State of Utah
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Governor

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Lieutenant Governor

Department of
Environmental Quality

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Executive Director

DIVISION OF RADIATION CONTROL
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Director

FILE FEB 8 2013 SR

February 7, 2013

Harold Roberts
Executive Vice President and Chief Operating Officer
Energy Fuels Resources (USA) Inc.
225 Union Blvd., Suite 600
Lakewood, CO 80228

DRC-2013-001243

RE: Radioactive Material License (RML) Number UT 1900479: Review of September 10, 2012 Energy Fuels Resources (USA) Inc. Responses to Round 1 Interrogatories on Revised Infiltration and Contaminant Transport Modeling (ICTM) Report, White Mesa Mill Site, Blanding, Utah, report dated March 2010

Dear Mr. Roberts:

Enclosed is URS Professional Solutions' review of Energy Fuels Resources responses to the Round I Interrogatories. The enclosed table (Table 1) and attached Technical Memorandum (Attachment A – Rev. ICTM Report Round 1 [Rd 1] Interrogatories, Responses, and Discussion) document the results of URS Professional Solutions' (Professional Solutions') review, conducted on behalf of the Utah Division of Radiation Control (the Division), of Energy Fuels Resources (USA) Inc.'s (EFR's) Responses to Round 1 (Rd 1) Interrogatories submitted by the on Revised ICTM Report dated March 2010 prepared by Denison Mines (USA) Corp. (now EFR).

Table 1 presented below is intended to succinctly state additional analyses and information required, to enable the Division to thoroughly evaluate EFR's Revised Infiltration and Contaminant Transport Modeling report and responses to the Round 1 Interrogatories previously submitted on that report. Salient additional information requested from EFR is summarized in the third column of the table. The table summarizes remaining technical issues related to the Revised ICTM Report (and associated appendices and other supporting documents), identifies additional actions, analyses, and/or revisions that are requested from EFR in conjunction with the review of the Revised ICTM Report in order to allow these identified issues to be adequately evaluated and resolved.

Attachment A restates the Rd 1 interrogatories the Division transmitted to EFR on the Revised ICTM Report, repeats EFR's responses to those interrogatories, and provides discussion summarizing the results of the review of each response. The Rd 1 Interrogatories and EFR's

Responses to those interrogatories are summarized in the same order in which the Rd 1 Interrogatories were originally submitted.

If you have any questions regarding this letter or the enclosure, please feel free to contact me at 801-536-4263.

Sincerely,

John Hultquist, Section Manager
LLRW/Uranium Mill Licensing Section

JH:jh

Cc: Jo Ann Tischler, Director, Compliance and Permitting

URS

Technical Memorandum

Date:	February 6, 2013 UT11.1102.004 OUT
To:	**John Hultquist, Utah Division of Radiation Control**
From:	Jon Luellen, URS Professional Solutions Robert Baird, URS Professional Solutions
Subject:	**Review of September 10, 2012 Energy Fuels Resources (USA) Inc. Responses to Round 1 Interrogatories on Revised Infiltration and Contaminant Transport Modeling Report, White Mesa Mill Site, Blanding, Utah, report dated March 2010**

The enclosed table (Table 1) and attached Technical Memorandum (Attachment A – Rev. ICTM Report Round 1 [Rd 1] Interrogatories, Responses, and Discussion) document the results of URS Professional Solutions' (Professional Solutions') review, conducted on behalf of the Utah Division of Radiation Control (the Division), of Energy Fuels Resources (USA) Inc.'s (EFR's) Responses to Round 1 (Rd 1) Interrogatories submitted by the on Revised ICTM Report dated March 2010 prepared by Denison Mines (USA) Corp. (now EFR).

Table 1 presented below is intended to succinctly state additional analyses and information required, in Professional Solutions' opinion, to enable the Division to thoroughly evaluate EFR's Revised Infiltration and Contaminant Transport Modeling report and responses to the Round 1 Interrogatories previously submitted on that report. Salient additional information requested from EFR is summarized in the third column of the table. The table summarizes remaining technical issues related to the Revised ICTM Report (and associated appendices and other supporting documents), identifies additional actions, analyses, and/or revisions that are requested from EFR in conjunction with the review of the Revised ICTM Report in order to allow these identified issues to be adequately evaluated and resolved.

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TECHNICAL MEMORANDUM

WHITE MESA MILLSITE – REVISED ICTM REPORT REVIEW

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COVER DESIGN OR ASSOCIATED ISSUE(S)	APPLICABLE REPORT SECTION(S) &/or INTERROGATORY RESPONSE ITEM(S)	REQUIRED ADDITIONAL PLANS, ANALYSES, &/or REVISION(S)	APPLICABLE REGULATORY CRITERIA AND GUIDELINES
INCONSISTENCIES BETWEEN REVISED ICTM REPORT AND RECLAMATION PLAN REV 5.0 (ISSUES RELATED TO PROPOSED COVER DESIGN)			
<u>Inconsistencies between Revised ICTM Report and Reclamation Plan, Revision 5 0</u> – In general, the Division has a concern that the infiltration modeling has not conservatively accounted for changes that could be expected to occur in the properties of the cover system soils over the service life of the cover that would alter/degrade the cover system with respect to its ability to limit future infiltration rates through the cover	EFR Response to Round 1 Interrogatory INT 01/1 on Revised ICTM Report – "Inconsistencies Between Revised ICTM Report and Reclamation Plan Rev 5.0" (09/10/12)	(See Section 1.0 of the Technical Memorandum for Details) With respect to infiltration modeling, the Division requests that EFR· EITHER more conservatively model the saturated hydraulic conductivity values of cover-system soils increasing over time to more conservatively account for changes that could be expected to occur in the properties of the cover system soils over the service life of the cover, due to animal burrows potentially excavating to deeper depths than currently estimated, potentially deeper plant root penetration depths than currently predicted, frost damage, desiccation, distortion, reduction in levels of, or loss of, vegetation due to seed or plant predation, dry periods, or other possible causes, or any other process that would alter/degrade the cover system and/or otherwise reduce its ability to limit future infiltration rates through the cover, OR Propose incorporating alternative components into cover system design or propose to revise the cover design to better deter such expected alterations from ever occurring.	UAC R313-24-4/ 10CFR 40 Appendix A; NRC 2003a, Sections 2.5.3 and 5.1.3; Benson et al 2011
<u>Inconsistencies between Revised ICTM Report and Reclamation Plan, Revision 5 0</u> – The infiltration modeling input assumptions have not conservatively accounted for changes in soil properties within the maximum penetration depth frost-damaged portion of the proposed ET cover	EFR Response to Round 1 Interrogatory INT 01/1 on Revised ICTM Report – "Inconsistencies Between Revised ICTM Report and Reclamation Plan Rev 5 0" (09/10/12)	(See Section 1.0 the Technical Memorandum for Details) EFR should complete an additional sensitivity analysis which incorporates modifications to the soil hydraulic properties in a manner that reflects the likely increased saturated hydraulic conductivity and alpha parameter expected to occur in cover soils in the maximum potentially impacted soil zone damaged due to freeze/thaw processes, or other forms of soil structure development or pedogenesis. Parameters that should be modified may include residual and saturated soil water contents, soil water retention function parameters alpha and n, and saturated hydraulic conductivity. The soil hydraulic	UAC R313-24-4/ 10CFR 40 Appendix A, NRC 2003a, Sections 2 5 3 and 5 1 3, Benson et al. 2011

