HLWYM HEmails

From: Budhi Sagar [bsagar@swri.edu]
Sent: Monday, February 05, 2007 11:06 AM
To: wesley.patrick@swri.org
Subject: FW: Analysis to Assess Self-Arresting Potential of Thermally Induced Drift Degradation
Attachments: ProgressiveSpalling&TMEffects.pdf; Attachment-1 Effect of Rubble on Drift Wall Temperature.pdf; Attachment-2 Effect of DriftDegradation on RoofTemperature..pdf

Wes,

Here is the email from Goodluck on drift degradation analysis.

Budhi

-----Original Message-----
From: Goodluck Ofoegbu [mailto:ofoegbu@cnwra.swri.edu]
Sent: Thursday, February 01, 2007 10:08 AM
To: Mysore Nataraja
Cc: bsagar@cnwra.swri.edu; Marissa Bailey; James Rubenstone; 'Asadul Chowdhury'; 'Luis Ibarra'; 'Scott Painter'; cmanepally@cnwra.swri.edu; jrd1@nrc.gov; Timothy McCartin; 'Brittain Hill'; 'Mahendra Shah'; Chris Grossman; 'Randall Fedors'; rkazban@cnwra.swri.edu
Subject: Analysis to Assess Self-Arresting Potential of Thermally Induced Drift Degradation

The attached document, ProgressiveSpalling&TMEffects.pdf, describes the analyses performed to address the NRC staff inquiry regarding potential self arresting of thermally induced degradation of emplacement drifts. Two additional attachments (Attachments 1 and 2) provide details of the completed analyses.

The completed analyses indicate a potential for self arresting of thermally induced degradation because of the drift roof extending into cooler areas of the host rock. The analyses, however, do not provide an estimate of the amount of degradation prior to the self arrest. We propose additional analyses to estimate both the rate and amount of thermally induced degradation prior to any self arrest. The proposed analyses can be completed with a six person-week effort.

Please setup a meeting to discuss the analyses and hopefully recommend a path forward. Thanks.

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Sent Date: 2/5/2007 11:06:21 AM
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Files	**Size**	**Date & Time**
MESSAGE	1875	2/5/2007 11:06:33 AM
ProgressiveSpalling&TMEffects.pdf	105623	
Attachment-1 Effect of Rubble on Drift Wall Temperature.pdf	186213	
Attachment-2 Effect of DriftDegradation on RoofTemperature..pdf	177287	

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Analysis to Assess Self-Arresting Potential of Thermally Induced Degradation of Emplacement Drifts

Analyses were performed to address an NRC staff inquiry regarding whether thermally induced drift degradation would self arrest because of changing thermal conditions at the drift roof caused by the degradation. The self arrest would occur if the changing thermal conditions cause thermal stress to decrease below values needed to initiate rock failure. Two effects of drift degradation that may contribute to reduced thermal stress in the drift roof were identified. First, the accumulated rubble may insulate the waste package and reduce the heat flux to the surrounding rock. Second, vertical extension of the drift roof increases the distance between the roof and the heat source, thereby decreasing roof temperature. Simplified analyses were performed to respond to the inquiry within two weeks as requested by NRC staff.

The first analysis examined the effects of rubble on temperature at the drift roof considering the insulating effects of rubble only. A heat flow analysis performed by Scott Painter (Attachment 1) indicates any decrease in temperature at the drift roof owing to the insulating effects of rubble alone would be negligible. A second analysis was performed to examine the combined effects of the two mechanisms, i.e., vertical extension of the drift roof into cooler areas and the insulating effects of rubble. The results of the second analysis (Attachment 2) indicate temperature at the drift roof may decrease enough to cause a self arrest of thermally induced drift degradation. The analysis, however, is not sufficient to quantify the amount of degradation prior to the self arrest.

