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Temperature as a Diagnostic for the Drift Scale Test

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by

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Introduction

The United States Department of Energy (DOE) is investigating Yucca Mountain, Nevada, for its feasibility as a potential deep geological repository of high-level nuclear waste. In a deep geological repository, the radioactive decay heat released from high-level nuclear waste will heat up the rock mass. The heat will mobilize pore water in the rock mass by evaporation, and even boiling, if the thermal load is great enough. The water vapor/steam will flow away from the heat source because of pressure and thermal gradients and the effects of buoyancy force. The vapor/steam may flow along fractures or highly permeable zones and condense into liquid water in the cooler regions. Gravity and fracture network will control the drainage of the condensed water. Some of the water may flow back toward the waste package and re-evaporated. This thermal-hydrological (TH) process will affect the amount of water that may come into contact with the waste package. Water is the main concern for the integrity of the waste package and the waste form, and the potential transport of radioactive nuclides. Thermally driven chemical and mechanical processes may affect the TH process. The coupled thermal-hydrological-mechanical-chemical (THMC) processes need to be understood before the performance of a repository can be adequately predicted. DOE is conducting field thermal tests to provide data for validating the model of the coupled THMC processes. Therefore, understanding the processes revealed by a field thermal test is essential for the model validation. This paper presents examples that temperature measurement is an effective tool for understanding the TH process.

Drift Scale Test

The Drift Scale Test (DST) is the biggest in situ thermal test conducted by DOE Yucca Mountain Project. The DST layout and design can be found in Sections 3 and 4 of Drift Scale Test As-Built Report [1]. The DST facility consists of a Heater Drift (HD), an Access-Observation Drift (AOD), and a Connecting Drift (CD). The HD is about 5.5m in diameter, and about 47m long. The heat source includes nine waste package-size electrical heaters on the floor of the HD and 50 wing heaters in boreholes on both sides of the HD (25 wing heaters on each side). A thermal bulkhead is placed near the junction of the HD and the CD. The xyz coordinates of the DST originate at the HD–side of the bulkhead. Instruments installed in the DST are to measure the spatial distribution and temporal variation of temperature, moisture content, deformation, air permeability, gas pressure, relative humidity, gas chemistry, water chemistry, heater power, and others. The total heating power from the nine floor heaters and the wing heaters are about 68 kW and 143 kW respectively. Each wing heater is divided into two sections. The power output for the inner section and the outer section are 1.145 kW and 1.719 kW respectively. The greater heat output from the outer section is to balance the edge cooling effect. The heaters of the DST were energized on 12/3/97. The test is planned to heat for 4 years, followed by a natural cool-down for 4 years. Recently, the heater power has been ramped down in order to keep the drift wall temperature at about 200°C. Currently, the heater power is at about 90% of its original level.

Temperature in the rock mass is measured by using resistance temperature devices (RTD) at various locations and orientations along the HD. Temperature is also measured on the drift wall of the HD, on the surface of the canister floor heaters, the surface of the hot side of the bulkhead, and in the multiple point extensometer (MPBX) holes. Only the temperature measured in the RTD hole is included in this paper, because the RTD holes are sealed with grout, therefore, the measured temperature is more representative of the rock mass temperature. There are 28 RTD holes in the DST. Two of the RTD holes (#79 and #80) are parallel to the HD at about 3.5 m above the mid point of the wing heater sections, at 9.5 horizontal distance from the axis of the HD. When looking at the bulkhead from outside the HD, #79 is on the right hand side, and #80 is on the left hand side. Sixteen RTD holes form two arrays (#137-#144 and #158-#165) intersecting the HD at 12m and 23m (from the bulkhead) respectively. Each of the two arrays forms a vertical plane with RTD holes spaced 45° apart. One six-hole RTD array (#170-#175) intersects the HD at 39m. This 6-hole array is similar to the two 8-hole arrays but without the two horizontal holes. The rest four RTD holes are two pairs of vertical holes (#133-#134 and #168-#169) drilled from the crown and the invert of the HD at 3m and 32 m from the bulkhead respectively.

Results and Discussion

Figure 1 shows snapshots of the temperatures measured along hole#159. This hole is 45° upward from the HD towards the AOD, at about 23m from the bulkhead. The RTDs are numbered so that #1 is near the collar, therefore closest to the HD, and #67 is the farthest into the hole, therefore, the highest in elevation (away from the heat source) and closest to the AOD. The main feature in this figure is the flat region in the temperature curves. The temperature at which the flat region forms is about the expected boiling point of water, based on the barometric pressure at the elevation of the DST block. This indicates that the pore water in a region of a few to several meters long along the hole is involved in boiling at the same time. The flat region in the temperature curves started around 12/3/99, formed from RTD#20 and up, and expanded with time. Water in the rock is evaporated when the temperature rises. The vapor flows away from the heat source and condenses into liquid water when it reaches cooler regions further away. Some of the condensed liquid water may be imbibed into the rock and increases its water saturation. Some of the water may be drained by gravity to regions below. This requires evaporating the water in the rock below RTD #20 to supply enough water to sustain a measurable boiling/rapid evaporation process. When time goes on, more rock is heated to the boiling point of water, and more water is available to sustain a greater boiling region. This process exists in other holes as well, except the timing and location of the boiling process varies.