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		parameter modifications should be adjusted in a manner that either is consistent with NRC recommendations for adjusting similar properties in this soil zone when estimating radon flux emanation (U.S. NRC 2003a, Section 5 1 3), or consistent with Benson et al. 2011 recommendations, whichever is more conservative for use in infiltration modeling Provide information demonstrating that the specific adjustments used in the infiltration modeling sensitivity analysis provide the most conservative results (See also discussion under Response to Rd 1 Interrogatory 02/1 on Revised ICTM Report below).	
<u>Cover Revegetation Plan Objectives, Goals and Details/ Anticipated Effectiveness of Vegetation in Promoting Evapotranspiration in ET Cover [Note: See also summary table in "Technical Memorandum</u> – White Mesa Mill Site Rev. 5 0 Reclamation Plan Review"] – The information presented is not sufficient to demonstrate that vegetation cover will be sustainable over the long term and that it will be effective in promoting evapotranspiration Additional information also needs to be provided to support/defend the range of root density values listed in Table 01/3-1 of EFR's Response to this interrogatory item.	EFR Response to Item No 3 of Round 1 Interrogatory 01/1 on Revised ICTM Report (09/10/12) EFR Revised Attachment G (Revised Appendix D, Vegetation and Biointrusion), to the Updated Tailings Cover Design Report, (08/15/12)	(See Section 1.0 the Technical Memorandum for details) Provide information on current vegetation on previously revegetated areas at the White Mesa Mill Site and the history of revegetation efforts and results at the site. Provide more detail on the results of vegetation surveys conducted in June 2012. Provide a map of current vegetation Provide information on soil properties at reference areas to document that "sustainable levels" are achievable. Provide additional information on procedures to be used during soil amendment and weed management practices to be employed. In the discussion of succession, address regionally common shrub species that may colonize the site from lower elevation, warmer and drier sites. Provide example root density calculations showing how the estimated root density values were derived Re-evaluate and further demonstrate that use of specific information contained in reference sources cited by EFR as the basis for deriving estimated root densities in soil are valid/appropriate for the semi-arid conditions at the White Mesa site. Revise the root density estimation approach and estimated range of root densities in the cover as needed based on this re-evaluation.	UAC R313-24-4/10CFR 40 Appendix A

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Biointrusion (Cover) Hazard Evaluation [Note: See also summary table in "Technical Memorandum – White Mesa Mill Site Rev. 5.0 Reclamation Plan Review"] – No specific biointrusion barrier is proposed to be incorporated in the ET Cover. Without a biointrusion barrier, the information presented in the EFR Response is not sufficient to demonstrate that biointrusion is unlikely to occur from shrub roots and burrowing mammals	EFR Response to Item No. 3 of Round 1 Interrogatory 01/1 on Revised ICTM Report, (09/10/12) EFR Revised Attachment G (Revised Appendix D, Vegetation and Biointrusion), to the Updated Tailings Cover Design Report (08/15/12)	(See Section 1 0 the Technical Memorandum for details) Provide documented, more-detailed information on the results of plant and animal surveys completed at the site in June 2012, provide additional discussion and analysis of those findings in the context of relevant published data obtained from other similar sites having similar site environmental conditions, similar soils types, and similar plant and animal species and distributions, and discuss potential applications to cover-system biointrusion. Provide a range of data on reported burrowing depths and revisit maximum numbers of burrows to ensure that they have been accurately and conservatively stated. Further address the range of rooting depths of shrubs that may colonize the revegetation areas, including consideration of additional information provided in the Technical Memorandum herein. Provide a literature review or observations to document that plant roots are unlikely to extend into compacted soils.	UAC R313-24-4/10CFR 40 Appendix A
COMPARISON OF COVER DESIGNS, SENSITIVITY ANALYSES, 'BATHTUB' ANALYSIS, AND RADON EMANATION MODELING			
Minimize Infiltration/Encourage Runoff [Note: See also summary table in "Technical Memorandum – White Mesa Mill Site Rev. 5.0 Reclamation Plan Review"] – The currently proposed ET cover design does not adequately ensure that infiltration rates into the tailings will be continue to be minimized throughout the cover's performance period of 200 to 1,000 years, given the likely/ potential effects of a range of future postclosure external environmental, biogenic/ biological, and physical processes on the cover, and geomechanical effects of potential differential settlement in tailings cells, especially Cells 2 and 3, on cover slopes, especially the cover topslope areas.	EFR Response to Round 1 Interrogatory INT 02/1 on Revised ICTM Report – "Comparison of Cover Designs, Sensitivity Analyses, 'Bathtub Analysis, and Radon Emanation Modeling" (09/10/12) Revised ICTM Report, Sections 3.3, 4.0, 5.1, and Appendices D through G of the Revised ICTM Report	(See Section 2 0 the Technical Memorandum for details) Based on the information and considerations presented in Section 2 0 of the Technical Memorandum, the Division requests that the cover incorporate a capillary barrier, or alternatively, provide detailed analyses and additional infiltration sensitivity analyses that demonstrate that a capillary barrier is not warranted, and incorporate a specifically designed biointrusion barrier component, and EITHER Increase the inclination in the proposed ET cover, especially over tailings Cells 2 and 3, to a minimum of 2-3 %, OR	UAC R313-24-4/ 10CFR 40 Appendix A, Criterion 4; NRC 2003a, Sections 2.3, 2.7, and 4 1

