Preprint
UCRL-JC-141237

Thermohydrologic Behavior and Repository Design at Yucca Mountain

T. A. Buscheck, N. D. Rosenberg, J. Gansemer, Y. Sun

This article was submitted to
2001 International High-Level Radioactive Waste Management Conference
Las Vegas, NV
April 29 through May 3, 2001

October 1, 2000

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

Thermohydrologic Behavior and Repository Design at Yucca Mountain

T. A. Buscheck*, N. D. Rosenberg*, J. Gansemer*, Y. Sun**

*Lawrence Livermore National Laboratory

**Weiss Associates

(all at: LLNL L-204, Livermore CA 94551)

Abstract submitted for 2001 International High-Level Radioactive Waste Management Conference, Las Vegas NV (10/27/00)

Introduction

Radioactive decay of nuclear waste emplaced at Yucca Mountain will produce an initial heat flux many times larger than the heat flux in some natural geothermal systems. This heat flux will change the thermal and hydrologic environment at Yucca Mountain significantly, affecting both the host rock and conditions within the emplacement tunnels (drifts). Understanding the thermohydrologic behavior in this coupled natural and engineered system is critical to the assessment of the viability of Yucca Mountain as a nuclear-waste repository site and for repository design decision-making. We report results from a study that uses our multi-scale modeling approach to explore the relationship between repository design, thermohydrologic behavior, and key repository performance measures.

Thermohydrologic Behavior at Yucca Mountain

In the host rock, local thermohydrologic behavior is dominated by whether a location is inside or outside of the zone of boiling temperatures, 96°C at the elevation of potential repository horizon at Yucca Mountain ~1100 m above mean sea level. Although evaporation and condensation occur at sub-boiling temperatures, significant rock dryout requires temperatures above the boiling point. Whether or not the boiling zones around individual drifts coalesce is important because global-boiling conditions greatly restrict condensate drainage/shedding, promoting the development of a thick condensate zone above the repository. Variability in heating conditions along the drift axis is also important because it promotes nonuniform boiling conditions (both inside and outside the drift) that increases the likelihood of ambient percolation and condensate flux being focused onto cooler waste packages.

Two important factors influence the thermohydrologic conditions within the emplacement drift: (1) whether or not temperatures at the drift wall are above the boiling point, which strongly affects the likelihood of water seeping into the drift, and (2) the temperature gradient between the waste package and drift wall, which strongly affects how much lower the relative humidity (*RH*) is on the waste package than on the drift wall. Backfill placed between the drift wall and the waste package is one way to create a significant thermal gradient between the two surfaces.

There are many engineering design variables that affect thermohydrologic behavior in an underground nuclear-waste repository. These design variables include areal heat-generation density of the waste inventory averaged over the repository footprint and lineal heat-generation density averaged along the drifts. For a given waste inventory, these two variables constrain both the distance between drifts and the size of the required repository footprint. Another key design variable is waste-package spacing. Line-load spacing places waste packages end to end, resulting in efficient sharing of heat between waste packages that limits the variability of heating conditions along the drift. Point-load spacing has relatively large gaps between waste packages, resulting in much less efficient sharing of heat between waste packages and greater variability of heating conditions along the drift. Other design variables include waste-package sequencing, duration and heat-removal efficiency of drift ventilation, and in-drift design and materials (e.g., backfill, drip shields). Natural-system factors that affect the thermohydrologic environment include: (1) thermohydrologic properties of the repository host rock, (2) overburden thickness above the repository, and (3) local percolation flux.

Modeling Study

We use the Multiscale Thermohydrologic Model described in elsewhere this volume by Buscheck and others[1]. We present model results comparing different repository designs (**Table 1**) in the form of six complementary cumulative distribution function (CCDF) plots (**Fig. 1**) that relate to various thermal management goals (**Table 2**). These CCDF plots include the nearly 5000 combinations of waste packages (with different heat output) and geographic locations in the repository (which reflect differences in stratigraphy, overburden thickness, and local percolation flux, as well as differences in proximity to the repository edge).

