CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Eleventh Thermal Workshop
(20.01402.661)

DATE/PLACE: October 5–6, 2000
Berkeley, California

AUTHORS: D. Hughson

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PERSONS PRESENT:

Representatives of the U.S. Department of Energy (DOE), Management and Technical Support Contractor (MTS), Management and Operating Contractor (M&O), Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), U.S. Geological Survey (USGS), and Nuclear Waste Technical Review Board (NWTRB) attended. Debra Hughson from CNWRA attended as an observer.

BACKGROUND AND PURPOSE OF TRIP:

The purpose of the trip was to attend the Eleventh Thermal Workshop held at Lawrence Berkeley National Laboratory to observe the DOE approach to testing and modeling of coupled thermal-hydrologic processes and to gather information to assist in issue resolution. These thermal workshops are the primary forum for dissemination of information and integration of activities regarding the DOE thermal testing program at Yucca Mountain, NV. The meeting itinerary is included as appendix A.

SUMMARY OF PERTINENT POINTS:

The Eleventh Thermal Test Workshop was held in Perseverance Hall, in Building 54, at the Ernest Orlando Lawrence Berkeley National Laboratory on October 5 and the morning of October 6, 2000. The format of this workshop differed from previous workshops. This workshop emphasized discussion of data and their interpretation rather than presentation of new data and modeling results.

Tim Vogt (DOE) began the first day with a presentation of the Drift-Scale Heater Test (DST) Events Database, a compilation and organization of data and events, such as power outages and water sampling activities, using Microsoft Excel. This is a relatively new endeavor, termed "an immature product" by T. Vogt, to organize the immense quantity of data generated by the DST and to facilitate identification of patterns, correlations, and anomalies.

Sandy Ballard (SNL) presented the latest power and temperature data. The first power reduction to stabilize drift wall temperatures to approximately 200 °C was made about day 820 of heating. Initially, a total of 188.5 kW was supplied to the DST heaters. After three power reduction stages, total power was reduced to 149.6 kW. The ends of the heated drift are cooler than the center, and the drift crown is cooler than the sides near the wing heaters. The target temperature of 200 °C at the drift crown midway along the heated drift is holding steady. Closer to the wing-heater boreholes temperatures are about 205–206 °C. Borehole 160 shows the highest recorded temperature of 240 °C. Barry Freifeld (LBNL) pointed out the distinct, very sharp drying front apparent in this data. S. Ballard also noted that this drying front slowed with time as a greater volume of rock was heated by the same constant amount of heat. Temperatures in Borehole 79 show the most interesting temperature behavior, indicative of interesting fracture hydrology. Temperature anomalies at y coordinates of about 12, 37, and 41 m appear to get hotter more quickly, stay at boiling longer, and remain cooler after passing above boiling than other locations. This is interpreted as steam rising in a fracture while the location is below-boiling causing early higher temperatures, greater supply of water flowing down the fracture causing a lengthening in time spent at boiling, and depression of the boiling isotherm by preferential fracture flow after temperatures increase beyond boiling. The anomaly at approximately y = 41m remained consistently more than 40 °C cooler than neighboring sensor locations, after passing above boiling temperature, and is correlated with a prominent feature identified in the borehole video log.

Wunan Lin (LLNL) talked about interpreting temperature data in terms of hydrology. For instance, he noted the difference in heat pipe size in the vertical-upward Boreholes 170, at y = 39 m, and 168, at 32 m. Also, the vertically-downward Borehole 173 at y = 39 m shows the flat 96 °C heat pipe signal more than Borehole 141 at y = 12 m. He noted that the flat temperature regions below the drift needed to be explained by some mechanism other than refluxing in a heat pipe. This is because below the heated drift vapor flux and condensate drainage should both be moving downward. Condensation of vapor moving away from the heat source and slow drying of the matrix may account for the flat regions seen in Resistivity Temperature Detectors (RTD) below the drift. The RTD sensors are spaced approximately 30 cm apart in the borehole fans. Regions of temperature flattened at 96 °C are up to 2-m long and variable from borehole to borehole. S. Ballard volunteered that he'd tried to correlate the size of the temperature flattened regions above and below the drift unsuccessfully. That is, he could find no vertical asymmetry in the flattened temperature regions nor any other consistent spatial pattern. He said the length of the flattened temperature regions appeared to be completely random from borehole to borehole.

Temperatures along the axis of the drift tend to drop off near the bulkhead faster below the heated drift than above. The steeper thermal gradient near the bulkhead in the invert indicates heat loss through the bulkhead is greater through the invert than through the crown. Also temperatures at RTD sensors near the bulkhead pass through the boiling temperature with less hesitation than other regions of the heated drift indicating there is less water in the rock near the bulkhead. The boiling temperature of water depends on gas pressure and appears to be about 3 °C higher near the wing heaters. This could be a consequence of the volume of heated rock at early versus later times and the associated heating rate. A smaller volume of rock would heat more rapidly, perhaps driving up gas pressure in the matrix.

In a discussion on moisture movement led by W. Lin, Abe Rameriz (LLNL) reported on the status of Electrical Resistivity Tomography (ERT). Two different models of the temperature dependent relationship between electrical resistivity and saturation give results bracketing the possible range of solutions. Referring to previous workshops and publications, A. Rameriz reported that model 2 appeared to be closer to reality than model 1. Anomalous temperature events seen in the longitudinal Boreholes 79 and 80 show up in ERT images as wetting fronts descending below the heated drift followed by drying fronts. Also, similar anomalies are seen in the ERT images at y = 35 and 41 m. In answer to a question on uncertainty, or error bars, in saturations in the ERT images A. Rameriz said that errors were spatially dependent and ERT data can be interpreted only qualitatively at this time. The error assessment, he said, could be based on the difference between the two models. In the large block test (LBT), in contrast to the DST, model 1 appeared to be better than model 2 based on comparisons to neutron probe data. The ERT and neutron probe moisture content data agree more closely in predicting the location of drying regions than wetting regions. The ERT data show wetting regions beyond the drying zone that are not seen in the neutron logs. A big assumption in the ERT models is that the resistivity depends only on temperature and not on ions in the water. Also, the ERT results are sensitive to the temperature map. The inverse algorithm, whether model 1 or model 2, also tends to smooth out spikes and thus exaggerates the size of discrete fracture features.