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		(1) provide detailed consolidation and 2D/3D numerical settlement analyses to demonstrate that future differential settlement will not result in slope reversal/ponding at any location in the proposed cover, and (2) conduct compacted clayey soil laboratory distortion tests to demonstrate that future differential settlement will not compromise the physical integrity and continuity of the cover system throughout the cover's required performance period of200 to 1,000 years.	
Revised Bathtubbing Analysis – The infiltration analyses presented in the Revised ICTM Report and described in the Response to the Round 1 Interrogatories on the Revised ICTM Report and on the Rev 5.0 Reclamation Plan are not sufficiently conservative to bound the uncertainty associated with possible future flattening of the cover topslope inclination, the range of potential future changes in climate conditions, and the possibility that vegetation on the cover may fail at some point in the future during the cover's service life, and does not incorporate sufficiently conservative estimated liner system leakage rates Additional information also needs to be provided on the possible effects of higher infiltration rates through the (rock riprap-covered) sideslopes on bathtubbing, under such assumed reasonably worst-case conditions	EFR Response to Round 1 Interrogatory INT 02/1 on Revised ICTM Report – "Comparison of Cover Designs, Sensitivity Analyses, 'Bathtub Analysis, and Radon Emanation Modeling" (09/10/12)	(See Section 2 0 the Technical Memorandum for details) The Division recommends that the value of infiltration used in the infiltration sensitivity analysis scenario for evaluating the potential for bathtubbing be the highest average infiltration obtained from the full range of model infiltration scenarios considered and that the analysis reflect results of additional adjustments made to infiltration model input parameters in response to all preceding items/issues described in this table , and that the same scenario include the following additional assumptions· (i) assumed maximum (upper bound) assumed hydraulic conductivities for the cover soils; (ii) the assumption of no shrub vegetation on the ET cover and no grass vegetation (or alternatively, if adequately supported by available data from other similar sites, a grass vegetation cover percentage lower than the 30% lower bound value currently assumed) , (iii) the assumption of a flattened topslope inclination (unless the topslope inclinations in the current proposed cover design are increased to a minimum of 2 to 3 %) and (iv) an assumption that liner conditions in tailings cells have the lowest geomembrane defect sizes and frequencies and least permeable soil/GCL underliner or /underlay values (effectively yielding the lowest overall calculated leakage rates)that EFR assigned/ estimated in its cell liner leachate leakage	UAC R313-24-4/10CFR 40 Appendix A

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		analyses. EFR also needs to provide additional information on infiltration rates through the sideslope portions of the proposed cover and the potential effects of enhanced infiltration rates through the sidelopes and potential impacts from "edge effects" (considering the geometric relationship of sideslope areas relative to areas covered by the cell liners and the potential for lateral (inward) migration of moisture on bathtubbing, under the above-described reasonably worst-case assumed conditions.	
MOISTURE STORAGE CAPACITY OF COVER			
<u>Moisture Storage Capacity of Cover</u> – The infiltration analyses presented in the Revised ICTM Report and described in the Response to the Round 1 Interrogatories on the Revised ICTM Report and on the Rev 5 0 Reclamation Plan are not sufficiently conservative to bound the uncertainty associated with possible future flattening of the cover topslope inclination, the range of potential future changes in climate conditions, and the possibility that vegetation fails on the cover at some point in the future during the cover's service life.	EFR Response to Round 1 Interrogatory INT 03/1 on Revised ICTM Report – "Moisture Storage Capacity of Cover" (09/10/12)	(See Section 3.0 the Technical Memorandum for details) Similar to the assessment for potential for bathtubbing, the Division recommends that the value of infiltration used in the infiltration sensitivity analysis scenario for evaluating the cover soil moisture holding capacity be the highest average infiltration obtained from the full range of model infiltration scenarios considered, and that the same scenario include the following additional assumptions: (i) assumed maximum (upper bound) assumed hydraulic conductivities for the cover soils, (ii) the assumption of no grass vegetation on the ET cover; (iii) the assumption of a flattened topslope inclination (unless the topslope inclinations in the current proposed cover design are increased to a minimum of 2 - 3 %)	UAC R313-24-4/10CFR 40 Appendix A
OTHER COVER DESIGN-RELATED ISSUES			
<u>Long-Term Erosion Protection</u> [Note· See also summary table in "Technical Memorandum – White Mesa Mill Site Rev 5 0 Reclamation Plan Review"] – Existing erosion protection calculations and assumptions are considered valid only if. (1) uniform grading will have been achieved during construction, and (2) Differential settlement has been shown to be insignificant (i.e , sufficiently small in magnitude everywhere across the tailings	Sections 3.1, 4.1 and Appendices E, F and G of the Revised ICTM Report EFR Response to Round 1 Interrogatories 02/1and 03/1 on Revised ICTM Report (09/10/12)	(See Sections 2.0 and 3.0 the Technical Memorandum for details) EITHER Provide additional detailed information and data that demonstrate that: (1) The proposed ET cover can be constructed to a uniform grade throughout its entire surface area, (2) Differential settlement will be insignificant; and (3) Slope reversal/potential ponding of surface water on covers for other tailings	UAC R313-24-4/10CFR 40 Appendix A, Criterion 4, NUREG-1623, Section 2 4

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embankment area to preclude flattening of topslope surface in any portion of the cover surface).		repository cover systems that have been constructed to a similar range of topslope inclinations and surface areas to those proposed has not, and will not, occur during the 200 – 1,000 year-long required performance period of those covers; OR Increase the inclination in the proposed ET cover, especially over tailings Cells 2 and 3, to a minimum of 2-3 %.	
<u>Suitability of Soils Tested in April 2012 for Use in Constructing ET Cover</u> – The results of April 2012 soil testing suggest that the on-site soils tested appear to be suitable for establishment of vegetation cover, with the use of soil amendments as discussed in Attachment G submitted by EFR in its Response. However, the Reclamation Plan, and specifically, Attachment G, do not provide sufficient information on the types, amounts, sources, methods of application, estimated costs, and limitations of the potential amendments that are discussed to demonstrate that use of the on-site soils will be suitable and cost-effective. The Revised ICTM Report, and the Rev 5 0 Reclamation Plan and Appendix G also do not provide sufficient details regarding future contingency measures that would be implemented for rectifying cover revegetation problems if they occur	EFR's Response to Round 1 Interrogatory 02/1 on the Revised ICTM Report (09/10/12)	(See Section 2.0 the Technical Memorandum for details) EITHER: Provide additional information in Attachment G to the Reclamation Plan, to allow the Division to determine that sufficient information has been provided on the types, amounts, sources, methods of application, estimated costs, and limitations of the potential soil amendments/ soil amendment practices to demonstrate that use of the on-site soils will be suitable and not cost-prohibitive. Further substantiate/demonstrate that use of the on-site soils will be adequate to facilitate sustainable performance of the cover with respect to the establishment and sustainability/longevity of vegetation on the cover for promoting evapotranspiration throughout the cover performance period (200 to 1,000 years). Provide additional details regarding maintenance and contingency measures (cover soil replacement, inspections, animal removal, multiple nutrient applications, etc...) for rectifying revegetation problems if they occur. Provide information demonstrating that such proposed future measures, if required, are reasonable and reflective of cover revegetation remedies that have been required/shown to be effective for other similar facilities (e.g., Monticello tailings repository),	UAC R313-24-4/10CFR 40 Appendix A, Criterion 4, Benson et al. 2011, NUREG-1620 (e g., Sections 2.0 and 5 1)