The first two plots (**Fig. 1ab**) provide information on the extent and duration of boiling conditions in host rock. We plot the time required for the drift wall to return to the boiling point during cooldown and the maximum lateral extent of boiling in the host rock at the repository horizon. The next two plots (**Fig. 1cd**) provide information on peak temperatures on the surfaces of the drift wall and on waste packages. The final two plots (**Fig. 1ef**) concern *RH* reduction. The first of these is a plot of the time it takes for the *RH* on the waste-package surface to return to 80% after the initial dryout period. The second is a plot of the waste-package temperature at this time.

We first consider conditions in the host rock and note that there are minor differences between the backfill and no-backfill designs. The host rock in the sub-boiling designs remain sub-boiling (by definition), so the CCDF curves are straight lines at 0 m (**Fig. 1a**) and 0 years (**Fig. 1b**), respectively. The local-boiling designs have a maximum extent of boiling of about ~9 m, indicating that less than 1/4 of the host rock at the repository horizon ever experience boiling conditions. Half of the waste packages have returned to sub-boiling drift-wall conditions in less than 520 years, and all have returned to sub-boiling drift-wall conditions by 1200 years. The duration and extent of boiling in the host rock is the greatest for the global-boiling designs; the boiling zones coalesce for about 87% of the possible combinations of waste packages and repository locations. There is a broad distribution in these CCDF curves, with half of the waste packages still experiencing boiling conditions at the drift wall at 1700 years. The longest boiling duration is 3840 years.

Peak drift-wall temperatures for the sub-boiling design are all below the boiling point (**Fig. 14c**), again by definition. The global-boiling no-backfill design has peak temperatures of 118-159°C. The local-boiling no-backfill design has peak temperatures of 116-146°C. Adding backfill causes a small increase (~5°C) in peak drift-wall temperatures (**Fig. 1c**).

We next consider conditions on the waste packages and note that there are substantial differences between the no-backfill and backfill cases. Peak waste-package temperatures in all cases are below 300°C (**Fig. 1d**), with peak temperatures for the sub-boiling no-backfill design below (or close to) the boiling point. For the no-backfill case, the local-boiling design has peak waste-package temperatures of 128-178°C; for the global-boiling design peak waste-package temperatures are a few degrees higher, 130-186°C.

For the no-backfill cases, the duration of reduced *RH* is 600-700 years for the majority of waste packages for both the sub-boiling and local-boiling designs and nearly twice as long (1170 years) for the global-boiling design. The temperature when the majority of waste packages first see *RH*=80% increases with increasingly hotter designs. This increase is from 87°C for the sub-boiling design, to 98°C for the local-boiling design to 102°C for the global-boiling design.

The addition of backfill significantly increases peak waste-package temperatures, ~100°C (**Fig. 1d**) and greatly affects *RH* reduction (**Fig. 1ef**). Reduced *RH* conditions persist long after boiling ceases for the backfill cases, while for the no-backfill cases, reduced *RH* conditions do not persist long after boiling ceases. Adding backfill to the sub-boiling design increases the duration of reduced *RH* conditions for the majority of waste package from less than 600 years to 1800 years. Note that this is about 50% longer than the duration of reduced *RH* conditions for the majority of waste package in the global-boiling, no-backfill design. In addition, the temperatures at which *RH* values return to 80% are also lower (8-16°C for CCDF=0.5) for the backfill cases. The fact that the ratio of *RH* on the waste package to *RH* on the drift wall for a given temperature difference between these two surfaces decreases with waste-package decreases makes a sub-boiling backfill design particularly effective with respect to *RH* reduction.

We want to stress that the hydrologic properties of backfill strongly affect thermohydrologic behavior. We have assumed a single-layer backfill of coarse sand with low capillarity (i.e., its tendency to wick water inwards is low) in this paper. A single-layer fine sand with high capillarity will not perform as well with respect to *RH* reduction.

