CNWRA
A center of excellence in earth sciences and engineering

Effects of Drift Degradation on Environmental Conditions in Drifts

Chandrika Manepally, Randall W. Fedors, George Adams, Steve Green, Doug Gute CNWRA - Southwest Research Institute, San Antonio, TX, USA - 78228; email: cmanepally@swri.edu

ABSTRACT

The occurrence of drift degradation could significantly influence the environment inside waste emplacement drifts at the proposed repository for high level waste at Yucca Mountain, Nevada. This poster presents the effects of drift degradation on the waste package, drip shield, and drift wall temperatures. Natural backfilling caused by drift degradation of the fractured tuff wallrock may occur throughout the repository drifts, with drifts estimated to be backfilled within 1000 years after closure. This leads to prominent increases in waste package temperature due to the insulating effect of the backfill material.

Drift degradation is linked to an algorithm for estimating in-drift temperatures. The algorithm includes heat-transfer processes of conduction, convection, and thermal radiation. The results indicate that thermal radiation and convection dominate the in-drift heat transfer in the absence of drift degradation effects. In case of presence of backfill due to drift degradation, conduction through the backfill was the dominant heat transfer process. Sensitivity analyses showed that the uncertainty of the thermal properties of the natural backfill lead to significant uncertainty in the estimation of in-drift environment.

APPROACH

A multi-mode algorithm for in-drift heat transfer processes was used to estimate waste-package surface temperature. The algorithm uses thermal output from the radioactive waste (heat load), wallrock temperature, and considers the in-drift thermal processes of thermal radiation, convection, and conduction. The effect of latent heat transfer was not included in this analysis. The drift and engineered barrier components are transformed into an equivalent radial geometry to allow 1-D solutions to be used.

Figure 1a. Geometry

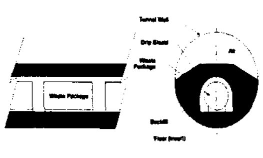
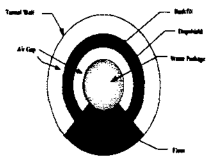
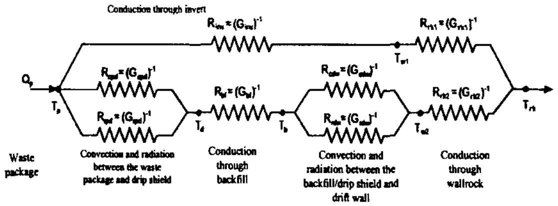


Figure 1b. Equivalent Geometry



The in-drift, multi-mode algorithm uses rock temperature estimated from the mountain-scale conduction-only model as an outer boundary condition. The multi-mode algorithm allows for fast analysis of new design features or different scenarios.

Figure 2



The thermal network can be described by the equation:

$$Q_{wp} = \left\{ \left[\frac{1}{G_{inv}} + \frac{1}{G_{rk1}} \right]^{-1} + \left[\frac{1}{G_{cpd} + G_{rpd}} + \frac{1}{G_{bf}} + \frac{1}{G_{cdw} + G_{rdw}} + \frac{1}{G_{rk2}} \right]^{-1} \right\} \left(T_{wp} - T_{rk} \right) \quad \text{EQN (1)}$$

where Q_{wp} is the heat supplied by the waste package and G refers to the conductance terms, which are the inverse of the resistance, R. The subscript *inv* refers to the invert, *rk1* and *rk2* to conduction in the rock below the invert and above the drift, *cpd* and *rpd* to convection and radiation between the waste package and the drip shield, *bf* to conduction through the backfill if present, *cdw* and *rdw* to convection and radiation between the drip shield or backfill and the drift wall. T_{wp} and T_{rk} refer to temperatures at the waste package and in the rock. T_{rk} is the boundary condition for the in-drift algorithm and is obtained from the mountain-scale conduction-only model.

The two conductance terms in brackets on the right-hand side of Equation 1 reflect the two pathways in the thermal network. A fraction is assigned that accounts for the portion following each pathway; one pathway from the waste package through the invert and one pathway through the airspace, drip shield and outward. Radial symmetry is assumed. Expressions for each conductance term follow the development in Fedors, et al. (2003) and Mohanty, et al. (2002).