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		OR, alternatively, Explain a plan for use of alternate soils, or the need for bentonite amendment of these higher-K_{sat} soils, if necessary, for constructing the cover, in order to satisfy applicable long-term cover design (e g., infiltration reduction) objectives, considering the results of additional infiltration sensitivity analyses using these amended soils that include more conservative assumptions regarding the effects of potential long-term changes in properties of these amended soils in the completed cover.	
EVALUATION OF FLOW THROUGH TAILINGS CELL LINERS			
<u>Evaluation of Flow Through Liners in Tailings Cells 2 and 3</u> – The information presented is not sufficient to demonstrate that significant leakage has not occurred/is not occurring from Cells 2 and/or 3, and the potential range of possible leakage rates from these two cells has not been conservatively estimated, considering the site and liner conditions and dewatering systems installed these two cells compared to liner conditions and the dewatering systems installed in Cells 4A and 4B.	Appendix L (Evaluation of Potential Flow through Tailings Cell Liners) of the Revised ICTM Report	(See Section 4.0 the Technical Memorandum for details) Revise conclusions presented in the Response to reflect a more conservative range of assumptions and results of revised analyses incorporating those more conservative assumptions, that coincide more closely with current site information and conditions. Revise and provide results of an additional leakage calculation or calculations incorporating a more conservative value of hydraulic conductivity for the compacted crushed sandstone, concrete sand layer or compacted bedrock material underlying the synthetic liners in Cells 2 and 3, or, alternatively, provide additional information to justify that the range of values currently used in the liner leakage analysis for Cells 2 and 3 conservatively represent the full range of materials that comprise portions of that underlay layer or compacted bedrock material; , Quantify the degree to which the revised analyses result in flux rates through the liner systems in Cells 2 and 3 indicate higher leakage rates than leachate flux rates currently observed through the primary liners in Cells 4A and 4B, under all comparable assumed operational conditions and all assumed	UAC R313-24-4/10CFR 40 Appendix A, Criterion 1

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		liner defect frequencies; and revised underlay layer/compacted bedrock hydraulic conductivity; and Provide a detailed travel time calculation or calculations, analogous to those discussed on p. 38 of 70 in "Response 1 (May 31, 2012)", but that instead calculate the vertical transport time of constituents potentially seeping from directly below the base of Cells 2 and 3 through the in- situ vadose zone bedrock materials to the top of the perched water zone Include information on the hydraulic conductivity value(s) assumed and the effective field porosity value assumed for the bedrock materials and provide a basis for the value assumed (i.e field measurements). Alternatively, if no single value of effective porosity is available or appropriate for the site, provide a range of assumed effective porosity values and use this range in the travel time calculations Compare the value(s) of effective porosity used to the default value of 10 percent recommended for use by NRC at Title I UMTRCA sites in Section 4.3.1.3.2 of NRC 1993 (considered by the Division to be a relevant conservative default value for this type of analysis).	
CONTAMINANT TRANSPORT MODELING			
<u>Potential Presence and Distribution of Fractures and/or Joints and Uncemented/Higher Permeability Intervals in the Unsaturated Zone Beneath/Downgradient of Tailings Management Cells Area</u> – Additional information needs to be provided and evaluated to assess whether new data confirms, refutes, or revises EFR's interpretation as provided in the Response to Item No 1 of this Round 1 interrogatory	EFR Responses to Round 1 Interrogatories on Revised ICTM Report (05/31/12) Revised ICTM Report, Sections 2.2 and 4.3	(See Section 5.0 the Technical Memorandum for details) Provide additional geologic data for the wellbores for Wells MW-33 through MW-35 and provide an evaluation and interpretation of those data with respect to the potential occurrence and distribution of fractures and uncemented/higher permeability intervals downgradient of the Cell 4 B/ tailings management cells area Corroborate, supplement and/or revise the interpretation provided in the Response to Item 1 of Rd Interrogatory 05/1 to reflect the results of EFR's evaluation of this new additional wellbore data.	UAC R313-24-4/10CFR 40 Appendix A

TABLE 1. SUMMARY OF REQUIRED ADDITIONAL ANALYSES AND REMAINING TECHNICAL ISSUES

COVER DESIGN OR ASSOCIATED ISSUE(S)	APPLICABLE REPORT SECTION(S) &/or INTERROGATORY RESPONSE ITEM(S)	REQUIRED ADDITIONAL PLANS, ANALYSES, &/or REVISION(S)	APPLICABLE REGULATORY CRITERIA AND GUIDELINES
Input Parameters - Geochemistry	EFR Responses to Round 1 Interrogatories on Revised ICTM Report (05/31/12 and 08/15/12) Revised ICTM Report, Section 3 4 4 Input Parameters, Geochemistry (p 3-13 and 3-14). Revised ICTM Report, Appendix C.	(See Section 5.0 the Technical Memorandum for details) The statistical analyses of the geochemical data for HFO and ANP presented in Appendix C appear to be incorrect based on misconceptions about the use of the geometric mean and geometric standard deviation for lognormally distributed data. Please revise the statistics for HFO and ANP, re-run the model sensitivity analyses, and revise the text, tables, and figures as appropriate. Alternatively, the most conservative HFO and ANP values can be used in the model based on the geometric mean divided by 2 geometric standard deviations.	UAC R313-24-4/10CFR 40 Appendix A
Input Parameters - Geochemistry	EFR Response to Round 1 Interrogatory 05/1 on Revised ICTM Report (05/31/12) Revised ICTM Report, Sections 2 2 and 4.3.	(See Section 5.0 the Technical Memorandum for details) Please provide further discussion of the rationale used for selecting a bulk density value of 2.0 g/cm^3 for bedrock for use in converting ANP and HFO values from rock mass to rock unit volume. Discuss locations of core samples considered with respect to: (1) locations of core boreholes with respect to the different disposal cells; and (2) the depth intervals of the core sample intervals considered with respect to the thickness of the vadose zone at each core interval location. Further justify the value of bulk density chosen (or different bulk density values that may be selected for use at different locations), including need for excluding any core intervals that lie within the saturated zone Please revise any affected calculations, re-run the model, and revise the ICTM report, as appropriate	UAC R313-24-4/10CFR 40 Appendix A
Input Parameters - Flow	EFR Responses to Round 1 Interrogatories on Revised ICTM Report (05/31/12 and 08/15/12) Revised ICTM Report, Appendix M, p. M-11	(See Section 5 0 the Technical Memorandum for details) Provide additional justification for establishing the initial soil water pressure heads within the bedrock vadose zone as those resulting from a recharge rate equal to 1 percent of the average annual amount of	UAC R313-24-4/10CFR 40 Appendix A

