# UTAH DIVISION OF RADIATION CONTROL

# DENISON MINES (USA) CORP'S
# REVISED INFILTRATION AND
# CONTAMINANT TRANSPORT MODELING REPORT

## INTERROGATORIES – ROUND 1

## MARCH 2012

## TABLE OF CONTENTS

Section Page

ACRONYMS AND ABBREVIATIONS ........ ii
INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 01/1: INCONSISTENCIES BETWEEN REVISED ICTM REPORT AND RECLAMATION PLAN REV 5.0 ........ 3
INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 02/1: COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS, AND RADON EMANATION MODELING ........ 6
INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 6(1); INT 03/1: MOISTURE STORAGE CAPACITY OF COVER ........ 13
INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 1; INT 04/1: EVALUATION OF POTENTIAL FLOW THROUGH TAILINGS CELL LINERS ........ 16
INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4 -05/1: CONTAMINANT TRANSPORT MODELING ........ 19

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACZ | ACZ Laboratories, Inc. |
| ANP | acid neutralization potential |
| CFR | Code of Federal Regulations |
| cm | centimeter |
| DO | Dissolved oxygen |
| DUSA | Denison Mines (USA) Corporation |
| E | East |
| ET | Evapotranspiration |
| ft | foot |
| HFO | hydrous ferric oxide |
| HP1 | Reactive transport model (HYDRUS-1D coupled with PHREEQC) |
| IUC | International Uranium Corporation |
| Kd | distribution coefficient |
| mg/L | milligram per liter |
| mi | mile |
| N | North |
| ICTM | Infiltration and Contaminant Transport Model |
| NRC | U.S. Nuclear Regulatory Commission |
| NUREG | Label denoting a collection of documents published by the US Nuclear Regulatory Commission |
| pCi | picocurie; $10^{-12}$ curie |
| Rev. | Revision |
| S | South |
| s, sec | second |
| SWCC | soil water characteristic curve |
| UAC | Utah Administrative Code |
| W | West |

**INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 01/1: INCONSISTENCIES BETWEEN REVISED ICTM REPORT AND RECLAMATION PLAN REV 5.0**

**REGULATORY BASIS:**

*UAC R313-24-4 invokes the following requirement from 10CFR40, Appendix A, Criterion 6(1): In disposing of waste byproduct material, licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years, and (ii) limit releases of radon-222 from uranium byproduct materials, and radon-220 from thorium byproduct materials, to the atmosphere so as not to exceed an average release rate of 20 picocuries per square meter per second (pCi/$m^2$s) to the extent practicable throughout the effective design life determined pursuant to (1)(i) of this Criterion. In computing required tailings cover thicknesses, moisture in soils in excess of amounts found normally in similar soils in similar circumstances may not be considered. Direct gamma exposure from the tailings or wastes should be reduced to background levels. The effects of any thin synthetic layer may not be taken into account in determining the calculated radon exhalation level. If non-soil materials are proposed as cover materials, it must be demonstrated that these materials will not crack or degrade by differential settlement, weathering, or other mechanism, over long-term intervals.*

**INTERROGATORY STATEMENT:**

***Refer to Executive Summary, Section 2.1, Figures 2-2 and 3-1, Table 3-1, and Appendices D through N of the ICTM Report Rev 2:***

1. *Revise the description of the proposed evapotranspiration (ET) cover, including revised cover material characteristics (e.g., soil textures [percent clay content, etc…], expected in-place saturated soil layer hydraulic conductivities, particle size distributions, porosities and bulk densities) for each layer of the cover and revised thicknesses, where applicable, to be consistent with the ET cover description that will be presented in the next revision of Reclamation Plan Rev. 5.0 reflecting the responses to comments contained in the Round 1 Interrogatories submitted on the Reclamation Plan rev. 5.0 and these Round 1 interrogatories. Update Figures 2.2 and 3-1 to reflect the ET cover thicknesses and materials and to be consistent with the descriptions to be provided in the updated Reclamation Plan.*
2. *Update analyses in the referenced Appendices to reflect ET cover characteristics that are consistent with the descriptions to be given in the next revision of the Reclamation Plan Rev 5.0.*

3. *Provide an updated Appendix D (Vegetation Evaluation for the Evapotranspiration Cover) that reflects information to be presented in the next revision of the Reclamation Plan Rev. 5.0 on vegetation occurrence and the proposed revegetation plan and that addresses the additional considerations and additional information described or requested in "INTERROGATORY WHITE MESA RECPLAN REV 5.0 R313-24-4; 10CFR40 APPENDIX A; INT 11/1: VEGETATION AND BIOINTRUSION EVUALATION AND REVEGETATION PLAN".*
4. *For Appendix E (Comparison of Cover Designs Based on Infiltration Modeling), Appendix F (Evaluation of the Effects of Storm Intensity on Infiltration through Evapotranspiration Cover), Appendix G (Sensitivity Analysis Comparing Infiltration Rates through the Evapotranspiration Cover Based on Vegetation, Biointrusion, and Precipitation), and Appendix H (Radon Emanation Modeling for the Evapotranspiration Cover):*
    a. *Provide revised discussion of the impacts of the results of an updated frost penetration calculation and the maximum predicted frost penetration depth for the cover system*
    b. *Provide revised discussion and revised infiltration analyses to:*
        i. *Reflect the results of the updated frost penetration depth analysis requested in "INTERROGATORY WHITEMESA RECPLAN 5.0 R313-24-4; 10CFR40, APPENDIX A, CRITERION 6; INT 10/1: TECHNICAL ANALYSES - FROST PENETRATION ANALYSIS"*
        ii. *Address the additional considerations and additional information described or requested in "INTERROGATORY WHITE MESA REV'D ICTM R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 02/1: COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS, AND RADON EMANATION MODELING"*
5. *For Appendices K through N, provide updated/revised information and/or results to reflect updated information and results provided as requested for Appendices E through H in Items 1 through 4 of this interrogatory.*

**BASIS FOR INTERROGATORY:**

*Section 3.3 and Figures 2.2 and 3-1 of the revised ICTM Report present the thickness of the ET cover as 9.3 feet extending from the cover surface to the top of the tailings. The Reclamation Plan, Rev. 5.0 (Section 3.2.2, Appendix G, and Figure 1-1 of Appendix G), describes the ET cover as being 9 feet thick from the cover surface to the top of the tailings. Revisions need to be made to the ICTM Report to be consistent with the ET cover details to be presented in the next revision of the Reclamation Plan Rev. 5.0. Also, the description of the materials comprising the ET tailings cover design is different in the ICTM Report than in the Reclamation Plan Rev. 5.0. The ICTM describes the ET tailings cover design from top to bottom as follows:*

- *0.5 ft (15 cm) Erosion Protection Layer (gravel-amended topsoil mixture)*

- *3.5 ft (107 cm) Water Storage/Biointrusion/Frost Protection/Radon Attenuation Layer (random fill soil [sandy clayey silt])*
- *2.8 ft (75 cm) Radon Attenuation Layer (highly compacted loam to sandy clay*
- *2.5 ft (75 cm) Radon Attenuation and Grading Layer (random fill soil [sandy clayey silt])loam to sandy clay*