Figure 2 shows the temperature history at some RTD locations in hole#159. A constant temperature in this temperature-time plot is a direct evidence of boiling. This figure shows that the boiling point of water varies with location along the hole. This hole inclines 45° upward, so that various locations along the hole imply various vertical distances from the heat source. As shown in this figure, the boiling point of water decreases with increasing vertical distance from the heat. The boiling point of water depends on two factors: the pressure on the water and the concentration of solutes in the water. Investigations are on-going to determine if this phenomenon is local or global, and to determine its cause.

Figure 3 shows snapshots of the temperature along hole#79, with the fracture distribution in that hole in the background. Hole #79 is a horizontal hole parallel to the axis of the HD, about 3.5 m above the mid-point of the wing heater plane. A survey of the hole indicates that this hole may be declined toward the wing heater plane starting at a Y value of about 10m. This is verified by the gradual increase of temperature as a function of distance from the bulkhead (the Y value). However, after one year of heating, some kind of convection flow was established to bring the temperature near the deeper 10m of the hole down. In addition, there are three zones where the temperature shows fluctuations: at Y=11 to 13 m, Y=35 to 36 m, and Y= about 39 m. In those zones, hot air/vapor brought the temperature up during earlier days, and cooler condensed water brought the temperature down during the later days. The temperatures seem to converge toward the boiling point of water. Similar features are also observed in hole #80, which is another horizontal hole parallel to the HD. Greater permeable zones are expected to be required to facilitate the fluid movements for this TH process. However those zones do not exactly lined up with the fractures in the hole. This discrepancy will be investigated further.

In summary, the temperatures measured in the DST reveal the TH processes are in general agreement with the conceptual model as described above. Temperature measurement is a good tool for investigating fluid movements and boiling of pore water.

References

[1]. CRWMS, 1998, *Drift Scale Test As-Built Report*, Civilian Radioactive Waste Management System Management & Operation Contractor, BAB000000-01717-5700-00003 REV 01, TRW Environmental Safety Systems Inc., 1261 Town Center Drive, Las Vegas, Nevada 89134-6352.

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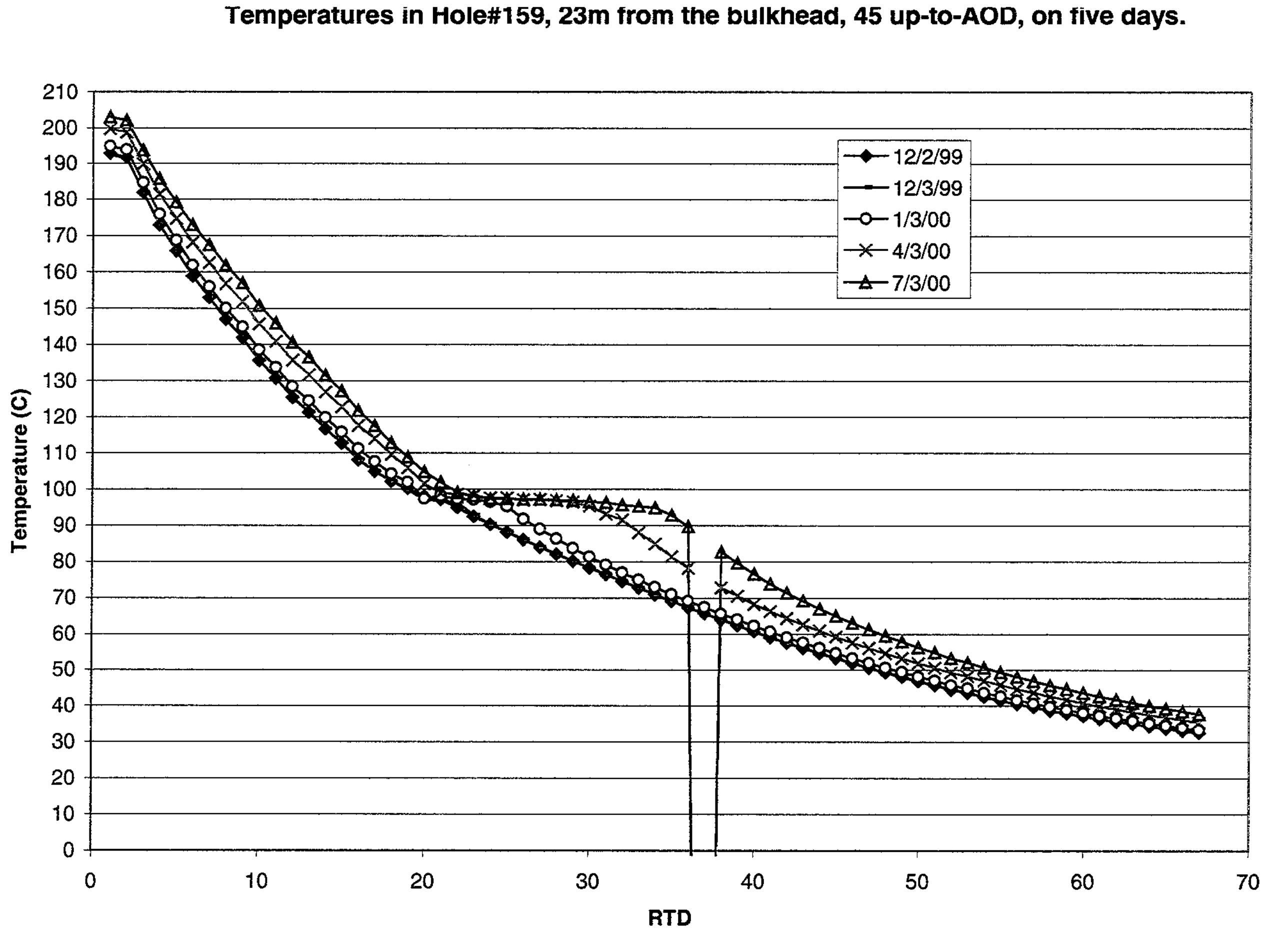