A finite element model is proposed for an iterative analysis to quantify the amount and rate of thermally induced degradation. The model (figure 1) would be used to perform a series of iterative thermal and thermomechanical analyses. The emplacement drift is represented by the octahedron ABCDEFGH; and rock above the emplacement drift that may be subjected to spalling is discretized into layers labeled b1, b2, b3, etc. (24 such layers are shown in figure 1, but there could be more). For thermal analysis: the heat source is represented by the red rectangle FGIJ; and in-drift space is discretized into layers labeled a1, a2, a3, etc., which may represent either air or rubble at various stages of the analysis. The in-drift space a1, a2, etc. grows as the rock b1, b2, etc. spalls. The model described in figure 1 is part of a larger drift-scale model that extends approximately 700 m vertically from the water table (approximately 350 m below the drift axis) to the ground surface, and 81 m horizontally between adjacent pillar centers. Only half of the horizontal extent is explicitly included in the model because of an assumed vertical symmetry plane through the drift axis.

Rock temperature, including any effects of drift degradation on temperature, is calculated in the thermal analysis; whereas rock spallation is calculated in the thermomechanical analysis. The layers a1, a2, a3, etc. initially are assigned thermal properties of air with a thermal conductivity suitable to represent radiative heat transfer. At the failure of b1 (from thermomechanical analysis), for example, a1 is assigned the thermal properties of rubble and b1 (re-designated a6) is assigned the thermal properties of air. The analysis would proceed iteratively until the thermomechanical analysis indicates no overstress in the drift roof. Both the rate and amount of thermally induced degradation can be calculated from the iterative analysis. The thermal and thermomechanical analyses will be performed using ABAQUS.

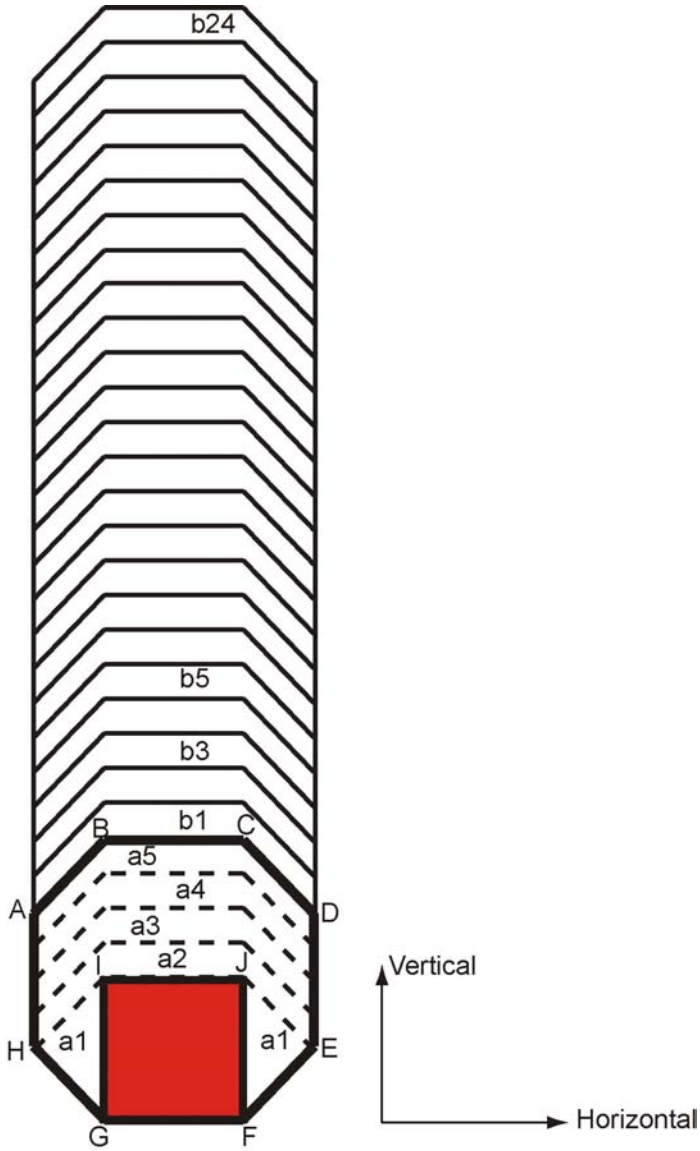


Figure 1. Concepts for A Finite Element Model for Iterative Thermal and Thermomechanical Analyses of Drift Degradation

The following features of the proposed analysis should be noted.