Richard Carlson (LLNL) continued with an update on the neutron probe data. Neutron data sees the total amount of hydrogen in both matrix and fractures only a few tens of centimeters around the borehole. Rock dried out by heat still contains a 2 percent volume fraction of residual water based on neutron counts. Grout is assumed to be 40 percent water by volume, and initial preheating spikes were interpreted to be grout-filled fractures. Borehole 70 shows zones refusing to dry out at about y = 12 and 35 m. This is interpreted as water being supplied by drainage through fractures.

After an update on the latest Ground Penetrating Radar (GPR) results from John Peterson (LBNL), S. Ballard showed saturation animations at y = 26 m of good comparisons between neutron probe data and dual-permeability (DKM) (without the active fracture model) simulations and ERT results obtained using model 2.

In contrast to the neutron probes, ERT, and GPR techniques that show saturation predominantly in the matrix, air permeability directly indicates changes in fracture saturation. Periodically, air permeability is measured and compared to a pretest baseline. Boreholes 57 and 59 above the heated drift show a decreasing trend in air-permeability with time due to condensation in fractures. Increases in air permeability farther away from the heat source in regions below boiling are interpreted by Yvonne Tsang (LBNL) as resulting from thermal-mechanical (TM) closing of fractures. B. Freifeld disagreed, saying that this increase above baseline could be attributed to holes initially drilled with water continuing to dry out over time.

In a discussion of mechanical measurements led by Ralph Wagner (DOE M&O), Jay Cho (DOE) presented the "cleaned up" Multiple Point Borehole Extensiometer (MPBX) data. As noted in previous workshops, the raw MPBX data is extremely noisy, showing wild oscillations off the graph. The MPBX boreholes also have RTD sensors grouted in and the noise is correlated with temperature. The noise decreases as temperatures rise above boiling. Oscillations below and at boiling are believed to result from water and steam refluxing in the borehole. The MPBX data were cleaned up by truncating the wild fluctuations leaving only the increasing trend of cumulative strain with time. Apparently, the noise has a smaller fluctuation component correlated with temperature and larger oscillation component of unknown origin. Change in the coefficient of thermal expansion (CTE) with temperature may show scale effects in that it depends on the length of the gauge. This apparent scale effect may also be influenced by heterogeneity and a damage zone around the drift. The CTE from the "cleaned up" MPBX data is roughly 50 percent of that seen in the lab data.

Steve Sobolik (SNL) presented data from the three arrays of strain gauge rosettes in the concrete liner at the far end of the heated drift and the concrete coupons placed on the floor of the heated drift. Four distinct regimes for CTE of concrete as a function of temperature are seen in the strain gauge rosettes. Below 100 °C, CTE increased initially during the first few days of the test then leveled off toward 100 °C. Above 100 °C the CTE increased to about 10–14 × 10^{-6}/°C up to 165 °C. Above 165 °C the CTE increases again to about 31–37 × 10^{-6}/°C. The CTE of the cast-in-place concrete coupons, on the other hand, apparently decreased between 165–200 °C, while in the reinforced concrete coupons the CTE increased. These changes may be attributed to mineral phase changes similar to what is seen in the lab from rock samples.

R. Wagner continued the discussion by enumerating a list of things to be done to verify assumptions regarding TM effects on hydrology for the AMR which replaces the Calculation done previously by Steve Blair (LLNL). This list included:

1. Expand the literature search from that done for the Calculation and apply it to the DST.
2. Compare model results statistically with MPBX data.
3. Assess confidence in model results based on this comparison.
4. Verify model-predicted shear displacement using fracture data from video logs.
5. Simulate shear and normal displacement at locations of air-permeability measurements.
6. Estimate the component of air-permeability change due to shear and normal displacement.
7. Assess relationship of DST air-permeability and displacement measurements.
8. Supplement this with laboratory measurements.
9. Improve the air-permeability and displacement relationship.
10. Resimulate the DST and assess higher-order effects.

Based on these results, determine if TM effects on hydrology are important.

S. Blair showed comparisons of the "cleaned up" MPBX data with his model calculations using a CTE of $7 \times 10^{-6}/°C$ and a low modulus of elasticity. S. Blair has about 50 major fractures in his model. These were based on fracture surveys by Jeff Wagoner. Major fractures were determined by aperture size from borehole logs. Fractures typically having the greatest extent are vapor-phase parting fractures, which are nearly horizontal and several meters long. In general, S. Blair's model under predicts the MPBX data. Maximum displacements of 3 cm in the model are, unfortunately, not in the area where the air-permeability measurements are made. Model displacements tend not to recover in this model. Boundary conditions in S. Blair's model are of the constant stress type.

W. Lin showed strain calculations compared to cleaned up MBPX data indicating that strain in the rock is not homogeneous.

Debbie Barr (DOE) made a short announcement regarding the upcoming Technical Exchanges between the DOE and the NRC. The Thermal Test Team may be involved in the Evolution of the Near-Field Environment (ENFE), Thermal Effects on Flow (TEF), and Repository Design and Thermal Mechanical Effects (RDTME) Key Technical Issues (KTI). The ENFE and TEF Tech Exchanges will be held back-to-back at Lawrence Livermore National Lab Jan 8–12, 2000. Leading up to this will be several telecons. D. Barr alerted the thermal test team members that they may be called upon to participate in these telecons. "This is where we get down to working out with NRC just exactly what is needed in the very near future," she said. The RDTME Technical Exchange will be the following week. D. Barr requested the thermal test team have a look at the Issue Resolution Status Reports (IRSR) for these KTI's. I gave her the outline of Chapter 5 of the TEF IRSR from Jeff Pohle.

In a discussion on Energy Balance of the DST led by Y. Tsang, Sumit Mukhopadhyay (LBNL) presented equivalent continuum (ECM) modeling results with the wing-heater boreholes represented as high-permeability conduits. Areas around the wing-heaters boil early in the test and steam can escape into the heated drift through these conduits and out through the bulkhead boundary. Y. Tsang emphasized that the property sets used were the ones given by the inverse modeling procedure. These results showed that the open boreholes made a big effect, and speculation in the audience centered around the possible effects of other boreholes not included in the model.