*However, Figure 1-1 of the Reclamation Plan Rev. 5.0 describes the water storage/biointrusion/frost protection/radon attenuation layer as a loam to sandy clay with the radon attenuation layer being comprised of highly compacted loam to sandy clay The intended proposed tailings cover design needs to be made consistent for the ICTM Report and the next revision of the Reclamation Plan Rev. 5.0.*

*Finally, on page E-2, it is stated that "TITAN Environmental (1996) completed a freeze-thaw evaluation based on site-specific conditions which indicated that that the anticipated maximum depth of frost penetration was 6.8 inches (0.6 ft)." The frost penetration depth estimate presented by TITAN Environmental (1996) is out of date and needs to be replaced with an updated frost penetration depth calculation.*

*Refer to the Basis for Interrogatory sections in "INTERROGATORY WHITEMESA RECPLAN 5.0 R313-24-4; 10CFR40, APPENDIX A, CRITERION 6; INT 10/1: TECHNICAL ANALYSES - FROST PENETRATION ANALYSIS", "INTERROGATORY WHITE MESA REV'D ICTM R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 02/1: COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS, AND RADON EMANATION MODELING" and "INTERROGATORY WHITE MESA RECPLAN REV 5.0; R313-24-4; 10CFR40 APPENDIX A; INT 11/1: VEGETATION AND BIOINTRUSION EVUALATION AND REVEGETATION PLAN" for additional information and bases for this interrogatory.*

**REFERENCES**:

*Denison Mines (USA) Corp. 2010. Revised Infiltration and Contaminant Transport Modeling Report, White Mesa Mill Site, Blanding, Utah (Revision 2), March 2010.*

*Denison Mines (USA) Corp. 2011. Reclamation Plan, White Mesa Mill, Blanding, Utah, Radioactive Materials License No. UT1900479, Revision 5.0, September 2011.*

**INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 02/1: COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS, AND RADON EMANATION MODELING**

**REGULATORY BASIS:**

*UAC R313-24-4 invokes the following requirement from 10CFR40, Appendix A, Criterion 6(1): In disposing of waste byproduct material, licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years, and (ii) limit releases of radon-222 from uranium byproduct materials, and radon-220 from thorium byproduct materials, to the atmosphere so as not to exceed an average release rate of 20 picocuries per square meter per second ($pCi/m^2s$) to the extent practicable throughout the effective design life determined pursuant to (1)(i) of this Criterion. In computing required tailings cover thicknesses, moisture in soils in excess of amounts found normally in similar soils in similar circumstances may not be considered. Direct gamma exposure from the tailings or wastes should be reduced to background levels. The effects of any thin synthetic layer may not be taken into account in determining the calculated radon exhalation level. If non-soil materials are proposed as cover materials, it must be demonstrated that these materials will not crack or degrade by differential settlement, weathering, or other mechanism, over long-term intervals.*

**INTERROGATORY STATEMENT:**

*1.* **Please refer to Sections 3-1, 4-1 and Appendix E, F, G, and H of the ICTM Report:** *Please provide the following:*

*a. Provide additional information to justify the assumed cover soil layer properties, including the value of porosity of 0.25 in Table H-3 for the Erosion Protection Layer. Demonstrate that the values used in modeling appropriately reflect: (a) the composition and characteristics of the soil and gravel components of the admixture layer and of other layers in the cover system; and (b) the level of compaction proposed for each cover layer (see also "INTERROGATORY WHITEMESA RECPLAN REV 5.0 R313-24-4; 10CFR40, APPENDIX A, CRITERION 6(4); INT 12/1: REPORT RADON BARRIER EFFECTIVENESS).*

*b. Provide additional sensitivity analyses projecting potential performance of the four different conceptual cover designs where the cover materials are assumed to have experienced degradation under postulated worst-case long-term conditions. Specifically, adjust parameters (including at least, bulk density and porosity, in* *accordance with recommendations in NUREG-1620, Section 5.1.3 [NRC 2003])) of soil and/or clayey materials within the maximum projected frost-impacted zone for the 1,000-year recurrence interval (see also "INTERROGATORY WHITEMESA RECPLAN 5.0; UAC R313-24-8; 10CFR40, APPENDIX A, CRITERION 6; INT 10/1: TECHNICAL ANALYSES - FROST PENETRATION ANALYSIS"). Consistent with recommendations provided in Benson et al. 2011, adjust other cover soil properties (e.g., hydraulic conductivities and the α [or alpha] parameter in the mathematical expression for the soil water characteristic curve [SWCC]) consistently for all alternative cover systems considered (or justify why inconsistent parameter values are appropriate) in assessing long-term degraded conditions.*

c. *Define and justify a range of possible future climate conditions that may reasonably be expected to occur during the performance period of the closed tailings embankment system (up to 1,000 years), taking into account the projected variability of climate conditions over such time periods. Provide infiltration modeling results that incorporate such peak/higher precipitation and/or minimum evapotranspiration conditions. Alternatively, provide detailed justification why consideration of such changed climatic conditions in the infiltration simulations is not justified or would be otherwise inconsistent with relevant guidance and policy determinations and with regulatory precedent established on other projects of a similar nature (Note: on similar projects, formal future climate analysis techniques have been used to forecast possible future climate states occurring during the next 1,000 years, and infiltration sensitivity analyses were performed to assess long-term future cover system performance under these projected future climate conditions). Incorporate worst-case meteorological conditions into the sensitivity analyses and the "bathtub" analysis for the proposed evapotranspiration (ET) cover system.*

d. *Extend the timeframe for calculations projecting the "bathtub effect" to a period of up to 1,000 years. Adjust soil properties in the proposed ET cover components to include initial and worst case long-term degraded cover conditions as stated in Item 1 of this interrogatory. Incorporate potential worst-case forecasted future climate conditions as stated in Item 2 of this interrogatory.*

e. *Provide additional justification for selecting a three-consecutive-year period for the higher precipitation regime in the infiltration sensitivity analysis provided in Appendix G. Discuss and evaluate the appropriateness of results and/or recommendations from other published studies (other than the Khire et al. 2000 study cited in Appendix G) for arid and semi-arid sites and assumptions that were made for other similar projects (e.g., Monticello, Utah tailings repository design, where a 10-consecutive-year wetter period was used in infiltration sensitivity analyses). Demonstrate that the duration of the wetter period used in the sensitivity analyses ensures that dynamic equilibrium conditions will be achieved in modeling the cover system performance.*

2. ***Refer to Revised ICTM Report, p. ES-6, Sections 4.1.2 and 5.1.2, and Appendix G:*** *Please justify assuming a tailings porosity of 57% in evaluating infiltration/potential for "bathtubbing" of leachate on the liner systems. Perform and report results of sensitivity analyses that assess the dependence of result on variations in the values of tailings porosity used in analyses.*

3. ***Refer to Appendix E, p. E-5, Paragraph 2 of the ICTM Report:*** *Please clarify/provide the information referenced as being included in Attachment E-1 (not apparently provided in the report).*