IN-DRIFT TEMPERATURE ESTIMATES

Drift Degradation

The mean case from stochastic analyses of Gute, et al. (2003) indicates that the drift will be fully degraded by 750 years. Figure 3 shows the equivalent thickness as a function of time. Since the side wall of the drift negligibly degrades, the horizontal lines in Figure 3 illustrate the time at which natural backfill was set to a constant value.

Figure 3

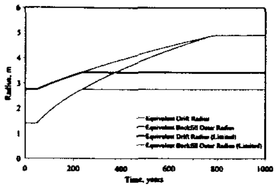
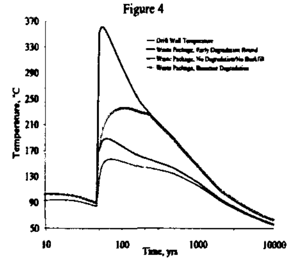


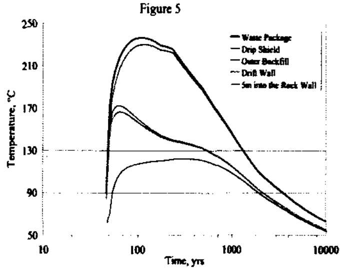
Figure 4



Temperature Estimates at Different Locations

Figure 5 shows estimated temperatures at various locations in the drift and wallrock for the mean case of drift degradation. The outer boundary condition is at 5 m from the drift wall. The insulating effect of the drift degradation rubble pile is evident.

Figure 5



Bounding Scenarios

Three scenarios are shown in Figure 4

- no drift degradation
- base case degradation
- instantaneous degradation

Instantaneous drift degradation leads to the highest peak temperatures. Delays in drift degradation are highly beneficial for reducing peak temperature estimates.

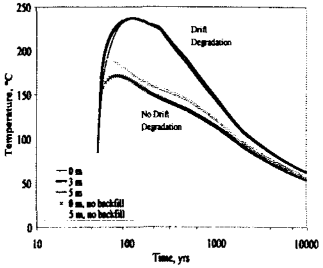
EFFECT OF BOUNDARY CONDITION

The outer boundary condition for the thermal network algorithm is taken from a mountain-scale, conduction-only analytical solution. Since the mountain-scale model misrepresents the in-drift thermal processes, there may be some error in the waste package temperature estimates. A common modeling approach to reduce the effect of errors in boundary condition estimates is to move the boundary condition further from the zone of interest.

Figure 10 shows the effect on waste package temperatures as the boundary condition is moved further from the drift wall for distances of 0 to 5 meters.

- Negligible effect when drift degradation occurs
- Significant effect when no degradation occurs

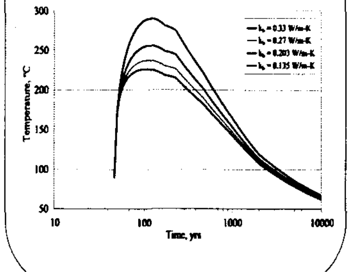
Figure 10



PARAMETER UNCERTAINTY

Measurements and literature-based values of thermal conductivity for natural backfill are lacking. Natural backfill may be more poorly packed than emplaced backfill because of the likely irregular (e.g., plates or slabs) shapes of rocks spalling off the drift ceiling. Thus, the thermal conductivity may be less than that used for emplaced backfill (0.27 W/m-K).

- Peak waste package temperatures vary by 65 °C using reasonable values of thermal conductivity of the natural backfill



Unit Conversions 1 m = 3.28 ft 13.87 W/m-K= 1BTU/ft-h-°F °F = 1.8 x T °C+ 32

EFFECT OF LINEARIZATION

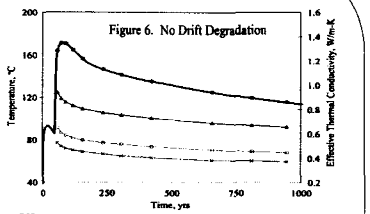
Equation 1 uses linearized approximations for the convection and radiation terms, however:

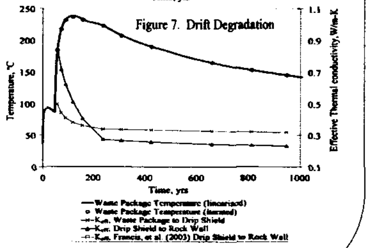
- The effective thermal conductivity (K_{eff}) term for heat transfer by natural convection is assumed constant, regardless of the temperature difference across the gaps.
- Radiation is a function of the difference of temperatures on either side of the gap to the fourth power.
- Inherent in the temperature difference used in Equation 1 is the assumption that all radiation and convection terms can be calculated using the temperature difference between T_{wp} and T_{rk}.