B. Freifeld continued with a presentation of the Global Energy Balance of the DST. His slides are attached to this report as appendix B. He did an energy accounting of two models: S. Mukhopadhyay's ECM model with the high-permeability wing-heater boreholes conduits and an inverse-distance interpolation using just the temperature data at 2000 RTD locations. The ECM model would enforce a global energy balance in the numerical model results, whereas interpolating the temperature data would not. As the boiling isotherm extends out and a dry out zone forms around the drift as water is boiled from the rock, water vapor can either enter the heated drift and escape through the bulkhead or move out into the surrounding rock and condense. He pointed out that a volume of 1 m^3 of water boiled from the rock is equivalent to 1000 m^3 of steam. Water vapor that moves out into the rock and condenses releases the heat of vaporization back into the rock. B. Freifeld found in his element by element energy balance that 76 percent of the energy input went into heating rock, while the remainder was split about evenly between heating water and vaporizing it. From the block by block energy balance (in the ECM model) of the energy from condensation and the energy into vaporization, B. Freifeld could infer the water balance between condensation and loss through the bulkhead. This exercise showed that of the 1200 m^3 of water vaporized in 34 months, 800 m^3 escaped through the bulkhead and out the ventilation system. For the comparison done by interpolating between 2000 temperature locations using inverse distances, he assumed that elements above 96 °C were fully dry and below 96 °C were at initial saturation. Again, a block by block energy balance showed way too much energy being put into the system to account for just rock and water heating and vaporization. The volume of rock encompassed by the boiling isotherms from this interpolation match that from S. Mukhopadhyay's ECM fairly well. B. Freifeld thought these results indicated that there is significant uncertainty about the fate of mobilized water. He felt that it was unknown whether water was condensing in the rock and draining through the fractures or escaping out the bulkhead, and that models could be made to give good matches to temperature data without resolving this uncertainty. He concluded that the only practicable way to decrease this uncertainty in the fate of mobilized water in the DST (condensing in the rock or escaping through the bulkhead) is to measure losses at the bulkhead. Even with a measurement at the bulkhead, it was pointed out, the problem would still be nonunique since a change of property sets would overwhelm subtle variations in temperature from moisture movement. B. Freifeld's analysis does show that about ¾ of the heat transport is by conduction. B. Freifeld also thought that the neutron probe data contradicted the ERT and GPR data by not showing any increase in saturation beyond the drying front. T. Buscheck (LLNL) pointed out that temperatures need to get up to 110 °C or higher to completely dry out the matrix in the models. This depends, however, on the matrix block size. It was agreed that residual saturation is a significant uncertainty. In a side conversation during break B. Freifeld told me he did not think that the DST could be used as evidence for the fate of mobilized water (refluxing above drifts or condensate shedding through fractures) because of these uncertainties.

Ken Lee (LLNL) reported on modeling results investigating the effect of barometric pumping on losses through the bulkhead. The time-varying boundary condition caused numerical difficulties when using the raw data so K. Lee applied a smoothed function with a lower frequency and lower amplitude peaks than the raw data to the boundary as a proxy. He showed a cumulative loss curve that increased sharply upward at around day 300, which is about when the drift wall boiling began. He found barometric pumping increased energy losses through the bulkhead by about 5–35 percent, depending on assumptions about bulkhead permeability. It was pointed out that in reality barometric pumping occurred throughout the mountain, whereas in K. Lee's model, it occurred only through the bulkhead.

Mark Conrad (LBNL) gave an update on gas sampling. Partial pressures of CO_2 are low in the above boiling dryout zones. Hole 78-3 showed the general trend of a steady slow increase in CO_2 percent until boiling then a drop off. There was an order of magnitude higher CO_2 concentration from Borehole 185-2 than in gas samples from other boreholes. Borehole 185 corresponds to a zone of much higher permeability. No anomalous temperatures were seen in this borehole, only anomalously high CO_2.

Eric Sonnenthal (LBNL) introduced his geochemical model as addressing the concern—will boiling in reflux zones lead to concentrated solutions potentially seeping into drifts, and will permanent changes in hydrologic properties result, such as fracture plugging, from mineral precipitation reactions. He noted that evolution of CO_2 in the gas phase is important for pH and geochemical evolution of fracture and pore water and thought the models were capturing the essential geochemical behavior. Still, there remain uncertainties in sample collection and CO_2 contributions from dissolution of calcite. E. Sonnenthal ran a simulation of 8 yrs with 6 years of heating and 2 years of cooling to see if any advantages could be obtained in terms of geochemical understanding from the 2 extra years of heating. He concluded that the extra 2 years of heating would provide no extra information on the evolution of CO_2 gas, but would provide a better understanding of calcite precipitation and dissolution. Also, with 2 extra years of heating there would be some possibility of collecting water from boreholes above the heated drift and there also may be some evidence of silica precipitation from condensate shedding around the tips of the wing heaters where the model predicts the most silica precipitation would occur. E. Sonnenthal said that he thought collecting water samples above the drift was very important for addressing the concern that refluxing would increase the concentration of water above the heated drift. Model results compare well with the sharp drop off in chloride concentration after dry out seen in the data from borehole interval 59-2. During the discussion of the heating and cooling schedule of the DST the idea of drilling a few new boreholes was considered as a relatively economical way of enhancing the utility of the DST for answering questions about water chemistry and mineral reactions. R. Wagner talked briefly about some of the trade-offs between heating an extra 2 years versus the original schedule of heating for 4 years. The extra 2 years of heating would delay obtaining data from the cool-down period. In addition, there is more likelihood for borehole packers to fail in the extra years of heating. The most recent packer failure occurred about one month before this workshop. Potential benefits of the extra heating are better data on mineral reactions and the possibility of collecting water samples above the heated drift.

