two greater than some of the k_b values that have been measured in TSw2 (the host rock for the repository horizon).

Intermediate (Reference SCP-CDR) Thermal Loads

For the 49.2 MTU/acre reference SCP-CDR thermal loading case, large-scale buoyant gas-phase convection occurring in the high-k_b (84 darcy) case reduces the duration of the boiling period, t_{bp}, from 666 yr to only 117 yr, relative to the intermediate-k_b (0.28 darcy) case. The peak temperature at the center of the repository, T_{peak}, is also reduced from 100.3 to 97.3°C. At t = 1000 yr, the temperature at the center of the repository is reduced by 13.1°C relative to the k_b case. Interestingly, B. Ross (an SNL subcontractor) has conducted a calculation for a case with nearly the same AML (47.5 MTU/acre), with the primary differences being that he assumes 30-yr-old SNF, yielding an APD of 35 kW/acre, and a k_b of 50 darcy. At t = 1000 yr, Ross found that buoyant gas-phase convection has reduced the temperature at the center of the repository by approximately 9.5°C, relative to the conduction-only calculation. When one takes into account that the Rayleigh number for this case is approximately 45% less th that applicable to LLNL's calculation, the two models are seen to be in reasonably good agreement. Moreover, the shape of the temperature curves predicted by the two different models are very similar.

For cases which never get significantly above the nominal boiling point, large-scale, buoyant, gas-phase convection can significantly affect the duration of boiling. This buoyant convective effect can only significantly impact repository temperatures if substantial quantities of water vapor are transported from the repository horizon to the far-field. The transport of water vapor (and latent heat) that is sufficiently large to reduce repository temperatures is also associated with dramatic changes in the moisture redistribution. Simply put, in order for the hydrological (buoyant gas-phase) flow system to dominate heat flow generated by the repository, that repository-generated heat flow must have had a dominant impact on the hydrological flow system, including both liquid-phase and gas-phase flow.

For the reference SCP-CDR case, the intermediate k_b (0.28 darcy) results in a very small vertical dry-out zone thickness, h_{dz}. For example, at t = 100 yr, h_{dz} is only 12.2 m. The maximum h_{dz} (14.4 m) occurs at t = 300 yr. At t = 1000 yr, the dry-out zone has nearly re-wetted back to ambient saturation. For the high-k_b case, h_{dz} at t = 300 yr is 23.3 m, nearly twice the h_{dz} of the intermediate-k_b case. Although boiling ceases at t = 117 yr, h_{dz} continues to increase as a result of the large-scale, buoyant, gas-phase convection of water vapor under sub-boiling conditions, resulting in h_{dz} = 109 m at t = 1000 yr. At t = 5000 yrs, h_{dz} has grown to 167 m and the overlying condensate zone (where $S_1 > 90\%$) is 213 m in thickness. It was also found that the net increase in liquid saturation, S_1, within the condensate zone exceeds the net decrease in S_1 within the dry-out zone. This indicates that large-scale, buoyant gas-phase convection is transporting water vapor from the lower dry-out zone (which in turn is supplied by water that is imbibed from the SZ) faster than the rate at which buoyant gas-phase convection can transport water vapor to the atmosphere.

Incidentally, it was assumed that the large values of k_b are also applicable to the nonwelded vitric PTn even though preliminary data indicate that the PTn may be sparsely fractured. Had a smaller k_b been applied to the PTn, this unit would effectively act as a barrier to the upward convection of water vapor, thereby enhancing the net rate of condensate buildup in the upper TSw2 and TSw1, relative to these calculations. It should also be noted that the model used the Equivalent Continuum Model (ECM) assumptions which preclude the occurrence of nonequilibrium fracture flow. Water vapor which is being generated "ubiquitously" throughout the connected fracture system is likely to return as spatially heterogeneous channelized fracture flow. Because this channelized fracture flow will probably exceed the ability of the local gas-phase flow system to evaporate that flow, this will result in nonequilibrium fracture flow persisting for some depth below the condensation zone. It is important to realize that a k_b of 84 darcy is not likely to be applicable throughout the UZ. However, within shear or fault zones, the local value of k_b is likely to be at least that large. Therefore, these calculations indicate the possibility of condensate generated above the repository draining back to the repository horizon (and possibly down to the water table) for tens of thousands of years following the end of the boiling period for the reference SCP-CDR thermal loading case.

For 27.1 MTU/acre (30-yr-old SNF, yielding an APD of 20 kW/acre), the intermediate-k_b case (0.28 darcy) results in virtually no net change in liquid saturation distribution; however, significant sub-boiling refluxing of water vapor and condensate does occur. This sub-boiling refluxing occurs as large-scale, buoyant, gas-phase convection drives water vapor upward to where it condenses and drains downward. The intermediate-k_b case does not result in an upward mass flow rate of water vapor that is sufficiently large to exceed the mass flow rate at which condensate returns. For k_b = 84 darcy, large-scale, buoyant gas-phase convection begins to have a noticeable (but very small) effect on temperatures and moisture distribution. For k_b = 168 darcy, large-scale buoyant gas-phase convection has a minor impact on thermal performance, but a substantial impact on moisture redistribution, particularly for $t > 5000$ yr. For k_b = 410 darcy, large-scale buoyant gas-phase convection has a more substantial effect on thermal performance and moisture redistribution, particularly for $t>1000$ yr. For example, h_{dz} is 150 m at t = 5000 yr and the overlying condensate zone (where $S_l > 90\%$) has a vertical thickness of 173 m (extending all the way to the ground surface). The thermal perturbation to the liquid saturation distribution persists for more than 100,000 yr. The effect of large-scale buoyant gas-phase convection for k_b = 840 darcy has a very substantial effect on thermal performance and moisture redistribution, particularly for $t>600$ yr.

