ATTACHMENT D

Numerical Analysis of Water Percolation through the Cover Cap of Piñon Ridge Mill Tailings

TAILING CELL CLOSURE DESIGN REPORT
ENERGY FUELS RESOURCE CORPORATION
PIÑON RIDGE PROJECT
This technical memorandum presents estimates by HCItasca Denver, Inc. (HCID) of water percolation rates through a closure cap for a proposed tailings landfill associated with the “Piñon Ridge” Uranium Mill located in Colorado. The results are based on numerical modeling of unsaturated water flow in soil under the influence of gravity. Unsaturated flow modeling was used to estimate the flux of water that will migrate through the various components (layers) of the cover. The analysis is based on a combination of soil properties (porosity, field capacity/specific retention, and moisture conditions), meteorological data, including precipitation, and data on vegetation cover. The data were collected and transmitted by Kleinfelder to HCID in September 2008.

DESCRIPTION OF MODEL AND ASSUMPTIONS

Figure 1 shows a) the proposed design for the cover and b) the model representation of the cover. The UNSAT-H code (M.J. Fayer, 2000) was used to provide numerical analysis of the movement of moisture because it was developed especially for problems similar to closure cap design.

The one-dimensional flow of water under gravity was assumed to be the dominating driving mechanism (heat and chemical potentials were not considered). The source of water is assumed to be precipitation but the volume of precipitation is reduced significantly by the processes of evaporation, vapor transport, transpiration, and storage of water within the soils. The model used 61 nodes over the depth of interest. The hydraulic properties of the soil layers used in the model are listed in Table 1.

Boundary Conditions

The upper boundary of the model was simulated as an open boundary with a prescribed water flux that varied daily. The daily precipitation data for Nucla, Colorado recorded for the years
between 1999 and 2007 (nine years) together with the following meteorological data: minimum and maximum daily temperatures, dew point temperatures, average wind speed, and solar radiation, were used. These data were used in the model to calculate the water fluxes that percolate into the subsoil or evaporate. If the daily precipitation amount exceeded the maximum that can be accepted by the soil and the amount that can be lost by evaporation, then the remaining amount of water would run off as referenced in *UNSAT-H*. HCID observed that the portion of run-off calculated by the model for this area of Colorado is negligibly small.

A time period of 50 years was simulated by the model. In order to have a precipitation record of 50 years, we used the nine years of data (1999 through 2007) for the first nine years of simulation with the next 41 years being a random selection (for each year) from the known data set. The total number of “dry” years for the period between 1999 and 2007 is approximately 30 percent. This “dry” year percentage was applied to the remaining period of simulation. Figure 2 shows the total annual precipitation used each year in the simulations for the Piñon Ridge site.

The lower boundary of the model is the top of tailings layer. This boundary was simulated using a unit hydraulic gradient so that water would readily leave the model at this boundary. The primary purpose of the modeling was to estimate the amount of flow through the lowest boundary of the cover cap. Another issue of the modeling was to calculate how much water can be accumulated in the soils of the cover cap, especially within the radon barrier.

Six different scenarios based on data collected by Kleinfelder were analyzed using the model. These scenarios were:

- **Scenario 1** – base case with expected hydraulic properties of the cap, no grass cover;
- **Scenario 2** – with lowest hydraulic conductivities for the soil materials, no grass cover;
- **Scenario 3** – with maximum hydraulic conductivities of the soils, no grass cover;
- **Scenario 4** – base case with an analysis of the impact of vegetation on water percolation;
- **Scenario 5** – same as Scenario 2 with grass cover; and
- **Scenario 6** – same as Scenario 3 with grass cover.

**Simulation of Transpiration**

The amount of water transpired is dependent upon the depth of the vegetative roots and the amount of leaf area. We assumed that depths of vegetative roots would not penetrate significantly below the depth of approximately 60 cm. This depth is within the bio-intrusion layer. The *UNSAT-H* user’s manual suggests that the normalized root biomass \( \rho_{rl} \) is related to the depth, \( z \), below cover surface as an exponential function. The equation used in the model is:

\[
\rho_{rl} = a \exp(-bz) + c
\]

where \( a, b, \) and \( c \) are different coefficients.
It was impossible at this stage of the investigation to determine a precise relationship between the root biomass and root depths for the proposed seed mixture (Kleinfelder, 2008). This mixture consists of 20% each of Needleandthread, Indian ricegrass, Thickspike wheatgrass and 10% each of Sandberg bluegrass, Bottlebrush squirreltail, Blue Grama and Galleta. We found that by varying the values for the $a$, $b$, and $c$ coefficients a combination of $a=1$, $b=0.07$, and $c=0$ provided an appropriate root distribution over the depth for the suggested cap design. Shown on Figure 3a is the calculated normalized root biomass versus depth used in the modeling.