Conclusions

The repository design tradeoffs can be summarized as follows. The presence of backfill increases the duration of *RH* reduction but at the cost of higher waste-package temperatures. A sub-boiling, no-backfill repository design does a good job of eliminating boiling in the host rock, but performs poorly with respect to duration of *RH* reduction. A global-boiling design does a good job of extending the duration of *RH* reduction, but at the expense of an extensive boiling zone in the host rock.

For many of the repository designs considered in this study, the CCDF curves are quite broad. This reflects the significance of location within the repository and waste-package type on thermohydrologic behavior, and illustrates a very important point—that there is a range of thermohydrologic behavior within the repository; therefore, thermohydrologic behavior in the repository is not well-represented by single, "average" parameter values.

References

1. Buscheck, N.D. Rosenberg, J. Gansemer, and Y. Sun, Multiscale Thermohydrologic Model: Addressing Variability and Uncertainty at Yucca Mountain, Proc. of 2001 International High-Level Radioactive Waste Management Conf, American Nuclear Society, La Grange Park, IL, 2001.

Figure Legends

Fig. 1 Complementary cumulative distribution function (CCDF) plots for the six different thermal designs considered in this study (**Table 1**). These CCDF plots include the nearly 5000 combinations of waste-package types and repository locations considered in the MSTHM.

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Table 1. Summary of repository designs considered in this study*

<table>
<tr><td>1</td><td>No Backfill</td><td rowspan="2">Sub-boiling host rock:
Initial thermal loading (in the absence of ventilation)= 18 MW/km^2
Pre-closure ventilation = 200 yrs</td></tr>
<tr><td>2</td><td>Backfill</td></tr>
<tr><td>3</td><td>No Backfill</td><td rowspan="2">Local-boiling host rock:
Initial thermal loading (in the absence of ventilation)= 18 MW/km^2
Pre-closure ventilation = 50 yrs</td></tr>
<tr><td>4</td><td>Backfill</td></tr>
<tr><td>5</td><td>No Backfill</td><td rowspan="2">Global-boiling host rock:
Initial thermal loading (in the absence of ventilation) = 27 MW/km^2
Pre-closure ventilation = 50 yrs</td></tr>
<tr><td>6</td><td>Backfill</td></tr>
</table>

*Each of these repository designs includes a pre-closure period in which the drifts are ventilated to remove 70% of the waste heat. Drip shields and, in some designs, backfill are emplaced during the post-closure period. We have used waste-package blending and "line-load" waste-package spacing for all six designs. We have assumed that all six designs share the identical repository footprint (approximately 4 km^2 or 1000 acres), although in reality, for a given waste inventory, the hot designs would occupy a smaller area.