The average k_b in the UZ is not likely to approach the largest two values of k_b used above; however, these calculations are probably indicative of local thermo-hydrological performance in highly fractured areas such as shear or fault zones. Even for 30-yr-old SNF (an APD of 20 kW/acre), the large-scale, buoyant gas-phase convection of water vapor will result in persistent condensate drainage in highly fractured zones for tens of thousands of years. Because some of this condensate drainage will occur as nonequilibrium fracture flow, it is likely to return to the repository horizon (and possibly to the water table). Therefore, if the definition of a "cold" repository is one that does not significantly perturb the ambient hydrological system, it appears very unlikely that a "cold" repository can be achieved.

B. Ross' analysis indicates that it requires about 1000 yr for large-scale, buoyancy-driven gas-phase convection cells in the UZ to become fully developed. LLNL's calculations also indicate that it requires about 1000 yr for large-scale, buoyant gas-phase convection cells to begin to significantly impact thermo-hydrological performance under sub-boiling conditions. Therefore, regardless of how substantial buoyant gas-phase convective effects may eventually become, the peak repository temperature, T_{peak}, for 30-yr-old SNF (which generally occurs within the first 600 yr) is not significantly influenced by large-scale gas-phase convective effects. For 30-yr-old SNF (an APD of 20 kW/acre), T_{peak} is 59.9, 59.9, 58.8 and 59.0°C for k_bs of 0.28, 84, 414, and 840 darcy, respectively.

Summary

Ross' SCP-CDR thermal loading case (47.5 MTU/acre), indicates that a k_b of 50 darcy (5.0×10^{-11} m^2) is sufficiently large to allow large-scale, buoyant gas-phase convection to significantly lower repository temperatures relative to the conduction-only case

(ΔT = 9.5°C at t = 1000 yr). LLNL's SCP-CDR thermal loading case (49.2 MTU/acre), indicate that 84 darcy is sufficiently large to significantly lower repository temperatures relative to what is effectively a conduction-only case (ΔT = 13.1°C at t = 1000 yr). For 27.1 MTU/acre (30-yr-old SNF and 20 kW/acre), LLNL's calculations indicate that a k_b of about 100 darcy is sufficiently large to result in large-scale, buoyant gas-phase convection significantly affecting repository temperatures and the UZ moisture distribution for t >1000 yr. Note that 27.1 MTU/acre and a k_b of 100 darcy result in the same Rayleigh number as Ross' SCP-CDR thermal loading case with a k_b of 50 darcy. Therefore, LLNL's determination of the "threshold" thermal loading and bulk permeability conditions for which sub- or marginal-boiling performance begins to become significantly affected by large-scale, buoyant gas-phase convection is corroborated by Ross' analysis.

Laboratory Experiments

Work continued to measure electrical resistivity as a function of moisture content of Topopah Spring tuff samples from U3hg-1 and GU-3 holes at room temperature. Four samples with different thicknesses were prepared from each rock type for the measurements. A gold electrode was deposited on the flat surfaces of the cylindrical disc samples. Two-electrode electrical resistance measurements were done on each of the four samples. The measurements have been completed in the drying phase. These measurements were made by using distilled water (DW) as pore fluid, DW has an electrical conductivity of ~0.4 µS/cm at 20°C. The same measurements will be repeated using a synthetic water with an electrical conductivity similar to that of J-13 water, which is about 33 siemens/m at 20°C. The purpose of following this experimental procedure is to determine the effect of the electrical conductivity of pore fluid on the relationship between the bulk electrical conductivity of a rock sample and the degree of saturation in it.

Work continued to investigate the different imbibition rates of water into a rock sample when the sample is either in a vapor environment or in liquid water. To understand the mechanism of the imbibition, capillary tubes of various inside diameters (ID) were put in a constant humidity chamber which will be set at various levels of humidity. The imbibition rate of water into each capillary tube will be determined. Last month it was found that a 100 micron ID is too large for the tubes to retain any moisture when they are put in a 95 - 98% relative humidity environment. Capillary tubes with ID ~33 microns have been obtained. They will be put in a 95 - 100% relative humidity environment and in liquid water. The amount of the imbibed water under these boundary conditions will be determined.

An experiment was started to determine the effect of fracture surface coatings on the imbibition of water into the matrix. Eight Topopah Spring tuff samples machined from Busted Butte outcrops were prepared for this purpose. Liquid water imbibition rates will be determined in these samples.