TABLE 1. SUMMARY OF REQUIRED ADDITIONAL ANALYSES AND REMAINING TECHNICAL ISSUES

COVER DESIGN OR ASSOCIATED ISSUE(S)	APPLICABLE REPORT SECTION(S) &/or INTERROGATORY RESPONSE ITEM(S)	REQUIRED ADDITIONAL PLANS, ANALYSES, &/or REVISION(S)	APPLICABLE REGULATORY CRITERIA AND GUIDELINES
		precipitation when 1 percent appears to be a the lower end of recharge rates for similar sites, or provide sensitivity analyses varying the initial average annual recharge rate within a reasonable range (e.g., 1 to 5 %) to demonstrate that 1 percent is acceptable and to demonstrate the sensitivity of the model results to the initial volumetric water contents and pressure head distributions.	
Contaminant Transport Governing Equation	Revised ICTM Report, Section 2 3.2 (p 2-18).	(See Section 5.0 the Technical Memorandum for details) Revise the governing equation for contaminant transport to include the internal source or sink for water ($Sc_{r,i}$) as shown in Equation 2.5 in Jacques and Simunek (2005) or provide justification for leaving the expression as is.	UAC R313-24-4/10CFR 40 Appendix A
Input Parameters - Source Term Concentrations	Revised ICTM Report, Section 3 4 4 Input Parameters, Source Term Concentrations (p. 3-13).	(See Section 5 0 the Technical Memorandum for details) Please revise the source term concentrations using geometric means and geometric standard deviations which is typically done for concentration data that are usually lognormally distributed or provide an adequate justification for using arithmetic mean and standard deviations.	UAC R313-24-4/10CFR 40 Appendix A
Input Parameters – Geochemistry	Revised ICTM Report, Appendix M (p M-10).	(See Section 5 0 the Technical Memorandum for details) Please show the calculation, including the appropriate units, used to develop the model term described as "the mass of HFO per unit volume of bedrock was 1.8 " Clarify, as appropriate, how these data and units are consistent with those discussed on p. M-10, p. C-5 and C-7, and shown on Figure C-4	UAC R313-24-4/10CFR 40 Appendix A
Sensitivity Analysis	Revised ICTM Report, Section 3 4 7 Sensitivity Analysis (p. 3-15).	(See Section 5.0 the Technical Memorandum for details) Please revise the sensitivity analysis section, as well as other portions of the Revised ICTM report, as appropriate, based on above comments/concerns.	UAC R313-24-4/10CFR 40 Appendix A

ATTACHMENT A
Rev. ICTM Report Rd 1 Interrogatories, Responses, and Discussion

1.0 Inconsistencies Between Revised ICTM Report and Revised Reclamation Plan

Round 1 (Rd 1) Interrogatory INT. 01/1 items related to the currently proposed ET cover design, EFR's Responses to those interrogatories, and the Division's findings based on review of those Responses, are discussed in the following section.

1.1 Round 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1: Inconsistencies Between Revised ICTM Report And Reclamation Plan Rev 5.0

Interrogatory White Mesa Revised ICTM Report ; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1: "Inconsistencies Between Revised ICTM Report And Reclamation Plan Rev 5.0" -– Referencing the 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, THE INTERROGATORY REQUESTED, that EFR do the following:

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"; and

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.

1.2 EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1: <u>Inconsistencies Between Revised ICTM Report And Reclamation Plan Rev 5.0</u>

IN ITS RESPONSE to the first two items of above interrogatory, EFR indicated the following:

- *"The Revised Infiltration and Contaminant Transport Modeling (ICTM) Report was submitted during March 2010 and was meant to introduce the conceptual design of an evapotranspiration (ET) cover. Infiltration modeling contained within the 2010 Revised ICTM Report indicated that the design and construction of a monolithic ET cover is the preferred alternative for infiltration control. The construction of an ET cover as proposed in the 2010 Revised ICTM Report was in contrast to previous iterations of the Reclamation Plan that were based on the cover design from 1996. Therefore, the Reclamation Plan Revision 5.0 submitted during September 2011 used the initial March 2010 conceptual design of the ET cover as a starting point, but modified some of the material descriptions and thicknesses to provide an update to the analyses based on additional information subsequently collected after the 2010 Revised ICTM Report was submitted. The gap in time between publication of these two reports, combined with the collection of additional soils data between March 2010 and September 2011, explains the* *discrepancy between reports. Consequently, the material layering, thicknesses, and physical characteristics presented in the next iteration of the ICTM Report including text, figures, and tables will be consistent with next iteration of the Reclamation Plan.*

- *In addition to the response to Comment One of this interrogatory, the analyses presented in the next iteration of the ICTM Report including information and analyses presented in the appendices will be consistent with the next iteration of the Reclamation Plan. Applicable appendices that would be updated include Appendices E, F, G, H, and N. However, as discussed later in this interrogatory response document, we propose eliminating Appendix F from the next iteration of the Report to minimize confusion."*

IN ITS RESPONSE to the third item of above interrogatory, EFR indicated that:

"The next iteration of the ICTM Report will include an updated Appendix D that reflects the request for additional information (i.e., vegetation occurrence and proposed revegetation plan). Revisions to Appendix D will be consistent with material presented in Attachment G included with Denison's August 15, 2012 Responses to the Reclamation Plan, Revision 5.0 Interrogatories (Denison 2012b). Overall, supporting text was updated to:

- *Include the results of a plant and burrowing animal survey that was completed at the mill site during June 2012.*
    - *The results of the plant survey were used to support the range of percent vegetative cover and root density/distribution for plant species that are expected to occur on the cover during the design performance period;*
    - *The plant survey, and the similarity in environmental conditions between Monticello and White Mesa, suggests that a plant cover estimate of 40% is a reasonable estimate for a long-term average, while a percent plant cover of 30% is a reasonable estimate for a reduced performance scenario. The root density/distribution for plants species expected to occur on the cover is summarized in Table 01/1/3-1; and*
- *Include a discussion regarding the sustainability of the cover system as it relates to potential climate change and plant community succession and potential for species colonization.*
    - *From the review of climate change literature applicable to the southwest United States and an analysis of the impact of various climate change scenarios, the most likely plant community type that will be maintained throughout the 200 to 1,000 year performance period is a community dominated initially by cool season grasses, with a long-term transition to dominance by warm season grasses as atmospheric CO2 and*

temperature continues to increase and precipitation decreases and shifts from winter storage to pulse dominated; and

- *While shrubs such as big sagebrush could establish through natural succession during the short-term, it is unlikely that big sagebrush will be sustainable on site, but it is likely to establish through natural succession before the effects of climate change alter the environment.*

Table for Response 3 (September 10, 2012):

Table 01/1/3-1. Root biomass for species expected to occur on the cover system

Depth (cm)	*Root Biomass Density, Anticipated Performance (g/cm³)*	*Root Biomass Density, Reduced Performance (g/cm³)*
0-15	*0.11*	*0.04*
15-30	*0.17*	*0.12*
30-45	*0.035*	*0.02*
45-60	*0.023*	*0.015*
60-75	*0.021*	*00.014**
75-90	*0.019*	*0.0*
90-107	*0.011*	*0.0*