**BASIS FOR INTERROGATORY:**

*Various sets of assumptions were made when estimating parameter input values for various cover materials for use in the infiltration model simulations and in the infiltration comparisons evaluating the hydraulic performance of the four different cover designs. However, several simplified assumptions were included, and additional justification/ rationale needs to be provided to support the representativeness and appropriateness of these input values. Site-specific testing data should be better developed and utilized and real correlations developed between field parameters and laboratory results, and between soil properties and soil compaction levels for each of the different proposed ET soil cover layers.*

*Properties assumed for the various soil layers in the proposed ET cover system need to be fully justified. For example, the porosity value of 0.25 listed in Table H-3 for the Erosion Protection Layer has not adequately been justified and appears to be low. The value should be determined through calculation (e.g., using the U.S. Bureau of Reclamation Earth Manual estimation formula for total density of a soil/gravel admixture), information in Earth Manual or elsewhere on predicted percentages of Proctor maximum dry densities obtainable using standard compactive effort in relation to percent of gravel present, and correcting for the percentage of maximum density corresponding to the specified compaction level), followed by calculations of the void ratio and porosity.*

*The meteorological and soil parameter values used in the sensitivity analysis should better reflect the range of possible future meteorological and hydrological conditions that may occur at the site during the long-term performance period of the closed tailings embankment cover system. Adjusted bulk density and porosity values for the portion of the cover potentially affected by the maximum frost penetration depth over a 1,000-year recurrence period should be employed in the radon emanation model as per NUREG-1620 recommendations. Equivalent or consistent adjusted soil properties should be used in cover infiltration simulations or adequate justification provided for assuming different material properties. The estimates of the material parameters used in the infiltration* *sensitivity analyses performed to assess long-term cover performance need to be reasonably conservative, considering the uncertainty associated with these values.*

*Determination of soil properties should be based on testing of soils from the site and more precise correlations of key soil properties (e.g., soil layer hydraulic conductivity vs. relative soil compaction level) should be developed with supporting information describing the test method and its precision, accuracy, and applicability provided. It needs to be demonstrated that the parameter values selected and used in the performance analyses are conservative. For example, the code (HYDRUS) default-defined hydraulic conductivity values (based on particle size gradation information – Table E-1 in Appendix E to the Updated Tailings Design Report) may not always be conservative. The infiltration model should result in a representative and a reasonably conservative (given the uncertainty in some values) long-term infiltration estimate. Determination of variations in hydraulic conductivity with actual relative compaction levels for on-site soil samples, and associated permeameter tests used to determine saturated hydraulic conductivities of ~~s~~on-site soils with testing of on-site soils to determine the soil water retention curves could likely result in considerably less uncertainty in soil parameter input values used in modeling (e.g., see McCartney and Zornberg 2006).*

*An adequate range of climate data providing a conservative representation of recorded historical climate conditions in the site area (e.g., Blanding, Utah climate data for the period 1904 through the most recent year available), and a conservative estimate of the range of future climate conditions that might reasonably be expected to occur during the performance period of the closed tailings embankment system are required for evaluating the long-term performance of the embankment's cover system. The evaluation should consider projections of long-term extreme events and potential shifts in climate states that could reasonably expected to occur over 100's of years to up to 1,000 years, as well as annual and decadal variability in meteorological parameters. To better capture and assess uncertainties in long-term performance of the tailings embankment cover system resulting from possible future changes in climate conditions, a projection (e.g., first approximation) of possible future climate states at the White Mesa site should be developed using a future climate forecasting approach similar to or equivalent in approach to the future climate analysis approach used in other recent studies completed for similar facilities in Utah, such as the Monticello tailings repository (e.g., see Waugh et al. 1995; Sharpe 2004). Identification of the potential climate conditions should be based on analysis of several facts and considerations, including, but not limited to: (1) Annual total precipitation amounts that have occurred at the Blanding Meteorological Station (e.g., 23.50 inches, and 24.42 inches, in 1906 and 1908, respectively) that are higher than the range of annual precipitation values considered in the current Infiltration and Contaminant Transport Model (ICTM) Report, which only considered Blanding climate data acquired between 1932 and 1988;*

*(2) Subtotals of precipitation amounts that have occurred during any two, or any three consecutive months at Blanding (e.g., 9.04 inches combined total precipitation for January and February 1993 and 11.33 inches combined total precipitation for December*

*1992 through February 1993; 7.98 inches combined total precipitation for January and February 2005 and 10.46 inches combined total precipitation for December 2004 through February 2005; 11.95 inches combined total precipitation for December 1908 through February 1909; 5.75 inches total precipitation for April and May 2011 combined ; etc…) which are higher subtotal amounts than for any of the same consecutive sets of months that were included in the 1932-1988 data set considered in the current ICTM Report and three-month sub-total precipitation amounts recorded at Blanding that were higher than during the same three months as the Summer 1987 summer monsoon period selected for use in the sensitivity analysis presented in the current ICTM Report. Also, in 1908 and 1909, the months of December alone were the second highest, and the highest of record, for any winter season months with 6.20 and 6.84 inches, respectively. This further suggests that winter-season precipitation conditions may be expected to be the most critical (most conservative) as a basis for extrapolating potential abnormal future wetter weather conditions for use in assessing the effects (sensitivity)of such possible future conditions on modeled infiltration performance (see also items (4) and (5) below);*

*(3) Site-specific monitoring data, if any, from measurements made within a cover test cell considered representative of the proposed ET cover system, that might indicate one or more sets of consecutive months of the year when infiltration rates in the cover would likely be the highest;*

*(4) Identification and justification for selecting a specific climatological data set such as choosing precipitation data for the wettest consecutive months or sets of consecutive months recorded at Blanding that may correspond to those months when the highest on-site infiltration rates would be expected to occur through the ET cover system, for use in extrapolating (forecasting) potential long-term climate conditions at the White Mesa site. In this regard, additional information should be provided to justify not selecting the wettest consecutive winter months observed for the precipitation period of record for Blanding, e.g., rather than selecting the 92-day-long 1987 summer monsoon season as was done in the sensitivity analysis in Appendix F in the current ICTM Report, as the basis for extrapolating potentially wetter future climate conditions, since doing the former could likely result in more moisture breakthrough than that predicted by the current modeling;*

*(5) A description of the specific historical climate data set (e.g., wettest three consecutive winter months, if selected), or other sub-annual or annual data set(s) selected, and a description of the procedure used for extrapolating this data set or these data sets to simulate inferred future climate conditions at the White Mesa site should be provided;*

*(6) A projection (e.g., first approximation) of possible future climate states at the White Mesa site should be developed based on paleoecological evidence and/or a global/regional climate change model using a future climate forecast approach, e.g., involving the use of analogue present-day climate sites, similar in rigor to the future climate analysis approach used in other recent studies completed for other similar facilities in Utah (e.g., see Waugh et al. 1995; Sharpe 2004); and*

*(7) A description of the correlation of the extrapolated climate conditions derived based on the considerations listed in items (1) through (5) above to future climate conditions (climate states) forecasted using the future climate analysis approach, as described in item (6) above, should also be provided.*