Figure 1. Snapshots of temperature measured at all RTDs in hole#159 of the DST.

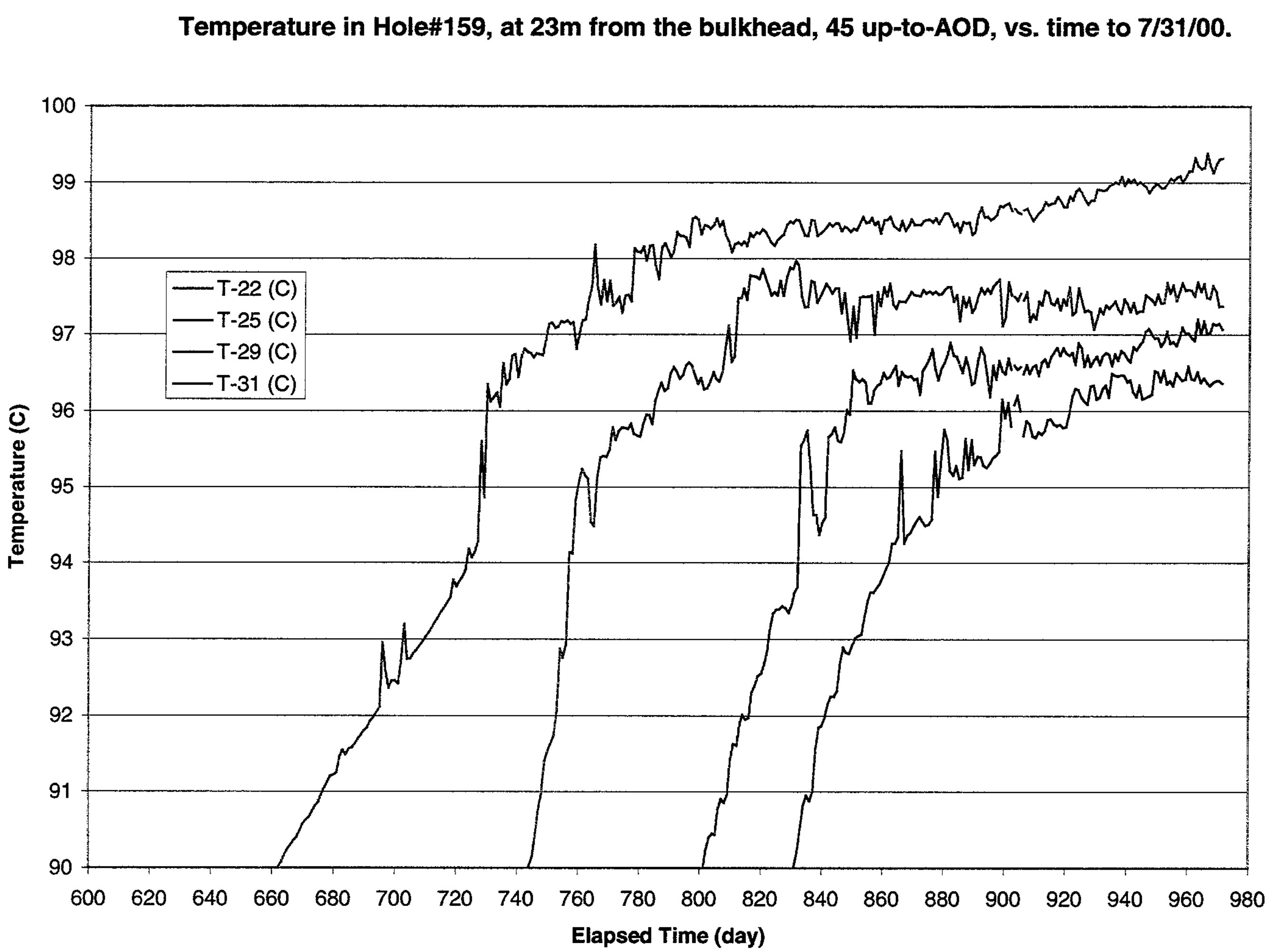

Figure 2. Temperature history at four RTDs in hole#159 of the DST to show spatial variation of the boiling point of water.

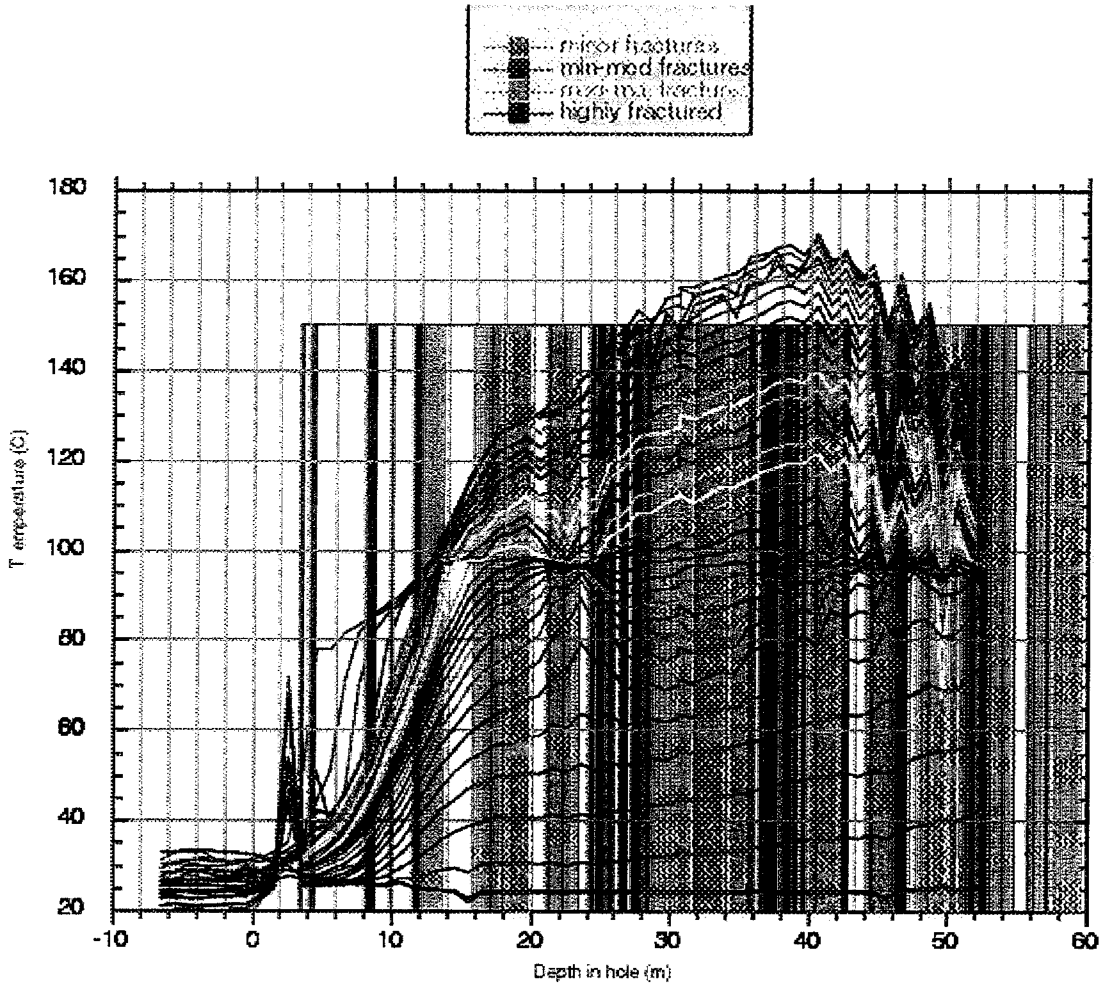

Figure 3. Snapshots of temperature in hole#79 at every 30 days since heating. The collar of the hole is at 0; the bulkhead is at about 11 m. The color bands in the background are the fractures intersecting the hole (see legend).

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