*Note: * Maximum rooting depth under the reduced performance scenario would be 68 cm."*

IN ITS RESPONSE (EFR Response 4a), to the fourth item of above interrogatory, EFR indicated the following:

"Frost Penetration

The frost penetration analysis for the tailings cover system was revised and presented in Denison (2012a) to address interrogatories for the Reclamation Plan, Revision 5.0 (DRC, 2012). This analysis again will be updated after approval of the conceptual final cover design is obtained. Revisions will be completed to be consistent with the revised cover design presented in the August 15, 2012 responses to the interrogatories for the Reclamation Plan, Revision 5.0

(Denison, 2012b). The frost penetration analysis requires revision to incorporate additional data collected from a site investigation conducted on April 19, 2012 to further evaluate cover borrow materials. It is anticipated that the results of the updated analyses will be similar to the analyses presented in Denison (2012a), with a frost penetration depth on the order of 81 cm (32 in).

Pedogenic Processes

Soil cover layers and their respective hydraulic and physical material properties potentially could be affected from wet/dry, freeze/thaw, and other pedogenic processes as suggested by Benson et al. (2011). However, as noted in Benson et al. (2011), potential changes to the cover can be minimized by designing the cover system to be as close as practical to the anticipated equilibrium state under long-term conditions; furthermore, their study also noted that long-term changes are more prone to occur for less permeable soils compared to more permeable soils. Because the frost penetration depth is not anticipated to exceed the depth of the erosion protection and water storage layers (combined depth of 107 cm), a minor increase or decrease in the frost penetration depth will not affect the radon barrier and grading layers that are located beneath 107 cm. Therefore, any potential modifications to the hydraulic and physical properties of the cover that could be influenced by freeze/thaw processes would be restricted to the erosion protection and water storage layers.

Hydraulic test results for the soils stockpiled at White Mesa are within the range of parameter values anticipated to occur long-term as noted by Benson et al. 2011 (See Interrogatory 02/1, Response 1 of this Response. Based on this comparison, and the relatively permeable nature of the soils, corrections to account for potential pedogenic processes are not warranted at this time because the physical and hydraulic properties at the emplaced conditions are such that postconstruction changes should be minimal."

IN ITS RESPONSE (EFR Response 4b), EFR also stated the following:

"The cover model has been updated from those presented in the 2010 Revised ICTM Report (see also Interrogatory 02/1, Response 1 of this [Response] document, to reflect additional laboratory test results and revisions to the cover design as presented in Denison (2012b). In regard to the next iteration of the ICTM Report, applicable appendices that would be updated include Appendices E, F, G, H, and N. However, we propose eliminating Appendix F from the next iteration of the Report to minimize confusion.

Revisions to the amount of percolation that may recharge the tailings affects the "bathtub effect" calculations, and are discussed in Interrogatory 02/1, Response 1 in this Response set. These potential effects and resultant calculations will be incorporated into the next iteration of the ICTM Report.

IN ITS RESPONSE to the fifth item of above interrogatory, EFR indicated the following:

The updated frost penetration analysis will not affect the analyses presented in Appendix K (tailings pore water source term chemistry). For the calculations presented in Appendix L (potential water flux rates through the liners), flux rates predicted at the end of dewatering were assumed to equal the rate during post-closure conditions. This approach was incorporated as an appropriate simplification based on discussions and comments previously received by the Division (DRC, 2009) and responses provided by MWH (2009). Additionally, the upper boundary condition assigned in Appendix M (reactive flow and transport model through the bedrock vadose zone) used the flux calculations presented in Appendix L. Therefore Appendices K, L, and M do not require revision based on modifications to the frost penetration analysis. Appendix N (model input/output files) will require revision once the infiltration modeling is updated and a future iteration of the ICTM Report is submitted."

1.3 Division's Assessment of EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1

Based on review of the information provided in the above EFR Response(s), the Division has concern that the argument provided by EFR that post-construction changes in soil properties at the White Mesa site should be minimal is not adequately-supported, e.g., it does not accord with published data, which show significant changes occur over time with nearly all soils, some more than others. EFR has not adequately demonstrated that the cover system has necessarily been designed to be close to the anticipated equilibrium state under long-term conditions, considering the many processes that can potentially disturb the soil over time in the currently designed cover system. These include freeze-thaw cycles, potential soil desiccation during drier climate episodes, reduction of or loss of vegetation in the cover, and deeper animal burrowing depths and deeper plant root penetration than currently estimated by EFR (see Section 11.3 of the Technical Memorandum and Table documenting the Division's review of EFR's Responses to the Rd 1 Interrogatories on the Rev 5.0 Reclamation Plan for additional details), coupled with the exacerbation of potential long-term biointrusion impacts due to the absence of a specifically designed biointrusion barrier in the currently proposed cover

Additional technical information needs to be provided to support the contention that post-construction changes in soil properties in the cover at the White Mesa site should be minimal. At a minimum, such information should include technical data on cover soil characteristics from other similarly-constructed soil cover systems using similar soils and at a site having climate, soils, and vegetation and animal species and population characteristics similar to those present at the White Mesa site. Such data should be acquired within several years (e.g., 5-10 years) after initial cover construction. Based on the April 2012 on-site soils testing, the geometric mean saturated hydraulic conductivity of soils expected to be representative of cover-system soils is approximately 9.5 x 10^{-4} cm/s (see data in Benson and Wang, 2012). This geometric mean saturated hydraulic conductivity value is outside (above) the range of values given above for long-term "terminal values"

expected for cover-system soils (8×10^{-6} to 6×10^{-4} cm/s [Benson et al. 2011). Therefore, the statement on Page 4 of 70 of the Response that "the hydraulic test results for the soils stockpiled at White Mesa are within the range of parameter values anticipated to occur long-term as noted by Benson et al. (2011)" is not technically correct. Although the magnitude of changes in hydraulic conductivity values that might be expected to occur in the cover using soils having the range of saturated hydraulic conductivity values determined from the April 2012 soil stockpile tests would likely be less than for a cover initially constructed with lower-permeability soils, data are limited and insufficient data have been provided to demonstrate EFR's contention that that post-construction changes in soil properties at the White Mesa site should be minimal.

Based on the above considerations, the Division requests that, for modeling purposes, EFR more conservatively model the saturated hydraulic conductivity values of cover-system soils increasing over time. Alternatively, EFR may propose incorporating alternative components into cover system design or propose to revise the cover design to better deter such expected alterations from ever occurring.