*NUREG/CR-7028, a peer-reviewed report published for the NRC in December 2011, reports the findings from investigations of several earthen and soil/geosynthetic cover systems to assess changes in properties of cover materials in those cover systems 5 to 10 years following their construction. A key conclusion of the report is that findings from these investigations demonstrate that changes in the engineering properties of cover soils generally occur while in service and that long-term engineering properties should be used as input to models employed for long-term performance assessments. The report indicates that changes in hydraulic properties occurred in all cover soils evaluated due to the formation of soil structure, regardless of climate, cover design, or service life. The report includes recommendations for appropriate input based on the data that were collected. This document therefore contains information important to the design of the final cover system for the White Mesa uranium tailings management cells area. Additional sensitivity analyses should be performed that allow for and incorporate effects of potential long-term degradation of the cover materials in a manner consistent with conclusions and recommendations given in NUREG/CR-7028, i.e., that "engineering properties of cover soils change while in service and…that long-term engineering properties for soils cover materials should be used as input for performance assessments".*

*Based on available information and data for other uranium mill tailings, a porosity value of 57% may be considered more representative of the finer particle fraction of the tailings (slimes) than the tailings materials on average (mixture of sands and clays/silt materials) in the saturated and unsaturated portions of the tailings masses in the cells. Although a porosity of 57% may be considered conservative for estimating radon flux through the cover (Appendix H of the ICTM Report), such an assumption may not be appropriate for the infiltration and bathtub analyses, for which a lower average porosity value appears to be warranted (e.g., approximately 39% to 40%, based on data for the Moab uranium tailings). Additional justification should be provided supporting the use of a lower porosity value in the infiltration/bathtubbing analyses and revised analyses and conclusions should be provided that incorporate the lower porosity value.*

*Material referenced as being included in Attachment E-1 of Appendix E was not provided.*

**REFERENCES:**

*Benson, C.H. W.H. Albright, W.H., Fratta, D.O.,Tinjum, J.M., Kucukkirca, E., Lee, S.H., J. Scalia, J., Schlicht, P.D., and Wang, X. 2011. Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term*

*Performance Assessment(in 4 volumes). NUREG/CR-7028, Prepared for the U.S. Nuclear Regulatory Commission, Washington, D.C., December 2011.*

*Denison Mines (USA) Corp. 2010. Revised Infiltration and Contaminant Transport Modeling Report, White Mesa Mill Site, Blanding, Utah (Revision 2), March 2010.*

*Denison Mines (USA) Corp., 2011. Reclamation Plan, White Mesa Mill, Blanding, Utah, Radioactive Materials License No. UT1900479, Revision 5.0, September 2011.*

*Khire, M.V., Benson, C.H., and Bosscher, P.J. 2000. Capillary Barriers: Design Variables and Water Balance. Journal of Geotechnical and Geoenvironmental Engineering. August 2000.*

*McCartney, J.S, and Zornberg, J.G. 2006. Decision Analysis for Design of Evapotranspirative Landfill Covers", Proceedings UNSAT '06, April 2-6, Carefree, AZ, ASCE, pp. 694-705.*

*NRC 2003. NUREG-1620: Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites under Title II of the Uranium Mill Tailings Radiation Control Act of 1978. Washington DC, June 2003.*

*Sharpe, S. 2004. Future Climate States at Monticello, Utah. Desert Research Institute, February 25, 2004.*

*Waugh, W.J. and Petersen, K.L. 1995. "Paleoclimatic Data Application: Long-Term Performance of Uranium Mill Tailings Repositories," in: W.J. Waugh (ed.), Climate Change in the Four Corners and Adjacent Regions: Implications for Environmental Restoration and Land-Use Planning, CONF̃9409325, U.S. Department of Energy, Grand Junction, Colorado, USA, pp. 16̃3185 (1995). Available at: http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=167170*

## INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 6(1); INT 03/1: MOISTURE STORAGE CAPACITY OF COVER

**REGULATORY BASIS:**

*UAC R313-24-4 invokes the following requirement from 10CFR40, Appendix A, Criterion 6(1): In disposing of waste byproduct material, licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years, and (ii) limit releases of radon-222 from uranium byproduct materials, and radon-220 from thorium byproduct materials, to the atmosphere so as not to exceed an average release rate of 20 picocuries per square meter per second (pCi/$m^2$s) to the extent practicable throughout the effective design life determined pursuant to (1)(i) of this Criterion. In computing required tailings cover thicknesses, moisture in soils in excess of amounts found normally in similar soils in similar circumstances may not be considered. Direct gamma exposure from the tailings or wastes should be reduced to background levels. The effects of any thin synthetic layer may not be taken into account in determining the calculated radon exhalation level. If non-soil materials are proposed as cover materials, it must be demonstrated that these materials will not crack or degrade by differential settlement, weathering, or other mechanism, over long-term intervals.* **INTERROGATORY STATEMENT:**

***Refer to Appendix F of the ICTM Report:*** *Please provide the following:*

1. *Redefine and further justify the critical meteorological design event (or sequence of contiguous events). State and justify the basis for the critical event conditions addressing the location of the meteorological weather station for determining the wettest year on record; duration of the critical event (i.e., single-day storm or multiple-day storm; number of consecutive days of rainfall followed by a large, single-day rainfall event). Justify excluding recorded historical monthly/daily precipitation data for Blanding, Utah from consideration in all infiltration analyses conducted in the ICTM Report that indicate larger two-month-long and three-month-long precipitation amounts than the 92-day-long 1987 summer monsoon season used in the sensitivity analysis in Appendix F (see also INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 02/1: COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS , AND RADON EMANATION MODELING above). Identify the month(s) of the year that would be expected to comprise the most critical percolation period. Justify why consideration of summer monsoon conditions (when plant cover would be more developed and ET rates more enhanced) has been considered to be more*

*conservative than assuming the most critical meteorological period as occurring during the winter months.*

2. *Provide additional details regarding the assumed gradient at the soil cover/atmosphere interface and include, as needed, an increase to an otherwise assumed gradient of unity to address the potential for higher infiltration rates into the cover due to matric suction gradients greater than unity (corresponding to low suction at the soil surface and a higher suction corresponding to the initial moisture content) - see, e.g., McCartney and Zornberg 2006. Discuss how localized surface ponding, if it were to occur, would or would not affect the assumptions about the gradient at the soil cover interface;*

3. *Revise the water balance analysis to demonstrate that the cover system will provide sufficient moisture storage capacity to retain precipitation resulting from a redefined, largest and most critical meteorological event/set of conditions (most stressful hydraulic condition(s)) that the cover might be exposed to during its required performance life (1,000 years, to the extent practicable and technically and economically feasible, and in no case less than 200 years).*

4. *Discuss, justify, and apply a recommended safety factor to the design of the cover to provide additional assurance that the thickness of the cover system will be adequate to accommodate the most stressful hydraulic conditions determined in Items 1 and 2 above , as required, and to also address uncertainties relating to the following (e.g., Khire et al. 2000; Hauser et al. 2001; Hauser and Gimon 2004):*
    a. *The size of the soil water reservoir in the cover soil must be adequate to contain the predicted extreme event/conditions (critical event or events) and potentially uncertain, intense future storm events;*
    b. *The potential variability of climate conditions over the required performance evaluation period;*
    c. *The time required to empty the soil-water reservoir; and*
    d. *Other factors, such as the potential long-term degradation of the cover materials due to desiccation cracking, water erosion, freeze-thaw damage, and other environmental processes (see, e.g., Benson et al. 2011).*