Table 2. Thermal design goals

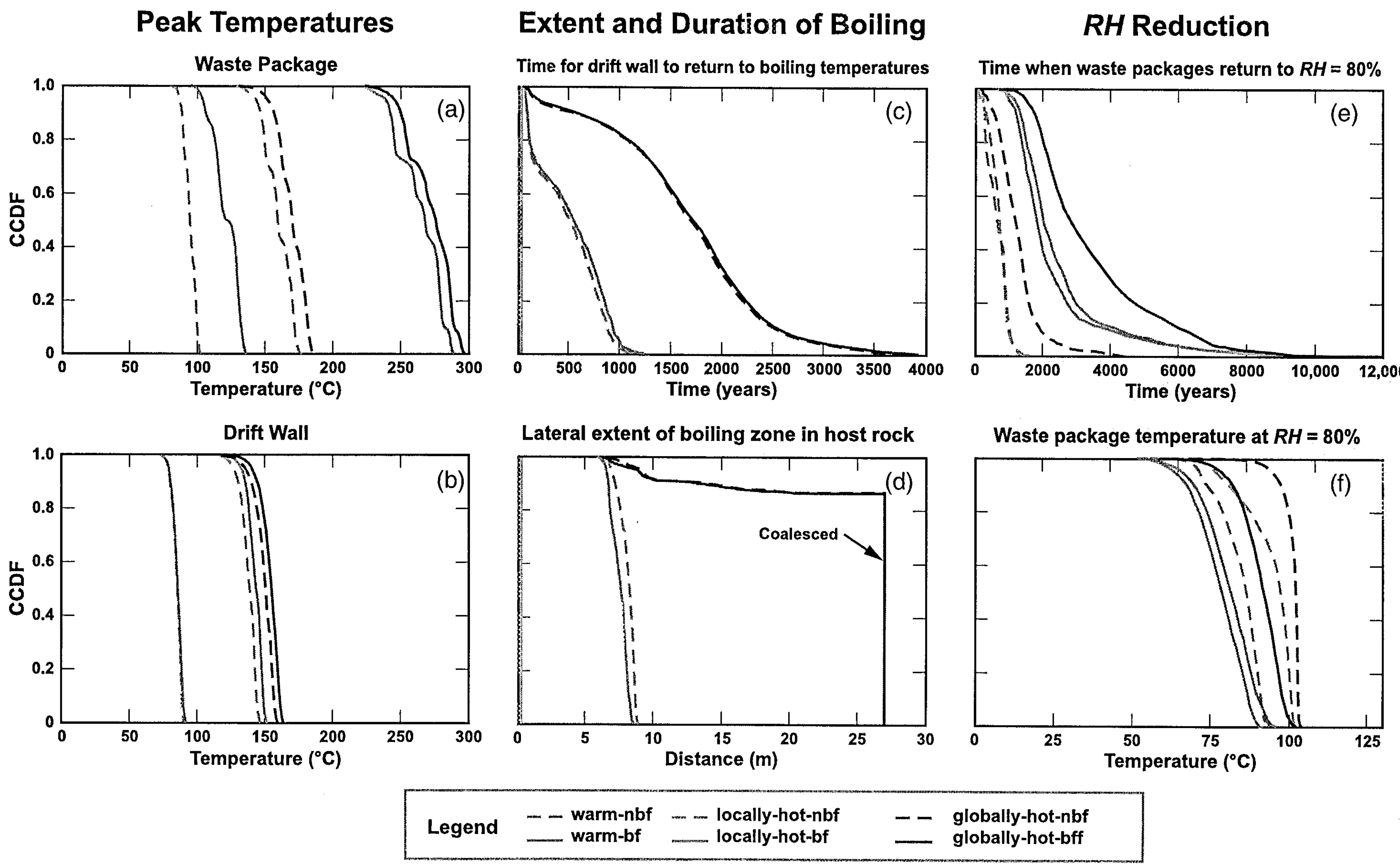
Maintaining favorable environment for waste packages:

- Keeping temperatures below critical temperatures for engineered materials. Temperatures are material-dependent, but are generally upwards of 300°C.
- Limiting water seeping into drift, which reduces the likelihood of seepage onto the waste packages. In general, seepage into repository drifts is much less likely to occur while above-boiling conditions exist at the drift wall.
- Keeping waste packages dry (i.e., low relative humidity) until cool. This goal concerns limiting degradational mechanisms that are enhanced with the presence of liquid films at elevated temperatures.

Reducing uncertainty in model predictions

2. Limiting the extent of boiling conditions in host rock. The premise is that complexity and, therefore uncertainty, can be reduced by avoiding processes and conditions associated with boiling conditions. The main concern is coupled thermohydrologic-chemical-mechanical behavior (e.g., mineral alteration in fractures from thermochemical processes).
3. Limiting the variability of heating conditions along drifts. Variable heating conditions lead to variable boiling and condensation conditions, making it more likely that water is focused onto cooler waste packages.

Fig. 1



Peak Temperatures
Extent and Duration of Boiling
RH Reduction
Waste Package
(a)
CCDF
Temperature (°C)
Time for drift wall to return to boiling temperatures
(c)
Time (years)
Time when waste packages return to RH = 80%
(e)
Time (years)
Drift Wall
(b)
CCDF
Temperature (°C)
Lateral extent of boiling zone in host rock
(d)
Coalesced
Distance (m)
Waste package temperature at RH = 80%
(f)
Temperature (°C)
Legend
warm-nbf
warm-bf
locally-hot-nbf
locally-hot-bf
globally-hot-nbf
globally-hot-bff

University of California
Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551