Tim Vogt presented results of a new effort to compare model predicted saturations with neutron probe data using statistical measures, such as mean-error and root-mean-squared-error. Model results tend to under predict neutron probe measured moisture content, such as from neutron probe Borehole 4, while temperatures are below boiling and tend to over predict moisture contents at above-boiling temperatures after dry out. The over-predicted moisture contents following dry out result from the 2 percent residual saturation seen in the neutron probe data whereas residual moisture contents from the model are lower or zero.

Similar statistical measures are also being used to compare results of Steve Blair's fracture displacement model with the cleaned up MPBX data. According to R. Wagner, this is part of the DOE uncertainty initiative to better quantify uncertainty in process models and data for use in TSPA.

Michael Itamura (SNL) spoke briefly on what TSPA would like to see from the Thermal Testing Team for performance assessments. He started off with the general topic of model validation and focused in particular on the validation of models used for thermal hydrology. Both the DKM and its modification with the active fracture model (AFM), and their associated property sets were developed and calibrated to ambient unsaturated flow conditions. M. Itamura wondered if those property sets were still valid for thermal-hydrologic simulations. Especially, what are the differences in predicted TH behavior obtained from the various property sets? Will liquid water flow down fractures through the above-boiling region and should this be included in TH models? He noted that the models may need to include heterogeneity at appropriate scales to allow for the possibility of flow through superheated fractures. Regarding the lower lithophysal unit of the Topopah Spring tuff, what effects might the lithophysal cavities have on TH and is the Cross-Drift

Thermal Test (CDTT) required to confirm model simulations of TH behavior in this unit? Referring to the Multiscale Thermohydrologic Model used to calculate TH variables for PA, M. Itamura wondered if this model could be validated against the DST. He thought that temperatures in the repository were fairly well known, but that the same was not necessarily true for fluxes and saturations. He felt that PA needed a quantitative evaluation of the uncertainty, or error bars, on predicted TH variables for the near-field environment. Finally, he wondered if thermal-mechanical effects on permeability could be assessed from the air-permeability measurements and could mineral precipitates clog up only the very small fractures, thus changing flow paths without significantly changing bulk porosity. In answer to questions about uncertainty in coupled thermal-hydrologic-mechanical-chemical (THMC) processes, Leon Reiter (NWTRB) advised everyone present to read the Nuclear Waste Technical Review Board (NWTRB) responses to the questions posed by Senator Joe Barton.

Most of the morning of October 6, 2000 was devoted to a discussion of uncertainties and a "hot" versus "cold" repository design. R. Wagner mentioned again the DOE uncertainty qualification initiative in scenario analysis, conceptual models, mathematical models, parameters, and variability (both spatial and temporal) and the consequences to dose. Paul Craig of the NWTRB reiterated the viewpoint that projecting corrosion rates of C-22 based on only a few years of testing is highly uncertain.

Bo Bodvarsson (LBNL) then initiated the discussion of uncertainties in a hot versus cold repository design by stating his belief that the real issue was uncertainty and not whether the repository design developed above-boiling temperatures or not. He encouraged the Thermal Test Team to draft an opinion paper on the hot versus cold design and coupled THMC processes. Bo said that, to the best of his knowledge, the entire YMP supports the current design and that the NWTRB's main concern is not the hot design, per se, but uncertainty and the reliance on C-22 (Note the NWTRB makes clear its position on above- versus below-boiling temperatures in the proposed repository in its answers to questions posed by Senator Joe Barton. These are available at http://www.nwtrb.gov/). He pointed out that a cold repository has its own uncertainties and is not necessarily any less uncertain than the hot design. For instance, a colder design may have a larger footprint area encompassing new, uncharacterized geology. For thermal-hydrology, he said the major uncertainty is where does the water go? Will it seep into drifts or drain through the pillars and for the in-drift environment what will the effect be on the dripshield and C-22 corrosions rates? For coupled THC, the uncertainty is whether fractures will seal and whether or not there will be focusing of flow. For thermal-mechanical effects he said the major uncertainty is whether or not there will be permanent changes in hydrologic properties.

Y. Tsang restated that for thermal hydrology the major uncertainty is the fate of mobilized water. While she felt they have a good understanding of TH processes, the key factor controlling uncertainty in seepage and shedding is spatial heterogeneity. She said that Charles Haukwa (LBNL) had included heterogeneity of over 4 orders of magnitude for two realizations into his mountain-scale TH model, with a grid block size of 1 m, and did not get liquid flow past the boiling isotherm barrier. However, this is still a work-in-progress, she said, and they need to evaluate larger scale discrete vertical faults and fractures. Also, she thought it would be useful to validate the TH models against Ron Green's concrete block experiment at the CNWRA. B. Friefeld asked of what use would be model comparisons against the DST since, referring to his presentation earlier, the fate of mobilized water in the DST is uncertain. Y. Tsang generally agreed with this statement, although she said the TH models could assist in determining where the water went in the DST. It was further pointed out by Harris Greenberg (MTS) that if half or two-thirds of the water mobilized in the DST went out through the bulkhead, then the observation that there has been no dripping in the heated drift of the DST has very little significance. In summarizing this discussion, Bo listed some action items needed to address the uncertainties in thermal hydrology. These included Monte Carlo simulations incorporating heterogeneity into TH models, validating the TH models against Ron Green's concrete block experiment, conducting the Cross-Drift Thermal Test, monitoring losses through the bulkhead of the DST, and more analysis of the fate of water vaporized in the DST. Tom Buscheck added that, if he could go back and redesign the DST, he would recommend that the bulkhead be placed far enough away from the heaters such that it would never reach boiling. He said that the greatest TH uncertainty in the current EDA II design is the "cold-trap" effect. That is a thermal gradient from the hot part of the repository causing mass movement toward the colder edges of the repository and condensing. He said there is significant uncertainty in the present ability to model the "cold-trap" effect and that, while it was too late for the DST, this should be considered in designing the CDTT.