1. Thermal analysis will be based on heat conduction with thermal-hydrological effects accounted for using temperature-dependent thermal conductivity (representing coupling of conductivity and saturation) and specific heat (representing latent heat effects). Also, the effects of radiation would be included through an equivalent thermal conductivity assigned to the air layers.

2. Rock bulking (i.e., volumetric bulking of rock after it breaks up to form rubble) is not included in the model. Therefore, a bulking factor would need to be applied to the

calculated amounts of rubble to estimate rubble amounts for performance assessment.

3. Rubble is not included in the mechanical model because the system is not expected to deform enough to generate any mechanical effect from rubble. Any failed rock is simply removed from the mechanical system, thereby increasing the amount of in-drift space.

The following should be factored into any consideration of the potential for self arresting of thermally induced drift degradation.

1. Previous analyses indicate a fraction of drifts would be subjected to overstress in the sidewall that would be persistent for a long time irrespective of thermal loading. The occurrence of overstress in the sidewall indicates potential progressive spallation of the sidewall area and may ultimately cause instability of the roof. Such instability is independent of the roof temperature.

2. The overstress analysis has hitherto been based on comparing the induced stress against the peak strength of the rock. Delayed failure of rock, however, could occur at stresses as low as approximately 60 percent of the peak strength.

3. Seismic ground motions with a peak ground velocity of 20–30 cm/s could cause rock failure, irrespective of DOE analyses that indicate a threshold velocity of 100 cm/s to initiate failure of lithophysal rocks.

Attachment 1
Effect of rubble on drift-wall temperature

Scott Painter 1/22/2007

Simulations were performed to assess the effects of rubble on drift wall temperature. The hypothesis is that rubble resulting from drift collapse will have only a minimal effect on in-rock thermal conditions (although the effect on waste package temperature may be large). This hypothesis is based on a simple scoping calculation, which is described first.

A typical thermal conductivity value for rubble is approximately 0.5 W/m-K. Specific heat should be similar to that of intact rock (~1000 J/kg-K). Bulk density is that of intact rock with adjustments for the larger porosity of rubble: (~2000 kg/m^3). Thus, the thermal diffusivity is $0.5/(1000 \times 2000)\ \mathrm{m^2/s} = 2.5 \times 10^{-7}\ \mathrm{m^2/s} = 7.9\ \mathrm{m^2/yr}$. The characteristic thermal time constant is the cross-sectional area divided by the thermal diffusivity. For a 5 meter diameter rubble pile, the characteristic thermal time constant is $\pi\ 2.5^2 / 7.9\ \approx 2.5\ \mathrm{yr}$. This is the characteristic time required for the rubble pile to equilibrate with the waste package. Given the long time scales of interest and the relatively slow variations in the waste package heat output, the 2.5 year lag is relatively unimportant, and it is thus adequate to consider the rubble in instantaneous equilibrium with the waste package. Once the rubble pile is equilibrated, the total heat flux entering the intact rock mass is the same as the waste package heat output. Thus, the rubble pile should have little effect on in-rock thermal conditions.

Two MULTIFLO/METRA simulations were performed to test this hypothesis. The simulations are based on standard two-dimensional "chimney" models of one drift. Equivalent three-dimensional modeling is described by Painter (2006). In a simulation of a nondegraded drift (i.e., a drift in the as-built configuration), heat from the waste package is applied instantaneously to the drift wall. The primary heat transfer mechanisms are thermal radiation and thermal convection; thermal capacity of air is very small and ignored. In a second simulation of a degraded drift, the drift is assumed to be filled with rubble (thermal conductivity = 0.5 W/m-K; specific heat =1000 J/kg-K; bulk density=2000 kg/m^3). The two simulations are identical in all other respects. Note that these are full two-phase thermal-hydrological simulations.

Temperature fields in the host rock for the two models at 60 years are shown in Figure 1. The temperatures in the nondegraded drift case are slightly higher, but the difference is relatively small and confined to a narrow region near the drift wall. A similar plot at 100 years is shown in Figure 2.

Figure 3 shows temperature at the drift crown versus time for the two cases. The case without rubble is shown in blue. The case with rubble is shown in black. The maximum temperature without rubble is 143 ºC; with rubble, the maximum temperature occurs a few years later and is about 141 ºC.