**BASIS FOR INTERROGATORY:**

*Estimates of deep percolation through the cover are of particular concern for ET cover design and evaluation. The performance of ET covers should be estimated for large and critical climatic events expected to occur during the service life of the cover. Therefore, a major concern for ET cover performance is the determination of the greatest storage capacity required for the ET cover during a defined, most-critical meteorological event or set of consecutive (contiguous) meteorological events. Critical events causing maximum soil-water storage may result from a single-day storm, a multiple-day storm, or other events.*

*As a further check for ensuring that the proposed surface cover layer thickness is adequate, an evaluation should be completed that uses suitable long-term simulations performed with the most stressful conditions that the cover is likely to endure (Khire et al. 2000). The assessment should include any potentially wetter future climate conditions that may reasonably be expected to occur during the performance period of the embankment cover system spanning up to on the order of 1,000 years following the end of the institutional control period, as described in INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10CFR40 APPENDIX A, CRITERION 6(1); INT 02/1: COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS, AND RADON EMANATION MODELING above.*

**REFERENCES**:

*Benson, C.H. W.H. Albright, W.H., Fratta, D.O.,Tinjum, J.M., Kucukkirca, E., Lee, S.H., J. Scalia, J., Schlicht, P.D., and Wang, X. 2011. Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment (in 4 volumes). NUREG/CR-7028, Prepared for the U.S. Nuclear Regulatory Commission, Washington, D.C., December 2011.*

*Denison Mines (USA) Corp., 2011. Reclamation Plan, White Mesa Mill, Blanding, Utah, Radioactive Materials License No. UT1900479, Revision 5.0, September 2011.*

*Hauser, V.L., Weand, B.L., and Gill, M.D. 2001. Alternative Landfill Covers. July 2001.*

*Hauser, V.L and D.M. Gimon 2004. Evaluating Evapotranspiration (ET) Landfill Cover Performance Using Hydrologic Models. January 2004.*

*Khire, M.V., Benson, C.H., and Bosscher, P.J. 2000. Capillary Barriers: Design Variables and Water Balance. Journal of Geotechnical and Geoenvironmental Engineering. August 2000.*

*McCartney, J.S, and Zornberg, J.G. 2006. Decision Analysis for Design of Evapotranspirative Landfill Covers", Proceedings UNSAT '06, April 2-6, Carefree, AZ, ASCE, pp. 694-705.*

*U.S. Nuclear Regulatory Commission (NRC) 2003. Standard Review Plan (NUREG–1620) for Staff Reviews of Reclamation Plans for Mill Tailings Sites under Title II of the Uranium Mill Tailings Radiation Control Act", NUREG-1620, June, 2003.*

## INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 1; INT 04/1: EVALUATION OF POTENTIAL FLOW THROUGH TAILINGS CELL LINERS

### REGULATORY BASIS:

*Refer to UAC R313-24-4, which invokes the following requirement from 10CFR40, Appendix A, Criterion 1: The general goal or broad objective in siting and design decisions is permanent isolation of tailings and associated contaminants by minimizing disturbance and dispersion by natural forces, and to do so without ongoing maintenance. For practical reasons, specific siting decisions and design standards must involve finite times (e.g., the longevity design standard in Criterion 6). The following site features which will contribute to such a goal or objective must be considered in selecting among alternative tailings disposal sites or judging the adequacy of existing tailings sites:*

- *Remoteness from populated areas;*
- *Hydrologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from ground-water sources; and*
- *Potential for minimizing erosion, disturbance, and dispersion by natural forces over the long term.*
- *The site selection process must be an optimization to the maximum extent reasonably achievable in terms of these features.*
- *In the selection of disposal sites, primary emphasis must be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to consideration only of short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site and engineering design, overriding consideration must be given to siting features given the long-term nature of the tailings hazards.*

*Tailings should be disposed of in a manner such that no active maintenance is required to preserve conditions of the site.*

### INTERROGATORY STATEMENT:

***Refer to Appendix L (Evaluation of Potential Water Flow through Tailings Cell Liners) of the ICTM Report:*** *Please provide the following:*

1. *Revise and provide justification for the estimated saturated hydraulic conductivity of the compacted foundation [liner bedding] layers underlying the geomembrane in Cells 2 and 3, which are both comprised of a compacted gravel-sand mixture derived from crushing of loose sandstone. possibly with washed concrete sand used in some areas);*

2. *Provide additional justification to support the various assumed lower bound, base case, and upper bound geomembrane defect frequencies for the liners in Cells 2, 3, 4A, and 4B. Justify the upper bound assumption of 1 small hole and 3 large hole defects per acre for the geomembrane defect frequency in the Cells 2 and 3 liners and the assumption of 1 small-hole defect per acre as the base case assumption for the geomembrane defect frequency for Cells 4A and 4B, or alternatively, provide revised assumed defect frequencies to ensure that the assumed defect frequencies are adequately conservative and reasonably represent actual or potential in-place liner conditions; and*

3. *Revise the calculations of potential flow through the Cell 3 and Cell 2 liner systems using a more suitable and appropriate methodology such as the modified methodology developed by Giroud and others (Giroud et al. 1997a) for estimating the rate of liquid migration through defects in a geomembrane placed on a semi-permeable medium. Utilize and incorporate information from Giroud et al. 1997a as appropriate to interpolate between results obtained using the Giroud equation (as it was used in Appendix L of the current ICTM Report) and results that would be obtained using Bernouli's equation.*

**BASIS FOR INTERROGATORY:**

*The Construction Report, Second Phase Tailings Management System (Energy Fuels Nuclear, Inc. 1983) indicates that a gravel-sand mixture derived from crushing of loose sandstone, with some washed concrete sand in some areas, was used to construct the compacted bedding layer immediately underlying the geomembrane in Cell 3. That report also indicates that a similar process and similar materials were used for constructing the compacted bedding layer beneath the geomembrane liner in Cell 2. On page L-7 of Appendix L, the saturated hydraulic conductivity for these compacted bedding layers is assumed to be 2.0 x* $10^{-7}$ *cm/sec. This value is likely too low to be representative of these in-place compacted materials. Giroud et al. 1997a developed a modified methodology for calculating the rate of liquid migration through a defect in a geomembrane liner underlain by a semi-permeable medium. This modified methodology appears to be more appropriate for calculating leakage rates through the geomembrane liners in Cells 3 and 2 and should therefore be used instead of the method used in Appendix L for estimating flow through defects in liners in Cells 2 and 3.*

*Additional justification should be provided to support the various assumed geomembrane defect frequencies for the different geomembrane liners in Cells 2 and 3 vs. Cells 4A and 4B for the lower bound, base case, and upper bound scenarios. Additional justification should be provided to demonstrate why higher assumed base-case and/or upper bound defect frequencies would not be considered more reasonably conservative assumptions and more reasonably representative of actual or potential in-place liner conditions for some or all of the cell liners for the purpose of estimating potential leakage rates through the various liner systems. Justify why a lower bound assumption of 1 small defect per acre for Cells 2 and 3 (the same assumption as made for the base case for Cells 4A and*

*4B) is adequately conservative for the Cell 2 and Cell 3 liners given that they were constructed 30 or more years ago when construction quality assurance practices might have been somewhat less rigorous than those would have been used during installation of high density polyethylene geomembranes in Cells 4A and 4B. Additionally, the merit and applicability of assuming a geomembrane defect frequency (four defects per hectare (10,000 $m^2$) analogous to that discussed in Giroud et al. 1997b, which suggests an average of approximately 1.62 defects per acre for a typical defect frequency for a modern constructed liner, should be discussed for the Cells 4A and 4B liners, particularly given that this defect frequency was used in previous leakage equations for calculating leakage rates to support the design of the liner system in Cell 4B. Further, for assessing a range of potential upper bound (worst –case) defect frequencies for the Cell 2 and Cell 3 liners, consideration should be given to other published data, such as Nosko and Touze-Folz 2000, which provide estimates of actual liner defect frequencies (the Nosko and Touze-Folz data suggest a post-construction, pre repair average defect frequency of approximately 5 defects per acre of liner installed - based on study of over 300 landfill liners before construction quality assurance measures were undertaken to reduce the presence of defects but not eliminate them completely). Allowance should also be made for additional defects to occur after liner construction is complete.*

**REFERENCES**:

*Denison Mines (USA) Corp. 2010. Revised Infiltration and Contaminant Transport Modeling Report, White Mesa Mill Site, Blanding, Utah (Revision 2), March 2010.*

*Energy Fuels Nuclear, Inc. 1983. Construction Report, Second Phase Tailings Management System. White Mesa Uranium Project. SUA-1358. Docket 40-8681.*

*Giroud, J.P., King, T.D., Sanglerat, T.R., Hadj-Hamou, T., and Khire, M.V. 1997a. "Rate of Liquid Migration Through Defects in a Geomembrane Placed on a Semi-Permeable Medium", Geosynthetics International, Vol. 4, Nos. 3-4, pp. 349-372.*

*Giroud, J.P., King, T.D., Sanglerat, T.R., Hadj-Hamou, T., and Khire, M.V. 1997b. "Leachate Flow in Leakage Collection layers Due to Geomembrane Defects", Geosynthetics International, Vol. 4, Nos. 3-4, pp. 215-2922.*

*Nosko, V. and Touze-Foltz, N. 2000. Geomembrane Liner failure: Modeling of its influence on Contaminant Transfer. Proc. 2nd European Conf. on Geosynthetics, Bologna, Italy, 2: 557-560.*

**INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4 -05/1: CONTAMINANT TRANSPORT MODELING**

**PRELIMINARY FINDING:**

*Refer to UAC R313-24-4, which invokes the following requirement from 10CFR40, Appendix A, Criterion 1: The general goal or broad objective in siting and design decisions is permanent isolation of tailings and associated contaminants by minimizing disturbance and dispersion by natural forces, and to do so without ongoing maintenance. For practical reasons, specific siting decisions and design standards must involve finite times (e.g., the longevity design standard in Criterion 6). The following site features which will contribute to such a goal or objective must be considered in selecting among alternative tailings disposal sites or judging the adequacy of existing tailings sites:*

- *Remoteness from populated areas;*
- *Hydrologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from ground-water sources; and*
- *Potential for minimizing erosion, disturbance, and dispersion by natural forces over the long term.*
- *The site selection process must be an optimization to the maximum extent reasonably achievable in terms of these features.*
- *In the selection of disposal sites, primary emphasis must be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to consideration only of short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site and engineering design, overriding consideration must be given to siting features given the long-term nature of the tailings hazards.*

*Tailings should be disposed of in a manner that no active maintenance is required to preserve conditions of the site.*

**INTERROGATORY STATEMENT:**

1. ***Refer to Revised ICTM Report, Section 2.2 Site Characteristics and Section 4.3 Uncertainty and Assumptions:*** *Provide additional information on the potential presence and distribution of fractures and/or joints, and uncemented/higher permeability intervals in the unsaturated zone portions of the Dakota Sandstone and Burro Canyon geologic units underlying the site area, including the footprint area of and downgradient vicinity of Cells 1, 2, 3, 4A, and 4B. Describe the possible effects of such fractures and/or joints, and uncemented/higher permeability intervals, on the flow and transport of potential contaminants through the vadose zone, including potential effects on estimated contaminant travel times to the perched groundwater zone beneath the tailing management cells.*

2. ***Refer to Revised ICTM Report, Section 2.2.4:*** *Please summarize the geochemical characteristics of the perched groundwater and discuss in greater detail the potential relevance of perched zone water geochemistry to the development of specific geochemical modeling input assumptions made for the vadose zone in Appendix M (address, for example, the effects of dissolved oxygen concentration, redox conditions).*

3. ***Refer to Revised ICTM Report, Section 3.4.4, Contaminants Modeled:*** *Please provide the rationale and justification for using aluminum, versus some other constituent, to obtain charge balance in the HP1 (PHREEQC) simulations.*

4. ***Refer to Appendix C, Table C-4, p. C-15 in Appendix C to the ICTM Report:*** *Please provide a corrected maximum ANP value for MW-24 and corrected arithmetic and geometric means for ANP in the TW4-22 boring. Please confirm the results used in calculating the statistics for all of the borings and revise the summary statistics presented in Table C-4 as necessary. If the statistical results in Table C-4 for the entire population change, please revise reactive transport model as needed, to reflect these changes and report the results.*

5. ***Refer to Appendix M, p. M-10, Paragraphs 2 and 3:*** *Please provide and justify the bulk density of the bedrock used to convert the ANP and HFO values from rock mass to rock unit volume.*

6. ***Refer to Appendix M, p. M-11, Paragraph 1:*** *Please justify the assumption that the redox conditions in the tailing slimes drainage and the vadose zone are controlled by the oxygen ($O_2/H_2O$) couple. Perform and report results of sensitivity analyses that assess the dependence of result on variations in the values of redox value.*

7. ***Refer to Appendix M, p. M-11, Paragraph 2:*** *Please provide justification for using a chloride diffusion coefficient (1.75 $cm^2$/day) for seawater in the model. Perform and report results of sensitivity analyses that assess the dependence of results on variations in the values of the diffusion coefficient used in analyses.*

8. ***Refer to Appendix M, p. M-11, Paragraph 4:*** *Please justify the assumption to establish the initial soil water pressure heads within the bedrock vadose zone as ~~that~~ those resulting from percolation at a rate equal to 1% of the average annual precipitation. Compare the resulting pressure head distribution in the vadose zone with the water content distribution that could be expected to result from potential leakage from the tailings cells area, especially the area of Cells 2 and 3 (see also "INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 1; INT 04/1: EVALUATION OF POTENTIAL FLOW THROUGH TAILINGS CELL LINERS").*

9. ***Refer to Appendix M, Figures M-3 and M-4:*** *Please state and justify the value(s) of the effective uranium retardation factor that would be consistent with the HP1 model output for the bedrock vadose zone. Please see ~~(summarized in~~ Appendix M of the Revised ICTM Report, Figures M-3 and M-4,~~)~~ which show~~s~~ concentration profiles for sulfate and uranium, clearly indicating that uranium is transported more slowly than sulfate. Please quantify the rate of uranium transport relative to species, such as sulfates, that are not retarded.*

10. ***Refer to Appendix M, Figures M-3 and M-4, pp. M-25 and M-26:*** *Please clarify why the initial concentrations for sulfate or uranium are not shown at a depth of 0 feet on Figures M-3 and M-4 and/or revise the figures as necessary.*

11. ***Refer to Appendix M, Figure M-4.*** *Please explain why dissolved uranium concentration at the top of the vadose zone appears to decrease from 50 years to 100 years but then to increase from 100 years to 240 years.*

**BASIS FOR INTERROGATORY:**

*The initial soil water pressure heads in the vadose zone beneath existing Cells 2 & 3 may be higher than the initial soil water pressure heads derived from an assumption of 1% of the average annual precipitation (1% of 13.3 in/yr or 3.4 mm/yr). Leakage from Cells 2 & 3 may have already occurred. In Appendix L the estimated leakage rate through the liners in Cell 2 and 3 during the operational phase is calculated as 8.3 mm/yr (Base Case scenario) with estimated lower and upper bound values of 3.5 and 18 mm/yr; these values are~~a~~ likely underpredicted as the methodology used in that calculation does not appear to be conservative (see also "INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 1; INT 04/1: EVALUATION OF POTENTIAL FLOW THROUGH TAILINGS CELL LINERS"). Please discuss the potential effects on vadose zone flow and transport if the initial soil water pressure heads in the vadose zone were derived from the flux rate through the Cells 2 and 3 liners as calculated using the alternative flux rate calculation approach (Giroud et al. 1997) recommended in INTERROGATORY WHITE MESA REV'D ICTM; R313-24-4; 10 CFR40 APPENDIX A, CRITERION 1; INT 04/1: EVALUATION OF POTENTIAL FLOW THROUGH TAILINGS CELL LINERS" .*

*The presence and distribution of fractures and/or joints and/or uncemented zones in the bedrock materials beneath the tailing management cells area is not discussed in the Revised ICTM Report, and no discussion is provided regarding the potential effects of such fractures and/or joints and/or uncemented zones on subsurface contaminant flow and transport. The possible presence and distribution of such fractures and/or joints in the bedrock materials should be discussed in the Revised ICTM Report, along with an evaluation of the potential effects of such fractures and/or joints and/or uncemented zones on subsurface contaminant flow and transport. For example, the 1978 Environmental Report (e.g., see Dames & Moore 1978., p. 2-106) indicates the* *following: "…jointing is common in the exposed Dakota-Burro Canyon sandstones along the mesa's rim…more often than not, the primary joints are parallel to the cliff faces and the secondary joints are almost perpendicular to the primary joints… two sets of joint attitudes exist [in these sandstone units] ..to the west side of the project site…These sets range from N 10-$18^0$ E and N 60-85 $E^0$ and nearly parallel to the cliff faces".*

*In addition, information provided by UMETCO (UMETCO 1993, p, 2-3) indicates that "during an investigation of the White Mesa site, a number of fracture attitudes were measured (in the Dakota and Burro Canyon sandstone units) along the rims of Corral and Cottonwood Canyons [in the general site area], ..(with) analysis of the data indicating the presence of two joint sets… [and] distances between the joints in each set varies from 5 to 20 feet, …the primary joints strike from north-south to N $20^0$ E with a vector mean of N $11^0$ E and the secondary fractures have a strike ranging between N $40^0$ W to N $60^0$ W with a vector mean of N $47^0$ W… All joint sets observed were near vertical to vertical."*

*The boring log for Borehole No. 19 (see Dames & Moore 1978, Plate A-9; International Uranium Corporation [IUC] 2000, Figure 1.5.3-1), installed near the Cell 4B footprint, indicates horizontal fracturing may be present at one or more depth zones (e.g., 45 ft, and 53-58 ft below ground surface) within the Dakota Sandstone unit underlying and/or adjacent to the area of proposed Cell 4B. That boring log also indicates the occurrence of some orange iron staining and considerable limonite staining along bedding fractures (which suggest zones of localized movement of groundwater) as well as some uncemented zones of rock within the Dakota Sandstone materials.*

*An injection test conducted within the Dakota unit in Boring 19 penetrating the Dakota and Burro Canyon units yielded permeability values that differed by more two orders of magnitude, depending on whether the tested interval spanned a zone (37.5 – 52.5 ft below ground surface) containing "considerable near horizontal fracturing and some orange staining" (permeability of $9.12 \times 10^{-4}$ cm/sec) or had no reported fracturing (permeability $6.77 \times 10^{-6}$ cm/sec).*

*The issue of the potential presence of fractures and/or joints and/or uncemented zones in the bedrock materials beneath and in the vicinity of the Cell 4B tailing management cells area and the potential effects of such features on vadose zone flow and transport was previously considered and evaluated in responses provided by Denison Mines (USA) Corp (DUSA), with attached letters from Hydro Geo Chem, Inc., to First Round Interrogatories submitted to DUSA by the Division on the Cell 4 B Design Report (DUSA 2010a ) and Second Round Interrogatories submitted to DUSA by the Division on the License Amendment Request and Environmental Report for Cell 4B (DUSA 2010b; 2010c). A similar discussion/evaluation should be included in the ICTM Report to assess~~es~~ the potential significance of such features on the transport modeling assumptions and approach.*

*The maximum ANP value of 27 g $CaCO_3$/kg rock listed for MW-24 (Table C-14, p. C-15 of Appendix C) does not appear to be correct based on a review of the ACZ analytical data sheets provided in Appendix A. The correct maximum value appears to be 25 g $CaCO_3$/kg rock. It also appears that the arithmetic and geometric means for ANP in the TW4-22 boring may also be incorrect. Data used to randomly check the arithmetic and geometric means for boring TW4-22 were obtained from the ACZ analytical data sheets. Statistical results for the entire population presented on Table C-4 are used as input to the Reactive Transport Model described in Appendix M. If these results change, please modify the reaction transport model as needed.*

*The discussion presented in Section 2.2.4 of the ICTM Report refers to a number of hydrogeologic and background groundwater quality reports but does not summarize information on any pertinent geochemical conditions that are relevant to the development of input parameters for use in the transport modeling. The potential relevance of the perched zone geochemical data, if any, to the development of geochemical modeling input assumptions made in Appendix M should be discussed and discussion should be provided as to whether the vadose zone input and results are consistent with existing perched water geochemical conditions at the site.*

*The fixed dissolved oxygen concentration (2 mg/L) arbitrarily chosen and used to define the ($O_2$/$H_2O$) redox couple may be an overestimate of the likely redox potential conditions in the tailing slimes drainage. With modeling conditions fixed in this way, all calculations in Eh-pH space will be confined to a line just below the upper stability limit for water. Bass Becking et al. (1960) and Garrels and Christ (1965) showed the inadequacy of this approach for all but a few rare surface geologic situations. Redox equilibrium is typically not established in most waters because of the presence of living organisms, the dependence of most redox reactions on biological catalysis, and the slow kinetics of many oxidation and reduction reactions. The redox potential should therefore correspond to the potential range of the predominant redox reaction under given conditions.*

*The tailing slimes drainage chemistry data presented in Table K-1 indicate that the tailing slimes contain ammonia and dissolved iron which suggests that the redox conditions in the tailing slimes drainage may be less than those defined by the chosen fixed dissolved oxygen concentration for the oxygen redox couple. It is important to have a reasonable redox estimate for both the tailing slimes and the vadose zone because ~~it~~ the redox potential value controls solubility and/or precipitation of some constituents/solids such as $Fe^{2+}$/HFO during reactive transport. For example, if more reducing tailing slimes drainage percolates through the vadose zone, the assumed redox condition in the vadose zone may be less and result in the dissolution of HFO which serves as a sorption site for uranium and other constituents. Thus, less sorption would occur and uranium might be transported to the underlying perched zone. Because the reactive transport model will likely be sensitive to redox and the uncertainty in redox, the redox value should be included as a parameter in the sensitivity analyses.*

*A summary of the existing dissolved oxygen (DO) and/or oxidation-reduction potential (ORP) data for the vadose or perched zones, as well as area groundwater seeps should be presented so that these data can be compared to the dissolved oxygen concentration (2 mg/L) assumed for the vadose zone (pages M-10 thru M-12 in Appendix M) to determine if the assumed vadose zone oxygen content is consistent with those found in the perched zone. Relevant information might be found in the INTERA hydrogeology reports, background reports, etc. cited on pages 2-12 and 2-13 of the Revised ICTM Report.*

*The diffusion coefficient would be expected to affect transport of solutes through groundwater, including the amount of time required for peak solute concentrations to arrive at a downgradient location.*

*Chloride diffusion coefficients reported in the literature (e.g., Barone et al 1990; Barone et al 1992; Kincaid et al 1995; Rowe and Badv 1996; Badv and Faridfard 2005) suggest that a smaller chloride diffusion coefficient may be more reasonable than the one selected because the salinity of water in the vadose zone will be less than seawater. Because the reactive transport model will likely be sensitive to the diffusion coefficient, the diffusion coefficient should be included as a parameter in the sensitivity analyses.*

*The HP1 reactive transport model (HYDRUS-1D coupled with PHREEQC) does not use the traditional concept of a distribution coefficient (Kd) from which a retardation factor can be calculated; rather it uses a surface complexation modeling approach that is functionally similar to the methodology developed by the U.S. Geological Survey for the U.S. Nuclear Regulatory Commission, as presented in NUREG/CR-6820 (Davis and Curtis 2003). According to information presented in Appendix M, in this modeling approach, uranium adsorption is allowed to compete with other metals, which would decrease the total amount of uranium that could adsorb. The transport model shows the concentration front of uranium proceeding more slowly than the concentration of species, such as sulfate, that are not retarded (see Appendix M, Figures M-3 and M-4). Therefore, while the conceptual basis of the transport model is different from a simple Kd and retardation factor approach, the predicted uranium transport could still be described by an "effective" retardation factor, e.g., relative to the "effective" retardation factors for other modeled species. An estimate should be made of effective retardation factor for uranium, that would be consistent with the output of the reactive transport model, and the resulting predicted "effective" attenuation behavior for uranium should be further discussed and compared to observations or model predictions for other case studies/ similar sites, if available, and further discussion and evaluation provided in the context of demonstrating the suitability/adequacy of the modeling approach used.*

*The model results depicted on Figures M-3 and M-4 do not appear to show the initial concentrations for sulfate (62,847 mg/L) or uranium (24.3 mg/L) introduced at depth 0 feet. The initial concentrations should be shown.*

**REFERENCES**:

*Badv, K. and M. R. Faridfard. 2005. Laboratory determination of water retention and diffusion coefficient in unsaturated sand. Water, Air, and Soil Pollution, v. 161, no. 1-4, pp. 25-38*

*Barone, F. S.; R. K. Rowe, R. M. Quigley. 1990. Laboratory determination of chloride diffusion coefficient in an intact shale. Canadian Geotechnical Journal, v. 27, no. 2, (April), pp. 177-184.*

*Barone, F. S.; R. K. Rowe, R. M. Quigley. 1992. Estimation of chloride diffusion coefficient and tortuosity factor for mudstone. Journal of Geological Engineering, v. 118, no. 7, (July), pp. 1031-1046.*

*Bass-Becking, L.G.M., I.R. Kaplan, and D. Moore. 1960. Limits of the natural environment in terms of pH and oxidation-reduction potentials. Journal of Geology, v. 68, pp. 243 - 284.*

*Dames & Moore 1978. Environmental Report - White Mesa Uranium Project, San Juan County, Utah for Energy Fuels Nuclear, Inc. January 30.*

*Davis, J.A. , and G.P. Curtis, 2003. Application of Surface Complexation Modeling to Describe Uranium(VI) Adsorption and Retardation at the Uranium Mill Tailings Site at Naturita, Colorado, Report NUREG CR-6820, U. S. Nuclear Regulatory Commission, Rockville, MD., pp. 223.*

*Denison Mines (USA) Corp. 2010a. Round 1 – Interrogatory Response for the Cell 4B Design Report, White Mesa Mill Site, Blanding, Utah. January 2010.*

*Denison Mines (USA) Corp. 2010b. Second Round of Interrogatories from Review of License Amendment and Environmental Report for Cell 4B. DUSA Letter with attachment dated February 8, 2010.*

*Denison Mines (USA) Corp. 2010c. Second Round of Interrogatories from Review of License Amendment and Environmental Report for Cell 4B. DUSA Letter with attachment dated February 12, 2010.*

*Denison Mines (USA) Corp. 2010d. Revised Infiltration and Contaminant Transport Modeling Report, White Mesa Mill Site, Blanding, Utah (Revision 2), March 2010.*

*Garrels, R.M and C. L. Christ. 1965. Solutions, Minerals, and Equilibria. Freeman, Cooper & Company, San Francisco, California. 450 pp.*

*Giroud, J.P., King, T.D., Sanglerat, T.R., Hadj-Hamou, T., and Khire, M.V. 1997. Rate of Liquid Migration Through Defects in a Geomembrane Placed on a Semi-Permeable Medium", Geosynthetics International, Vol. 4, Nos. 3-4, pp. 349-372.*

*International Uranium (USA) Corporation (IUC). 2000. Reclamation Plan – White Mesa Mill, Blanding, Utah. Source Material Reference No. SUA-1358. Docket No. 40-8681. Rev. 3, July.*

*Kincaid, C. T., J. W. Shade, G. A. Whyatt, M. G. Piepho, K. Rhoads, J. A. Voogd, J. H. Westsik, Jr., M. D. Freshley, K. A. Blanchard, B. G. Lauzon. 1995. Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford, WHC-SD-WM-EE-004, Rev. 1, Westinghouse Hanford Company. Richland, WA.*

*Rowe, R. K. and K. Badv. 1996. Chloride migration through clayey silt underlain by fine sand or silt. Journal of Geotechnical Engineering, v. 122, no. 1 (January), pp. 60-68.*

*UMETCO Minerals Corporation 1993. Peel Environmental Services. Groundwater Study, White Mesa Mill. January.*