For the coupled thermal-chemical effects, B. Bodvarsson said the THC models that show no fracture sealing need to be reconciled with the laboratory tests that do show sealing. E. Sonnenthal thought that the coupled THC models need to get a better handle on fracture aperture distribution since sealing would likely take place in very small apertures or at points of contact in fractures. Wunan Lin noted that mineral dissolution at the points of contact in fractures could cause fractures to close under stress or "heal." Another major uncertainty is the extent of the wetted fracture surface area. The models now assume that mineral precipitation is distributed over the entire fracture surface area. Other important uncertainties are heterogeneity of the heat source from different types of waste, uncertainty in geophysical measurements of saturation, and uncertainty in the effects of ventilation on fracture sealing. T. Buscheck pointed out that the ventilation could cause a sort of "caliche" layer to form due to evaporation and moisture removal over time.

For reducing uncertainty in TM models, B. Bodvarsson said that laboratory experiments were needed to bound changes in permeability and to refine models. The models also need to account for changes in permeability due to shear deformation. Cool-down data is needed from the DST to verify if TM changes were permanent or could be reversed.

T. Buscheck mentioned some of his recent modeling studies that incorporate heterogeneity similar to Charles Haukwa's work-in-progress. He said that, even with 4 orders of magnitude of heterogeneity, they were unable to get liquid water to flow past the boiling isotherm. To examine the effects of dripping on the in-drift environment while drifts are above boiling, T. Buscheck said they simply put a source term for liquid water into the drift above the drip shield. During the period when the drift is above boiling, T. Buscheck said the effect of water in the drifts is negligible except for a greatly increased rate of evaporation off the drip shield. However, dripping in the drifts after temperatures have dropped below boiling has a strong effect on in-drift variables, particularly relative humidity. From this analysis T. Buscheck concluded that the uncertainties of in-drift thermodynamic variables are greater when the drift is below boiling than when the drift is above boiling. He also reiterated that the greatest uncertainty in present TH calculations is the cold-trap effect and that this is important both when temperatures are above boiling as well as below boiling.

Robin Datta (DOE M&O) summarized the current understanding of heat-driven coupled processes at Yucca Mountain. First, conduction-only models adequately predict sub-boiling temperatures. This is supported by B. Friefeld's global energy balance that found over ¾ of the energy in the DST went into heating the rock. There are indications that heat-mobilized water driven away from the heat source drains through the fractures below the heated drift, but there are significant uncertainties in this interpretation. Regarding rock fall and drift stability, after 34 months of heating there are no observable adverse consequences for either the concrete-lined or unlined drift. In fact, it appears that heating improves drift stability due to "hoop stress." However the effects of cooling have yet to be observed. There appears to be a significant scale-effect on the CTE of the fractured rock. Also, the CTE determined from the DST appears to be roughly 50 percent of that determined in the lab. For coupled THC, it appears that CO_2 exsolves as soon as heating starts, a halo of CO_2

gas moves outward, and the CO_2 gas has a large effect on water chemistry. Thirty water samples from the DST had pHs between 6 and 8, however there are uncertainties about condensation in sampling lines. It was mentioned that there appears to be more chloride in the lower lithophysal unit than the middle nonlithophysal unit of the Topopah Spring tuff. It was also noted that fluoride concentrations were important (they have been measured) and more effort is needed to evaluate potential concentration of trace elements. R. Datta also reported that pore water centrifuged from the matrix at the DST was more concentrated than J-13 water and had a slightly higher pH of about 8.1.

In side-bar conversations during breaks T. Buscheck informed me that the Multiscale TH calculations for drifts with no backfill have been completed and that the results are substantially different than for drifts with backfill. He also said he was considering incorporating a Mountain-scale Line-averaged heat source Thermal Hydrological submodel in the Multiscale TH model to evaluate the potential cold-trap effect of moisture movement along drifts and condensation in cooler regions. Regarding the CDTT, Harris Greenberg informed me that this test has not been canceled but merely postponed due to budgetary constraints. It should be noted that, according to the current design of this test, it will be conducted outside the bulkhead of the ECRB and will not interfere with the closed-bulkhead studies.

CONCLUSIONS:

The general theme of this workshop was interpretation of data in terms of coupled processes and uncertainties in data and process models. The Thermal Test Team appears to be making a concerted effort in many areas to characterize and attempt to quantify data and model uncertainty.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

RECOMMENDATIONS:

The TEF KTI, along with the ENFE and RDTME KTIs will be following closely the progress of ideas and plans proposed at this workshop for characterizing uncertainty and increasing confidence in process models.

SIGNATURES:

Debra Hughson
Sr. Research Scientist

Oct 19 2000
Date

CONCURRENCE:

Asad Chowdhury
Manager, Mining, Geotechnical, and Facility Engineering

10-19-2000
Date

Budhi Sagar
Technical Director

10-19-2000
Date

APPENDIX A

Eleventh Thermal Test Workshop
Lawrence Berkeley National Laboratory
Berkeley, California
October 5-6, 2000

There will be a thermal test workshop in Berkeley, California on Thursday-Friday, October 5-6, 2000 to discuss the results to date from the thermal tests. The workshop, hosted by Yvonne Tsang, will be held in the Perseverance Hall next to the Cafeteria at LBNL. We will follow the agenda given below :

Thursday, October 5, 2000

8:30AM	Welcome and introductions	Yvonne Tsang

DRIFT SCALE TEST

8:35 AM	The Events Datab?se – Its Features and Use	Tim Vogt
8:45 AM	Update of DST Temperature and Heater Power Measurements	Sandy Ballard
8:55AM	Measured Temperatures as Diagnostic of Hydrologic and Other Processes – Discussion led by	Sandy Ballard
9:45 AM	Moisture Movement -Integrated Analysis of ERT, GPR, Neutron and Air-K Measurements - Discussion led by	Wunan Lin
10:30 AM	Break	
10:45 AM	Use of Mechanical Measurements – Discussion led by a) Cleaned-up MPBX Data b) Concrete Strain Measurements c) Corelation of measured displacements, mapped fractures, and permeability changes (by Air-K) d) Rockmass Coeff. Of Thermal Expansion from displacement measurements	Ralph Wagner
11:45 PM	Lunch	
1:00PM	NRC Technical Exchanges on Near-Field Environment KTIs	Deborah Barr
1:10 PM	Energy Balance of DST – Discussion led by	Yvonne Tsang
1:40 PM	Update of Gas Sample Compositions	Mark Conrad
1:55 PM	THC Processes and Heating/Cooling Schedule – Discussion led by	Eric Sonnenthal
2:30 PM	Statistical Evaluation of Predictions/Measurements Comparisons – Temperatures/Saturations/displacements	Tim Vogt

3:10 PM	Break	
3:25PM	Interactions with Endusers of Thermal Test Results	Ralph Wagner
3:45PM	Heat-driven Coupled Processes – What Do We Understand/Know – Discussion led by	Robin Datta
4:55PM	Adjourn to Friday morning	

Friday, October 6, 2000

8:30AM	Uncertainties in Below-boiling and Above-boiling Repository – Discussion led by	Bo Bodvarsson
10:15Am	Miscellaneous Topics	
10:45AM	Adjourn	

APPENDIX B

Global Energy Balance of the DST:

What is in it for me?