These results indicate any decrease in drift-roof temperature owing to the drift filling with rubble would be negligible. However, the waste package temperature may be strongly affected by the presence of the thermally insulating rubble.

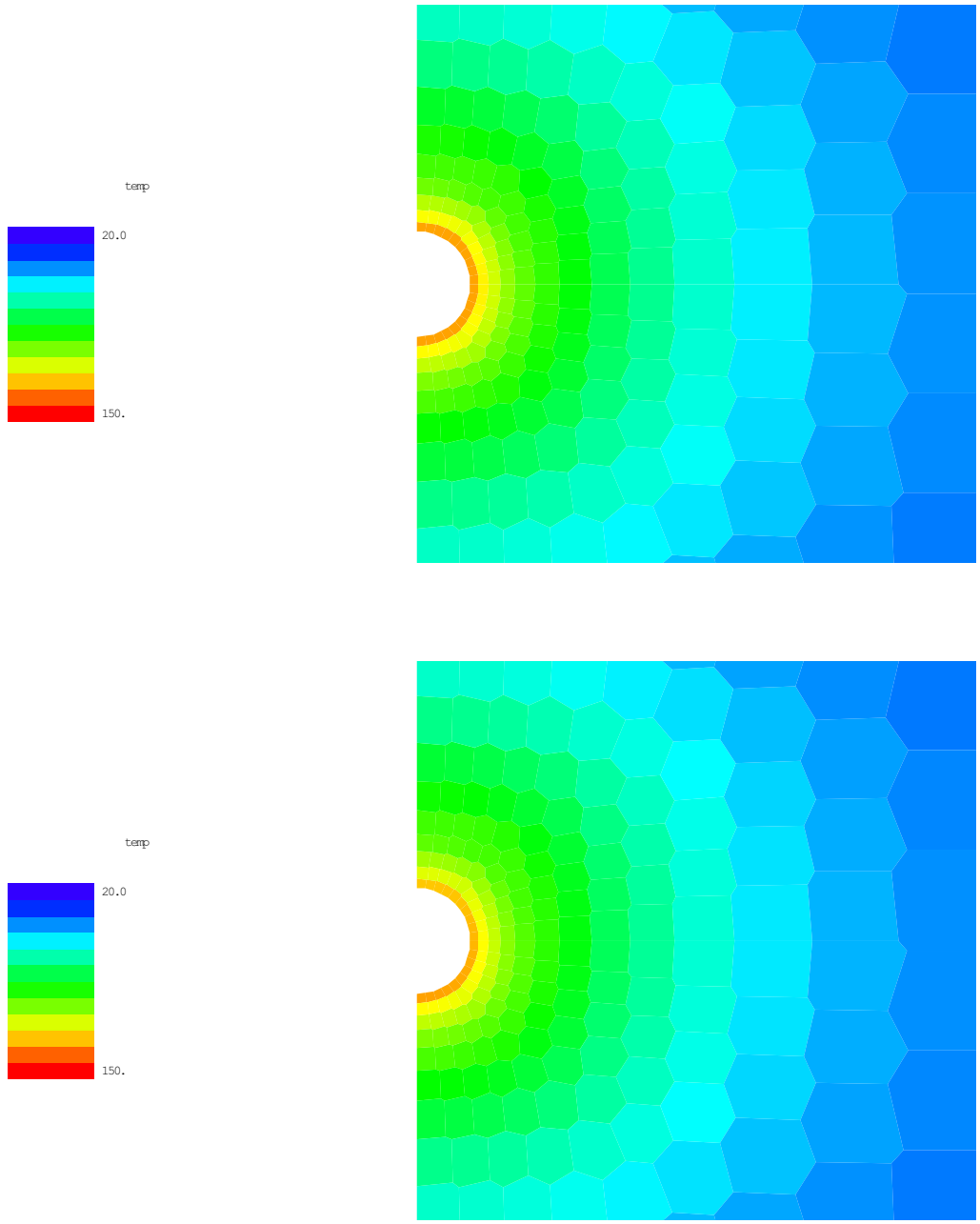


Figure 1. Temperature field in a 30 x 30 meter region near the drift at 60 years (10 years post-closure) with (bottom) and without (top) rubble in the drift. The in-drift temperatures are not shown. Note that only half the drift is modeled because of symmetry.

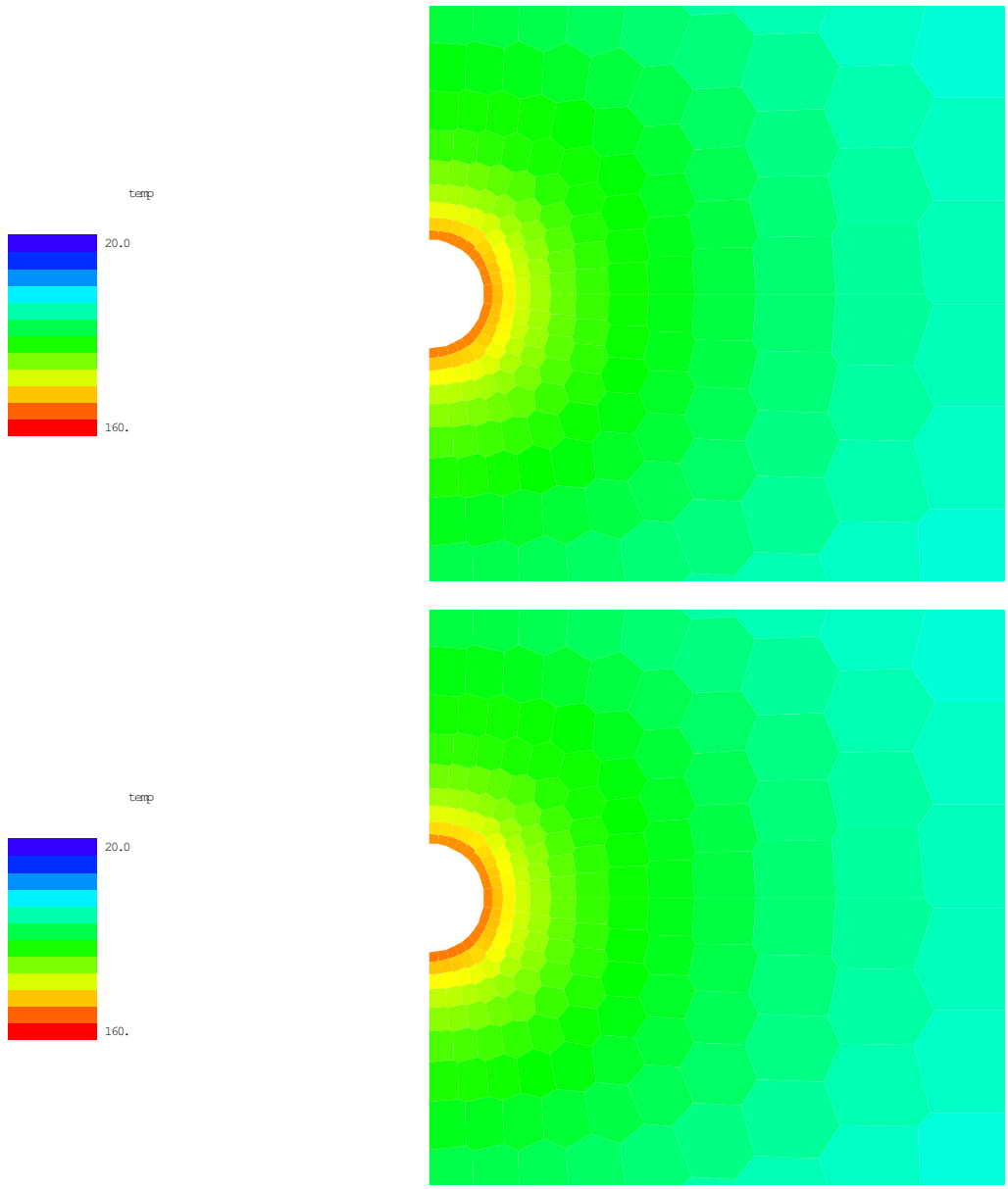


Figure 2. Temperature field in a 30 x 30 meter region near the drift at 100 years (50 years post-closure) with (bottom) and without (top) rubble in the drift. The in-drift temperatures are not shown. Note that only half the drift is modeled because of symmetry.