The Division also requests that EFR complete a sensitivity analysis by modifying the soil hydraulic properties (e.g., residual and saturated soil water contents, soil water retention function parameters alpha and n, and saturated hydraulic conductivity) in a manner consistent with the likely increased saturated hydraulic conductivity and alpha parameter expected in the maximum potentially impacted frost damage zone due to soil structure development. The soil hydraulic parameter modifications shonld be adjusted in a manner that either is consistent with NRC recommendations for adjusting similar properties in this soil zone when estimating radon flux emanation (U.S. NRC 2003a, Section 5.1.3), or consistent with Benson et al. 2011 recommendations, whichever is more conservative for infiltration modeling. Provide information demonstrating that the specific adjustments selected and used in the infiltration modeling sensitivity analysis provide the most conservative results (i.e., highest infiltration rate) (See also discussion under Response to Interrogatory 02/1 below).

EFR's response also addressed items in Interrogatory White Mesa RECPLAN Rev 5.0 R313-24-4; 10CFR40 Appendix A; Int. 11/1 relating to the "Vegetation and Biointrusion Evaluation and Revegetation Plan" by referring to new information presented in Revised Attachment G dated August 2012. Based on review of that document, the information presented is not sufficient to demonstrate that vegetation cover will be sustainable over the long term and that it will be effective in promoting evapotranspiration. The Division requests that EFR: (i) Provide information on current vegetation on previously revegetated areas at the White Mesa Mill Site and the history of revegetation efforts and results at the site; (ii) Provide more detail on the results of vegetation surveys conducted in June 2012; (iii) Provide a map of current vegetation; (iv) Provide information on soil properties at reference areas to document that "sustainable levels" are achievable; and (v) Provide additional information on procedures to be used during soil amendment and weed management practices to be employed. In the discussion of succession, EFR should address

regionally common shrub species that may colonize the site from lower elevation, warmer and drier sites.

Additional information also needs to be provided to support/defend the range of root density values listed in Table 01/1/3-1 of EFR's Response to Interrogatory 01/1, Item 3 on the Revised ICTM Report. The Division requests EFR provide example root density calculations showing how the estimated root density values were derived, and that EFR re-evaluate and further demonstrate that use of specific information contained in reference sources cited by EFR as the basis for deriving estimated root densities in soil are valid/appropriate for the semi-arid conditions at the White Mesa site. EFR should revise the root density estimation approach and estimated range of root densities in the cover as needed based on this re-evaluation (see discussion below). Additional comments on Revised (August 2012) Attachment G relative to sustainability of the vegetation cover and biointrusion issues are provided in Section 2.3 below and in the Technical Memorandum and Table documenting the Division's review of EFR's Responses to the Rd 1 Interrogatories on the Rev 5.0 Reclamation Plan.

In its Response, EFR indicated (Page D-13 in Revised Attachment G appended to the Response to the Rd 1 interrogatory) that the estimates of root density listed in Table D.7 of Revised Attachment G were based on the information contained in the following references: Bartos and Sims (1974), Sims and Singh (1978), Hopkins (1953), Lee and Lauenroth (1994), Jackson et al. (1996) and Gill et al. (1999)

In the Revised ICTM Report, stated root density values (e.g., 4.3 g/cm^3) were off by several orders of magnitude and were revised downwards in EFR's Response to the Rd 1 interrogatories. However, root density calculation results still appear to be in error considerably. No calculations are shown. The Division request that pertinent calculations be provided. Supporting references were not provided. However, references were cited on Page D-13 of the Revised Attachment G.

~~These references include Bartos and Sims (1974) and Sims and Singh (1978), who are also~~ referenced in regard to this topic in the original Revised ICTM Report. These particular references are not for semi-arid-zone plants but for grasses in other biomes, where root density may be greater than is realistic to assume for plants in a semi-arid environment. Use of t data from those references therefore may not be appropriate for describing root density in the cover-system soils at White Mesa under semi-arid conditions. Values obtained using those data should therefore be reconsidered when making application to synthetic soils in a different environment in southeastern Utah. Please address this issue and justify, if possible, the use of Bartos and Sims (1974) and Sims and Singh (1978).

Bartos and Sims (1974) reported yearly-averaged densities of shortgrass at four sites in Ft. Collins, Colorado of up to 1309 g/m^2 in the upper 80 cm of soil. Dividing 1309 g/m^2 by 0.80 m yields 1636 g/m^3, or 1.6 x 10^{-3} g/cm^3 for a[n average, near-surface] root density on a per-volume basis. This value is one to two orders of magnitude smaller than what is claimed in

Table 1/1/3-1 of the Response to the Rd 1 interrogatory for anticipated performance at a comparable depth.

Sims and Singh (1978) reported a maximum value of average root biomass for grazed grasslands at eight areas of North American as varying from 71 to 1547 g/m^2 in the upper 10 cm. Dividing 71 g/m^2 by 0.10 m yields 710 g/m^3, which is equal to 7.1×10^{-4} g/cm^3 [for an average, near-surface root density]. Dividing 1547 g/m^2 by 0.10 m yields 15470 g/m^3, which is equal to 1.5×10^{-2} g/cm^3 [for an average, near-surface root density]. Thus, average root biomass for grazed grasslands at the eight areas of North American studied by Sims and Singh (1978) tends to vary from 7.1×10^{-4} g/cm^3 to 1.5×10^{-2} g/cm^3. These values are also one to two orders of magnitude less than what is claimed in Table 1/1/3-1 of the Response for anticipated performance at a comparable depth. It therefore appears that the root density values listed in Table 01/13-1 of this Response may be in error by one to two orders of magnitude.

Other references cited on Page D-13of Revised Attachment G include Hopkins (1953), Lee and Lauenroth (1994), Jackson et al. (1996) and Gill et al. (1999). Hopkins (1953) work was done on fertile farmland in Kansas, not comparable to the semi-arid land typical of southeastern Utah or to the synthesized soil material planned for fabrication and use for constructing the cover system. Such differences in soil characteristics notwithstanding, calculating root biomass for the fertile Kansas soil, based on Hopkins' (1953) numbers, an estimate for the root biomass, for example for the 30-45 cm depth interval, is 0.002 g/cm^3. This is an order of magnitude lower than 0.035 g/cm^3, the anticipated performance root biomass for that depth interval claimed in Table D.7. (The estimated root biomass (on a per-volume basis) for the 30-45 cm depth interval based on Hopkins (1953) data can be made in the following way. The soil columns are described in Hopkins (1953) as being three (3) inches thick, and 12 inches wide. The roots are cut into 6-inch segments, each representing a 6-inch long vertical section of earth. Thus, the block of earth for a Hopkins (1953) listed weight of soil is 3" x 12" x 6", or 216 cubic inches (3540 cm^3). However, in this case, the relevant volume of soil is for a depth interval from 30-45 cm, equal to two and a half blocks (one from 30-36", one from 36-42", and one halfway down 42-48"). Thus, the volume of soil over that interval = 2.5*3540 cm^3 = 8850 cm^3. The total weight of roots for the 30-36" block, plus the total weight of roots for the 36-40" block, plus some fraction of the weight from the 40-45" block are added. For convenience, it is assumed that half of the root weight of the 40-45" block is in the upper part of that block. Dividing the total weight of roots (17.94 g) for these 2.5 blocks by the volume of the blocks gives 0.002 g/cm^3.