XXIII Thermal Testing Workshop

October 5, 2000

Barry Freifeld

Global Energy Accounting System

ELEMENTS IN THE ENERGY BALANCE:

- Heat added - Raise Temperature Rock
- Heat added - Raise Temperature Water
- Heat of Vaporization (Condensation)

NEGLECT:

—Heat added to air

—Chemical reactions

—Many secondary and tertiary effects

- degassing of water
- desorption of water from clays
- etc...

Energy Balance Equation

1) $E_{in} = E_{rock} + E_{water} + E_{vaporization}$

2) $E_{vaporization} = E_{bulkhead} - E_{condensation}$

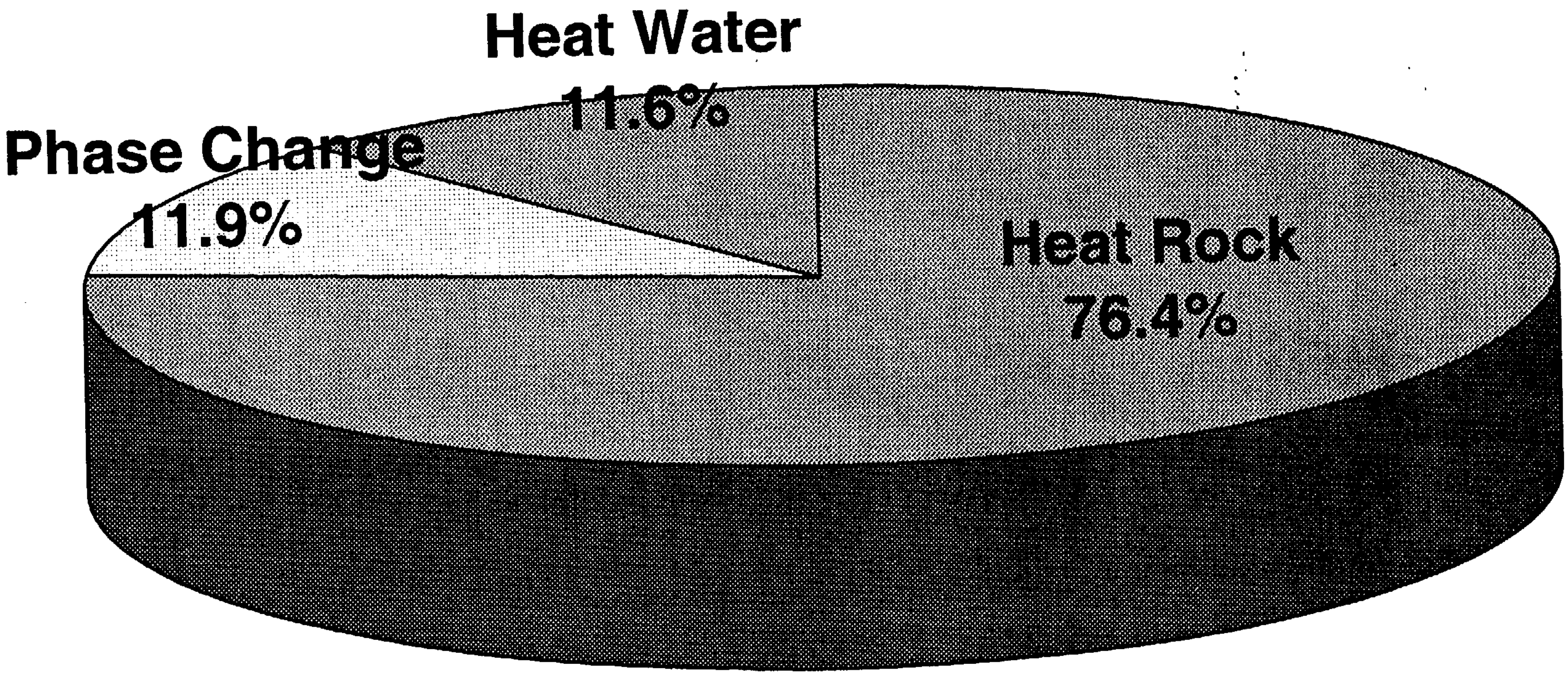
Why (2)?