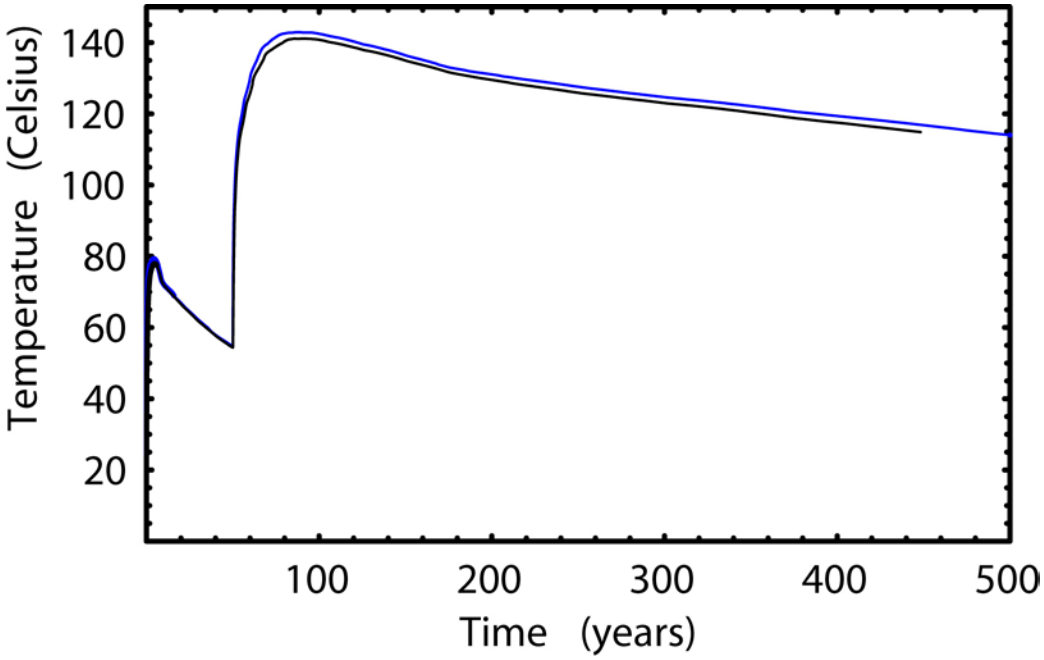


Figure 3. Temperature at the drift crown for the case of an open drift (blue) and a rubble-filled drift (black). The scenario modeled has forced ventilation up to 50 years, which is the reason for the sudden jump in temperature at that time.

REFERENCES.