An iterative, nonlinear algorithm was developed for the thermal network described in Equation 1. A comparison of the iterative and linearized results is presented in Figures 6 (no drift degradation) and Figure 7 (with drift degradation).

The range of values used for K_{eff} for the convection terms are also plotted in Figures 6 and 7. The values of K_{eff} used in the iterative algorithm were based on approach described in Raithby and Hollands (1975). For comparison, values of K_{eff} from Francis, et al. (2003) were based on relations developed from CFD simulations supported by laboratory test data.

- For the cases of no-drift degradation and drift degradation, the linearized solution is within 1 percent of the iterative result.
- It was observed that the temperature results were not sensitive to the value used for the K_{eff} within the range shown in Figures 6 and 7.





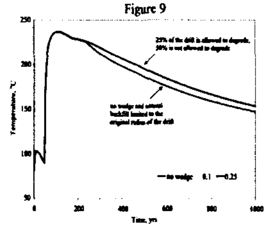
EFFECT OF ASYMMETRY

Ongoing thermohydrologic simulations using finite volume porous media models are testing the assumption of equivalent radial symmetry. However, a simple modification of the network model allows for an assessment of the error. The pathway upward and outward can be further divided into a lateral and a vertical pathway. The natural backfill surrounding the drip shield is constrained to a maximum thickness related to the original drift radius, whereas the natural backfill in the vertical pathway is allowed to continue to grow while the drift ceiling continues to degrade. The downward pathway through the invert remains the same, with a fraction of 0.25 of the entire arc.

Figure 9 shows the results for a range of fractions for the upward pathway from 0.0 to 0.25

- It is not known what fraction of the arc to apply to the other pathways
- There is a 9 °C increase in temperature when a wedge of natural backfill is allowed to build upwards.

Figure 9



SUMMARY

- Drift degradation causes prominent increases in waste package and drip temperatures
  - peak waste package temperatures estimated were 360 °C for early degradation scenario, 236 °C for base case degradation, as compared to 189 °C for no degradation case
  - lengthens period of above boiling conditions at waste package and drip shield
- Uncertainties in natural backfill thermal properties leads to large differences in calculated temperatures and requires improved characterization
- Non-linear iterative results closely matched our linearized algorithm results for drift degradation and no-drift degradation cases
- Sensitivity analyses suggest that location of the outer boundary condition and the radial assumption need to be factored in the general analyses

Ongoing modeling efforts are intended to address simplifications of thermal network algorithm

- A finite volume, dual continuum, thermohydrologic, porous media model for in-drift and wallrock processes
- Computational fluid dynamics modeling of in-drift processes

REFERENCES

Fedors, R.W., G.R. Adams, C. Manepally, and S.T. Green. "Thermal Conductivity, Edge Cooling, and Drift Degradation - Abstracted Model Sensitivity Analyses for Yucca Mountain." CNWRA Report, San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2003.

Francis, N.D., S.W. Webb, M.T. Itamura, and D.L. James. 2003. "CFD Modeling of Natural Convection Heat Transfer and Fluid Flow in Yucca Mountain Project (YMP) Enclosures." SAND2002-4179. Albuquerque, New Mexico: Sandia National Laboraties.

Gute, G.D., G. Ofoegbu, F. Thomassy, S. Hsiung, G. Adams, A. Ghosh, B. Dasgupta, A. Chowdhury, and S. Mohanty. "MECHFAIL: A Total-System Performance Assessment Code Module for Evaluating Engineered Barrier Performance Under Mechanical Loading Conditions." CNWRA 2003-06. San Antonio, Texas: CNWRA. 2003.

Mohanty, S., T.J. McCartin, and D.W. Esh. "Total-system Performance Assessment (TPA) Version 4.0 Code: Module Descriptions and User's Guide." San Antonio, Texas: CNWRA. 2002.

Raithby,G. D. and K.G.T. Hollands. 1975. "A General Method of Obtaining Approximate Solutions to Laminar and Turbulent Heat Transfer Problems," in Irvine, T. F. and Hartnett, J. P., eds., Advances in Heat Transfer , Vol. 11, Academic Press, New York, pp 265-315.

Acknowledgements : This paper was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-02-012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. This paper is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC.