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TEMPERATURE AND MOISTURE CONTROL USING PRE-CLOSURE VENTILATION

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1. Introduction

Pre-closure ventilation may enhance performance because it can reduce peak and average near-field temperatures (due to sensible and latent heat removal); reduce temperature variations between hot and cold spots along emplacement drifts; reduce waste package (WP) relative humidity (due to air dilution and rock dryout); and delay the return of water to the near-field (due to reduced rock moisture content).

This paper analyzes the results of ventilation studies conducted by the University of Nevada for the CRWMS M&O Contractor[1,2] and the Nuclear Waste Technical Review Board[3]. References 1 and 2 were used as input to a larger CRWMS M&O Report[4].

2. Work Description

An 83 MTU/acre areal mass loading repository with identical 26-year-old spent nuclear fuel WPs was used. The 1150 m long emplacement drifts were 5 m in diameter, with 22.5 m spacing. Center-to-center WP spacing in each drift was 16 m. At each drift entrance, 26°C air with 30% relative humidity was assumed. The results presented here are to 600 m drift length because the ventilation air enters the drift ends and exits at the drift mid-length, through a shaft to an exhaust drift below the repository horizon.

The Mackay School of Mines ventilation simulation model, MULTIFLUX, was coupled to the NUFT (Nonisothermal Unsaturated-Saturated Flow and Transport) code which was developed by Lawrence Livermore National Laboratory to model hydrothermal processes in the rock mass. MULTIFLUX was used to calculate temperature and humidity distribution in the air and the rock wall around the hottest emplacement drifts, several drifts from the repository edges. Three drift ventilation air quantities were used: 10, 1, and 0.1 m^3/s. A pre-closure time period of 100 years was assumed (the actual closure time could be earlier).

3. Results

Drift wall temperature envelopes are shown in Figure 1 for 10 m^3/s and 1 m^3/s, at the times of maximum temperatures and at 100 yrs. Each envelope includes the peak temperatures near the WP mid-lengths and the minimum temperatures near the middle of the gaps.

For high ventilation, the maximum rock temperature of 50°C is reached in ten years at the mid-drift-length (approximately 600 m from either end); the nearby gap temperatures are 7°C lower. For intermediate ventilation, the maximum temperature of 135°C is reached in 20 years, with gaps about 30°C lower. For low ventilation (not shown in Figure 1), the maximum temperature of 177°C is reached in 100 years, with gaps 15°C lower.

The moisture removed by air is shown in Figure 2 for the three ventilation rates. Percolation is also shown, assuming that either an average percolation flux of 10 mm/yr from mid-pillar to mid-pillar is focused to the drift (curve a) or that the same flux is uniformly distributed without focusing (curve e).

4. Conclusions and Discussion

The high pre-closure ventilation rate maintains the drifts below 50°C, within the capabilities of modern mining equipment. Mobile radiation shielding could make contact maintenance, WP inspection, and potential retrieval operations possible at these temperatures.

For intermediate ventilation, the maximum air temperature remains below 120°C. The pillar area is dominantly sub-boiling, allowing for efficient shedding of mobilized water through the pillars. This ventilation rate could potentially be supplied through the natural buoyancy pressure difference, using the waste decay heat to power air movement[5,6]. Such a design would be intrinsically reliable as long as the underground structure is stable.

The current reference design is the low ventilation rate, chosen to force flow away from occupied areas toward sensors and HEPA filters, in case of juvenile WP failures. Drift temperatures are substantially above boiling, narrowing or possibly eliminating (depending on the local percolation flux) the portion of the pillars that are available for efficient shedding of mobilized water. Ventilation does not remove much heat because the air heat capacity is not capable of removing sensible heat beyond 100 m to 400 m of drift (depending on the time). Beyond these locations, ventilation is limited to smoothing the longitudinal temperature variation, without affecting the average heat balance of the drift. Substantial dryout of the near-field can occur, but its extent and duration depend on the thermal-hydrologic properties of the nearby stratigraphic sub-units.

For each case, the moisture balances (Figure 2) include ambient and mobilized moisture removed by ventilation, but do not include additional contributions due to focusing of ambient and mobilized percolation.

For the high ventilation rate, moisture removal by ventilation (curve b) is limited because low temperatures do not mobilize much pore water. For 90 years, this ventilation rate is capable of removing unfocused ambient percolation (curve e) from the drift vicinity. In contrast, focused percolation (curve a) is considerably higher than the ventilation moisture removal. However, the calculation did not make focused flow available for removal by ventilation. In the calculation, (without focused flow), the drift surface remained dry, and the relative humidity in the drift was below 30%. Additional calculations are required to determine if the ventilation system can vaporize focused percolation (ambient or mobilized) quickly enough to prevent pre-closure seeps. Since the pillars will be sub-boiling, shedding will be facilitated, minimizing focusing.