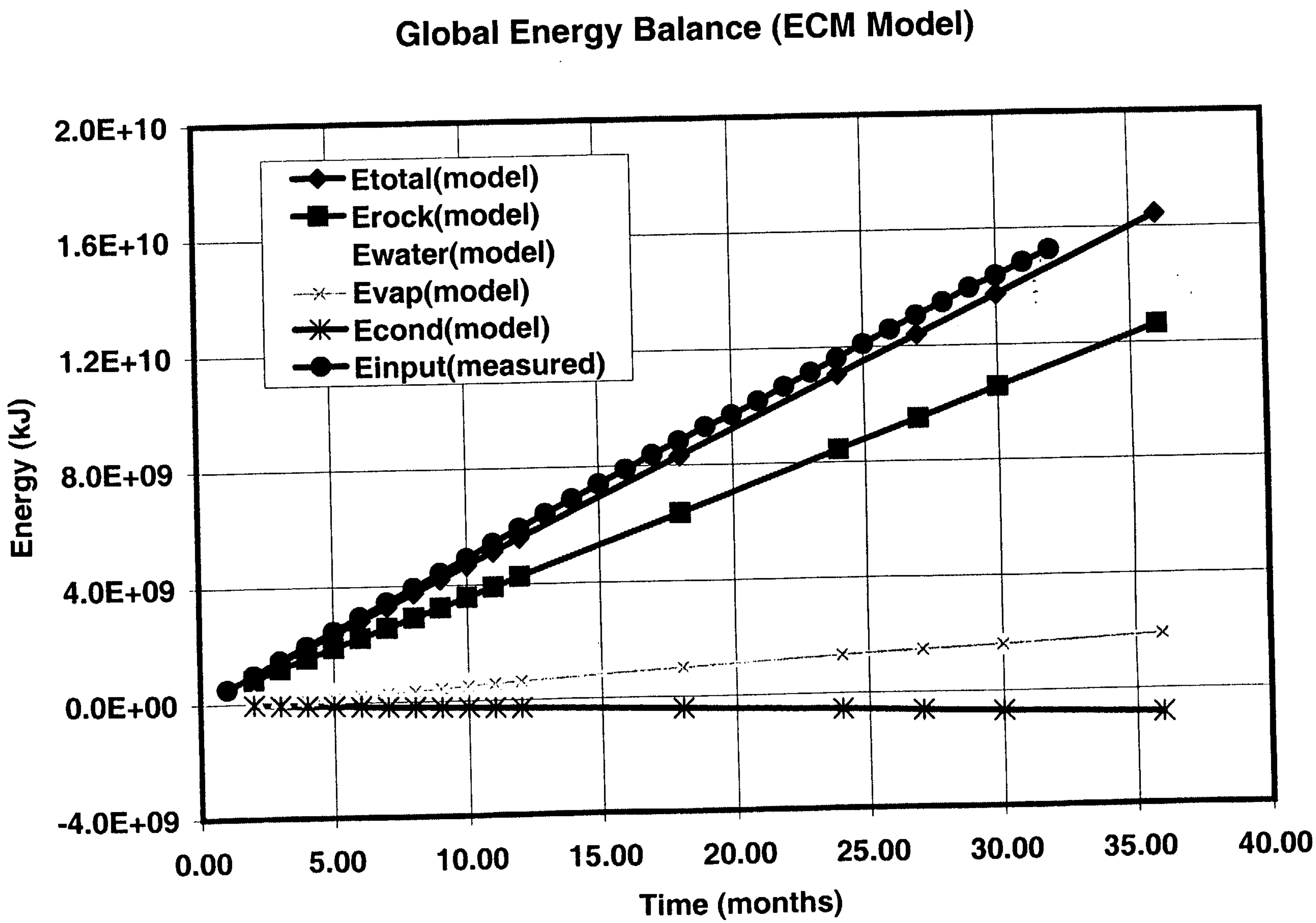
Volume steam >> Volume rock at T>96°C

⇒ Assume no system storage

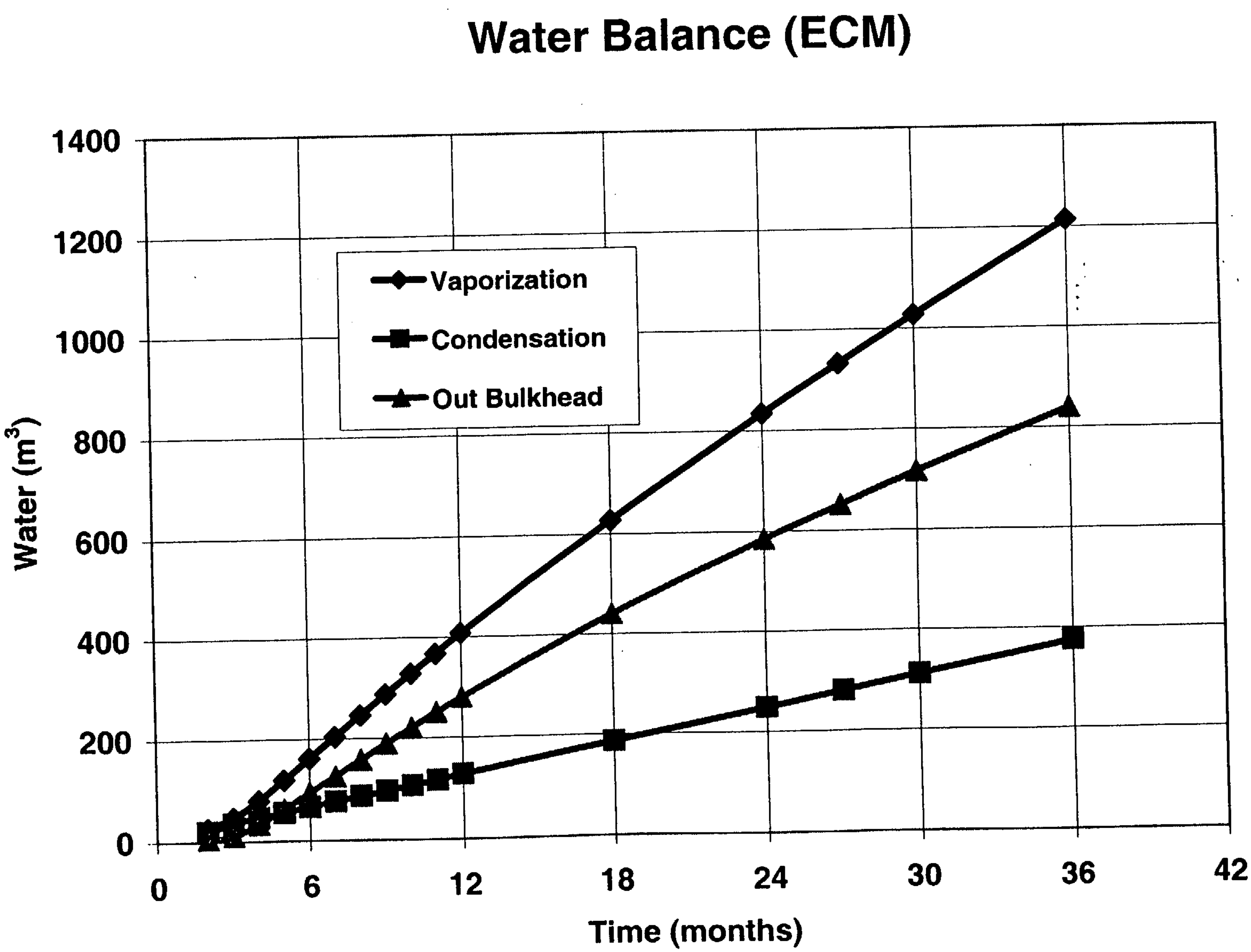
⇒ Steam condenses or exits system at bulkhead!