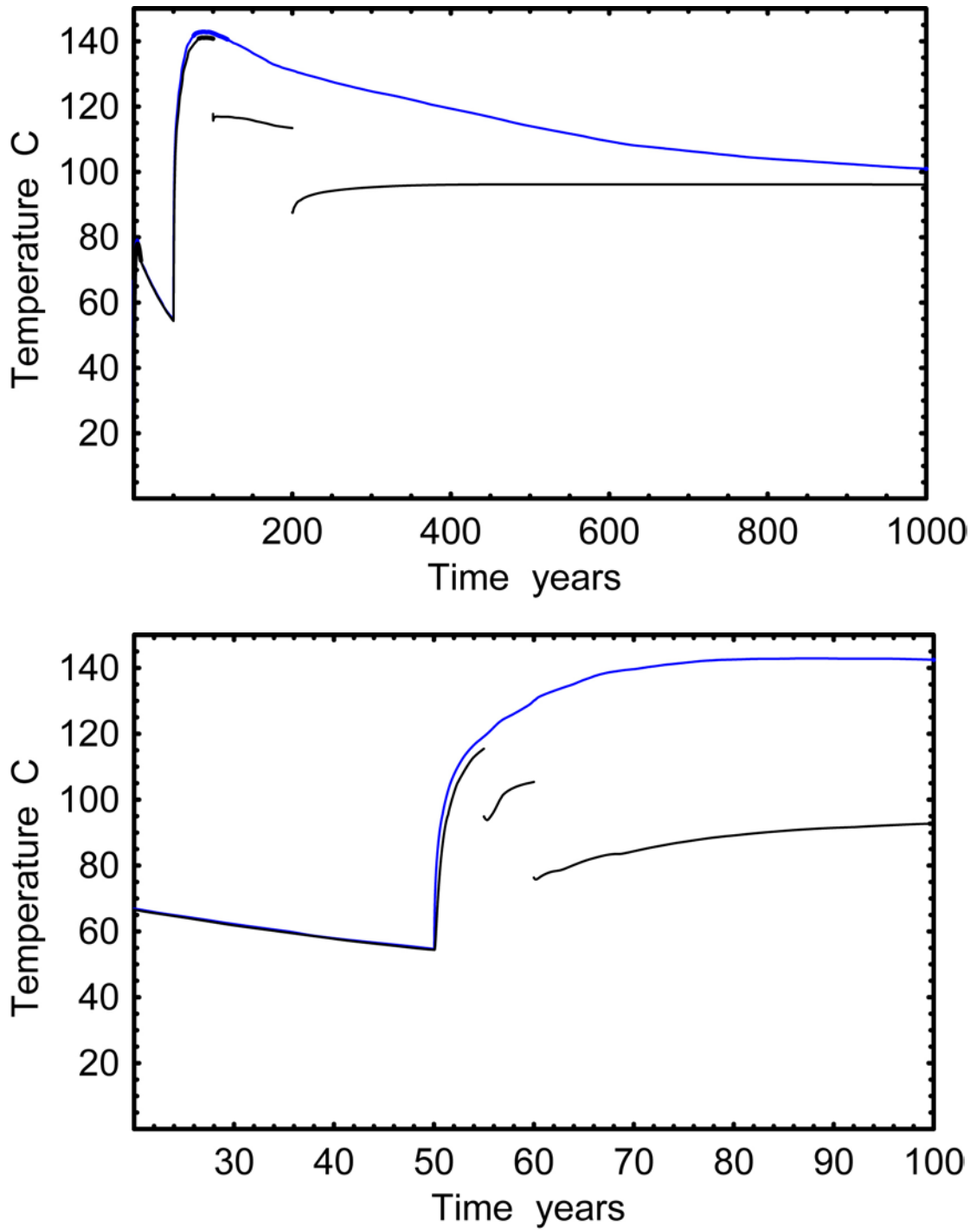
Painter, S.L. Modeling Ventilation Effects in Three-Dimensional Thermal Hydrological Simulations of a Potential Waste Repository at Yucca Mountain, Nevada. 2005 Transactions of the Society for Mining, Metallurgy and Exploration, Vol. 318, pp. 36-40, 2006.

Attachment 2
Temperature at drift wall following drift degradation
(CNWRA Scientific Notebook # 282E, 1.26.2007)

MULTIFLO/METRA simulations were performed to estimate temperatures at drift crown taking into account drift degradation. The issue is whether thermal spalling from drift crown will be a self-limiting process taking into account the fact that the intact rock wall will be receding from the heat source as thermal spalling occurs. The thermal insulating effects of a rubble pile may also have an effect if the rubble zone is large enough and asymmetrical.

The simulations were performed using the grid, thermal-hydrological properties, and heat load from a previous analysis. The simulations started with an intact drift. At t = t1, a zone extending 5 meters vertically from the drift center with the same footprint of the drift was converted to rubble. At that time the temperature monitoring point was moved from the original drift crown to a point 5 meters above the drift center. At t = t2, the rubble zone was extended to 10 meters with corresponding relocation of the temperature monitoring point.

Two scenarios were considered. In the first scenario t1=100 years and t2=200 years. In the second scenario t1=55 years and t2=60 years. Results are shown in the following two figures. Note that the heat removal effect of forced ventilation is stopped at t=50 years in each analysis. The blue curves are temperature without drift degradation and the black curves are temperature at the drift crown with drift collapse. The discontinuities in the black curves are due to the discrete failure events.



Temperature at drift crown versus time for two drift failure scenarios. In the top figure, drift failure occurs in a 5 meters zone at 100 years and in a 10 meter zone at 200 years. In the bottom figure the two failure events occur at 55 and 60 years. The blue curve in each is the temperature with no drift degradation.