For intermediate ventilation, moisture removal (curve c) is greater than for high ventilation, because more water is mobilized and available for removal at higher temperatures. Ventilation moisture removal is always higher than unfocused ambient percolation (curve e) and exceeds focused percolation (curve a) for 40 years. Beyond this period, additional calculations are required to determine if ventilation can prevent seeps. Because much of the pillar is sub-boiling, shedding through the pillars will likely limit focusing. In the present calculation without focused percolation, the relative humidity remained below 6%.

For low ventilation, high temperatures and near-field dryout result in moisture removal (curve d) lower than for intermediate ventilation, but much greater than for high ventilation. Low ventilation can easily cope with unfocused ambient percolation (curve e). For focused percolation flux, beyond 30 yrs, additional calculations are required to determine if ventilation can prevent seeps. Because much of the pillar reaches boiling temperatures, refluxing and focusing of percolation is a more likely possibility than for the other ventilation rates.

5. References

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Figure 1. Drift wall temperatures along the drift length, for 10 and 1 m^3/s. Peak temperatures and 100 year temperatures are shown. The envelopes span the rock temperatures near WPs and near gaps.

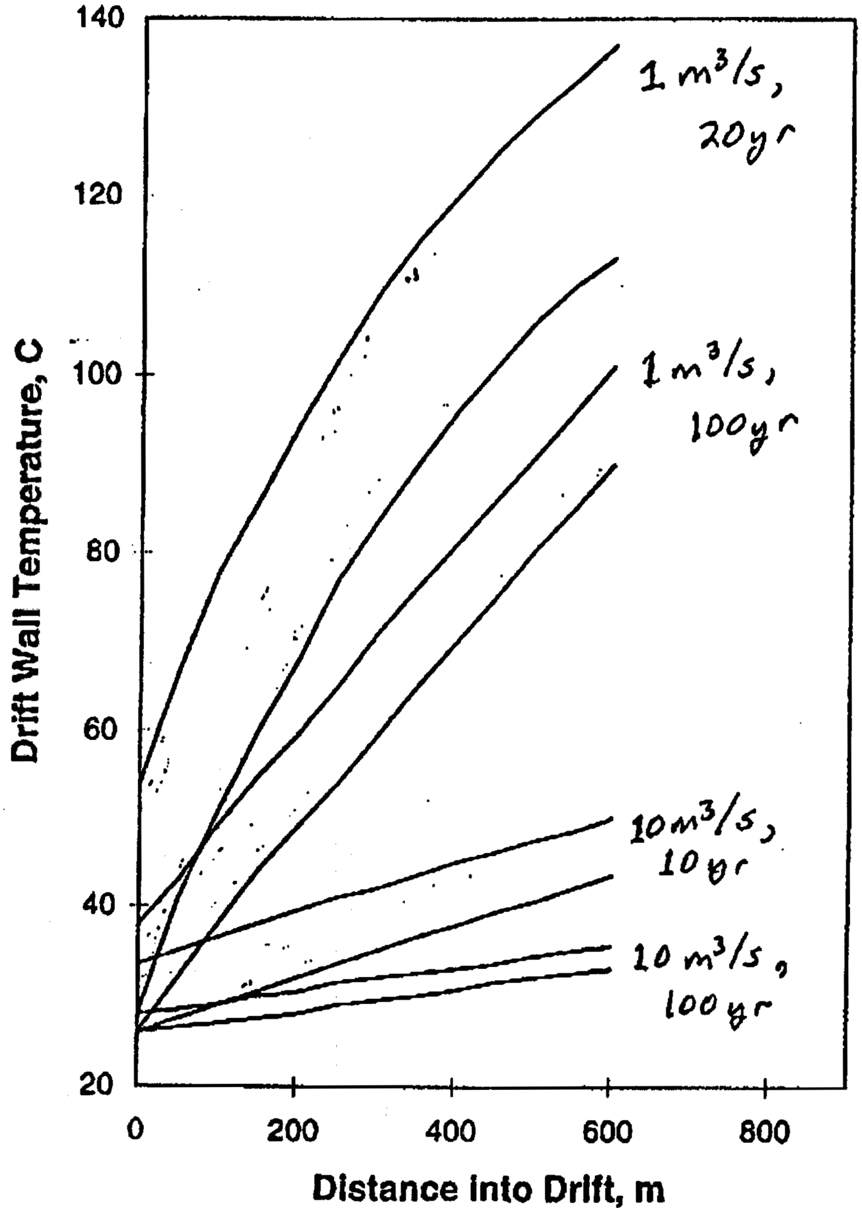

Figure 2. Moisture balance. The drift-length-averaged moisture removed by 10, 1, and 0.1 m^3/s ventilation rates (curves b, c, and d) was calculated using equivalent continuum models and thus does not include focused flow contributions. The moisture added by a 10 mm/yr ambient percolation flux, with and without pillar-to-pillar flow focused to the drift, is shown by curves a and e. The moisture mobilized by heat is not shown.