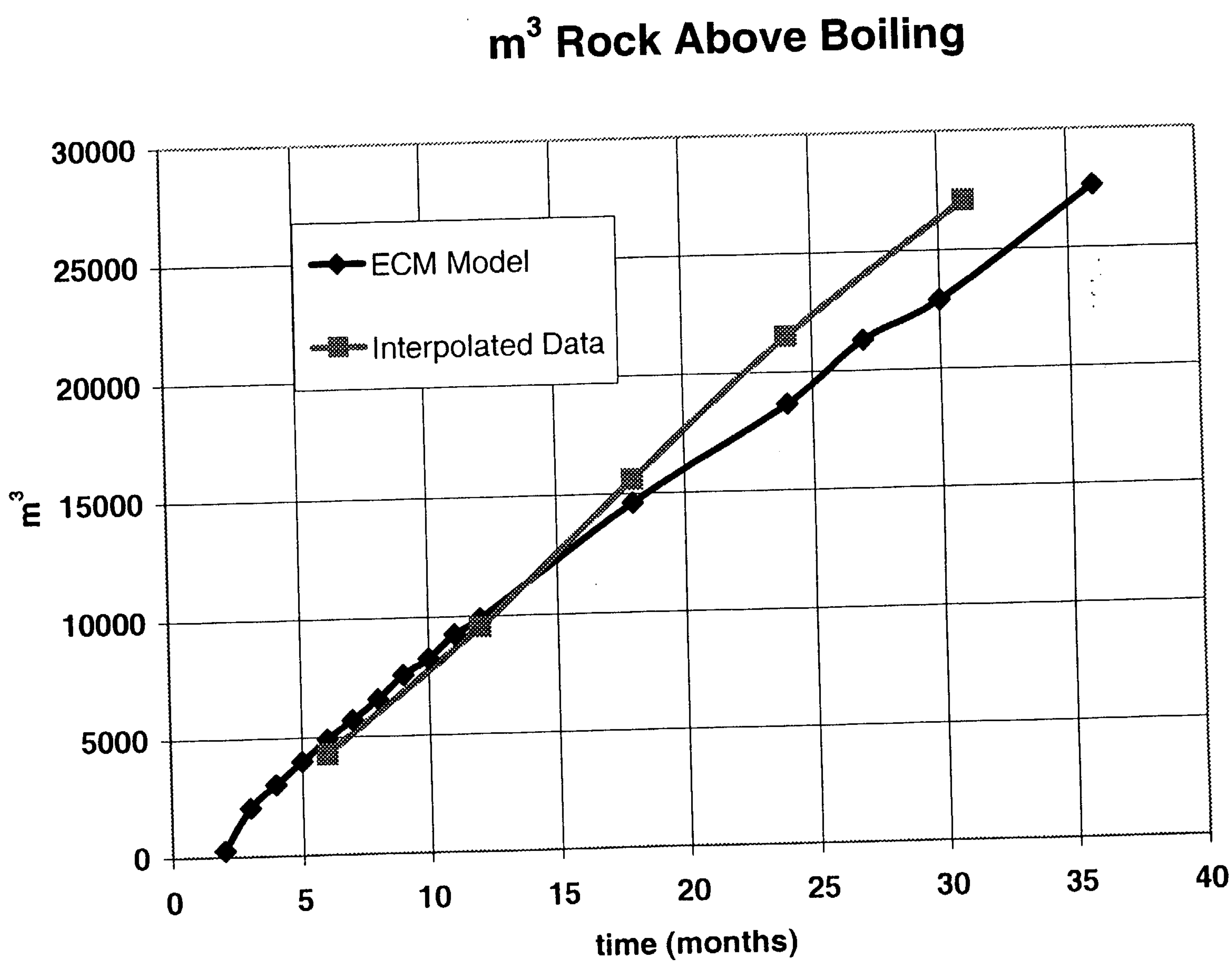
Distribution of Energy (2 Years)





Global Energy Balance (ECM Model)
Etotal(model)
Erock(model)
Ewater(model)
Evap(model)
Econd(model)
Einput(measured)
Energy (kJ)
2.0E+10
1.6E+10
1.2E+10
8.0E+09
4.0E+09
0.0E+00
-4.0E+09
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
Time (months)


Water Balance (ECM)
Vaporization
Condensation
Out Bulkhead
Water (m3)
1400
1200
1000
800
600
400
200
0
0
6
12
18
24
30
36
42
Time (months)


m3 Rock Above Boiling
ECM Model
Interpolated Data
30000
25000
20000
15000
10000
5000
0
m3
0
5
10
15
20
25
30
35
40
time (months)

Uncertainty in Fate of Mobilized Water

$$E_{in} = E_{rock} + E_{water} + E_{vaporization}$$

$$E_{vaporization} = E_{bulkhead} - E_{condense}$$

- Fate of water information (qualitative):
  - —Some wetting beyond boiling isotherm (air-K↓) and geophysics
  - —Steam comes out bulkhead
- To improve understanding:
  - —Measure $E_{condense}$ (intractable)
  - —Measure $E_{bulkhead}$ (tractable)

Conclusions

BERKELEY LAB

- Global energy balance is one equation with two unknowns. $E_{bulkhead}$ and $E_{condense}$ are not known.(NO DATA!)

- To understand fate of mobilized water we need to find $E_{bulkhead}$ or $E_{condense}$. Recommend $E_{bulkhead}$.

- Understanding fundamental flow of energy (and mass) based on "data," coupled with a phenomonologic understanding of TH processes derived from models will increase value of DST and allow more meaningful calibration of parameters.