Another parameter required by the model is the Leaf Area Index. For modeling purposes it was assumed that the active vegetation (active growth) will start on calendar day 120 and extend through calendar day 270. We assumed that the Leaf Area Index will change according to the Kleinfelder memo (August 2008) as shown on Figure 3b. The appropriate root growth schedule assumed in the model is shown on Figure 3c.

For model purposes it was assumed that effective vegetation cover will be only 35% of the area of the cover.

The purpose of incorporating vegetation in the model is to calculate how transpiration is important in reducing the moisture in the soil and preventing water discharge to the tailings.

RESULTS OF SIMULATION

Figure 4 shows the results of simulation in terms of water percolation in the tailings. According to the model, the recharge will consistently decrease over the simulated 50 years, and will achieve a steady-state value. The maximum steady-state discharge rate is estimated to be approximately 0.036 cm annually for Scenario 3 (the scenario where the largest hydraulic conductivities for the soil layers were assumed). The minimum calculated discharge rate is 0.008 cm/yr for the case of the lowest assumed hydraulic conductivities with a grass cover (Scenario 5). The base case scenario (Scenario 1), which uses the expected hydraulic conductivities for the native soils that are proposed for the cover cap design will have a calculated steady-state discharge rate of 0.027 cm/yr. Under Scenario 4, with seeded grass, the steady-state discharge rate would decline in 15 years, and it would eventually be reduced to a steady-state discharge rate of 0.012 cm/years to the tailings. These calculated values are recommended by HCID to be used for long-term water-balance calculations for the tailings.

Figure 5 shows the profile of water contents over the depth at the end of Year 1, Year 10, Year 20, Year 30, Year 40, and Year 50 for Scenarios 1 through 3. These scenarios assume only a soil cover without vegetation (grass cover). As shown, the water contents within the radon barrier (depth interval of 130 cm to 315 cm) will not change significantly between Scenarios 1 and 3. In these scenarios there is very little change in moisture content over time within the radon barrier. Figure 6 shows the distribution of water content for Scenarios 4 through 6. In all of these scenarios, grass is assumed to grow on the cover. As observed for Scenarios 4 through 6, the
vegetation covered cap will be able to reduce the water content in the cap despite the fact that the roots will not penetrate deeper than the depth of the bio-intrusion layer.

CLOSURE

Please contact us if you have questions regarding any of the items in this technical memorandum.

REFERENCES


Kleinfelder, 2008b, Piñon Ridge closure cover geotechnical and hydrogeologic properties, Calculation Number: 89241.7 – ALB08CA003, September.

Kleinfelder, 2008c, Nucla, Colorado, Daily meteorological data - Excel spreadsheets prepared by Sarah Walters, August.

Attachments:  Figure 1 - Piñon Ridge Closure Cover Formulation  
                      Figure 2 - Simulated Annual Schedule of Precipitation  
                      Figure 3 - Simulated Grass Cover Conditions  
                      Figure 4 - Predicted Inflow to Tailings through Landfill Cap  
                      Figure 5 - Predicted Water Contents within the Landfill Cover Over Time without Grass Cover  
                      Figure 6 - Predicted Water Contents with the Landfill Cover Over Time with Grass Cover  
                      Table 1 - Hydraulic Properties Used in *UNSAT-H* Model
Simulated Annual Schedule of Precipitation

YEAR OF SIMULATION vs. ANNUAL PRECIPITATION (cm)
Predicted Water Content within the Landfill Cover Over Time Without Grass Cover

End of:
- 1st Year
- 10th Year
- 20th Year
- 30th Year
- 40th Year
- 50th Year
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<th>Saturated Hydraulic Conductivity (cm/s)</th>
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<td>From</td>
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<td></td>
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1 Kleinfelder, 2008b.