If it were instead assumed that, for example, 70 percent of the weight of the roots is in the upper half of the deepest block, then a root biomass value of 0.0021 g/cm^3 could be estimated, essentially the same as when 0.5 was assumed)

Based on the above information, the Hopkins (1953) root mass values are an order of magnitude lower than those listed in Table D.7 of Revised Attachment G, i.e., 0.035 g/cm^3. It appears, therefore, that the values in Table D.7 are in error.

Lee and Lauenroths (1994) focused on only three species of plants and do not provide weights needed to assess root biomass density, but they do provide an assessment of percent root length as a function of depth. Jackson et al. (1996) offer root biomass expressed on a per-area basis (rather than on a per-volume basis as is used in the Response) for eleven different biomes, ranging from boreal forest to tundra. It is not apparent to the Division which of these biomes, if any, would be comparable to that of the finished cover system. It is also not readily apparent how root biomass expressed on a per-area basis would be transformed from this data to a per-volume basis. Gill et al. (1999) likewise offer root biomass expressed on a per-area basis, and it is not readily apparent how root biomass expressed on a per-area basis would be transformed to a per-volume basis.

In addition to showing examples of calculations for all new results, the Division requests that EFR correct errors in Table D.7 of Revised Attachment G and on Page D-13 and Page D-14 of Revised Attachment G and elsewhere in the Revised ICTM Report and other supporting documents, as needed, and make appropriate corrections in the model and in the expression of its results. Alternatively, justify the existing values, if possible. Please cite references appropriately, and justify how information used from these references is relevant and appropriate for conditions at the White Mesa site.

2.0 Comparison of Cover Designs, Sensitivity Analyses, 'Bathtub Analysis', and Radon Emanation Modeling

2.1 Round 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 02/1: Comparison of Cover Designs, Sensitivity Analyses, 'Bathtub Analysis', and Radon Emanation Modeling

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". Referencing Sections 3-1 and 4-1 and Appendices E, F, and G of the Revised ICTM Report, THE INTERROGATORY REQUESTED that EFR:

1. Provide the following:
   - 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, and 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;

- 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 2003a]) of soil and/or clayey materials within the maximum projected frost-impacted zone for the 200- 1,000-year recurrence interval; and, 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;

- 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, and provide infiltration modeling results that incorporate such peak/higher precipitation and/or minimum evapotranspiration conditions; or, 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). Therefore, please incorporate worst-case meteorological conditions into the sensitivity analyses and the "bathtub" analysis for the proposed evapotranspiration (ET) cover system;

- Extend the timeframe for calculations projecting the "bathtub effect" to a period of up to 1,000 years, including adjusting 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, and incorporating potential worst-case forecasted future climate conditions; and

- 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); and 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. Justify the assumption of a tailings porosity of 57% in evaluating infiltration/potential for "bathtubbing" of leachate on the liner systems; and perform and report results of sensitivity analyses that assess the dependence of result on variations in the values of tailings porosity used in analyses; and
3. Clarify/provide the information referenced as being included in Attachment E-1 (not apparently provided in the report).

2.2 EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 02/1: Comparison of Cover Designs, Sensitivity Analyses, 'Bathtub Analysis', and Radon Emanation Modeling

A discussion of EFR's Response(s) to the specific interrogatory items included in this Rd 1 interrogatory is provided below. The majority of the interrogatory items included in this interrogatory relate to the issue of estimation of long-term infiltration rates through the proposed ET, and ultimately to the long-term performance of the closed tailings management cells and cover with regard to limiting infiltration rates. Because this is a primary concern for the ICTM Report and site reclamation plan, EFR's response to these items are discussed in the framework of applicable cover performance objectives, relevant and applicable design criteria, and the analyses and documentation provided by EFR to demonstrate the projected (long-term) performance of the proposed ER cover.

Minimize Infiltration/Encourage Runoff

Minimizing infiltration and encouraging/promoting runoff of incident precipitation falling on the cover system throughout the required closed tailings cells embankment's performance period are important design criteria for assessing the likelihood that the cover system will achieve required long-term performance requirements. EFR's Responses to INT 02/1 on Revised ICTM Report – "Comparison of Cover Designs, Sensitivity Analyses, 'Bathtub Analysis', and Radon Emanation Modeling" are therefore discussed below in the context of design criteria and performance criteria that are important for evaluating the expected long-term effectiveness of the reclaimed tailings cell embankment at: (i) restricting infiltration rates into the tailings, and (ii) promoting lateral runoff of precipitation from the cover system, throughout the required performance period of the reclaimed tailings area of 200 to 1,000 years.

Cover Soil Layer Properties Related to Infiltration Reduction

IN ITS RESPONSE to the interrogatory item requesting further justification be provided for the assumed cover soil layer properties, EFR indicated that additional site-specific tests were conducted to evaluate the hydraulic and physical properties of stockpiled materials that will be used to construct the ET cover; therefore the cover soil layer material/hydraulic properties are updated from values previously used to support the Revised ICTM Report. The testing of borrow source materials (samples collected at the Mill Site in April 2012) was performed by the

Wisconsin Geotechnics Laboratory at the University of Wisconsin- Madison. The laboratory testing program consisted of two phases:

- *Phase I testing consisted of standard material characterization tests, including Atterberg limits, specific gravity, and full gradation. The test results were reviewed, along with the existing soils data, to refine the Phase II laboratory testing program.*

- *Phase II testing consisted of standard Proctor compaction, water retention characteristic testing, and saturated hydraulic conductivity tests in the vertical direction (Ks). The moisture retention and hydraulic conductivity tests were compacted to 85% of maximum dry unit weight and optimum water content from the standard Proctor compaction tests. Low relative compaction was used to simulate a structured soil representing a longer term condition, as suggested in Benson et al. (2011).*

EFR summarized the results of the laboratory testing program established to evaluate the hydraulic and physical properties of cover materials (as summarized below). EFR reviewed the results of the Phase I laboratory testing program (standard material characterization tests), along with the existing soils data, to define the Phase II laboratory testing program (compaction, water retention, and hydraulic conductivity tests). This information, along with the original laboratory data summary reports, is included in Attachment B of this Response (Denison [2012b]). EFR identified three different soil groups, based on evaluation of the index tests, and used the results of the Phase I program to select individual samples that would bracket the range in material properties within the three soil groups:

- *Group B: These materials are more broadly (B) graded with some to no plasticity, and represent approximately 48% by volume of the existing stockpiles. On average, these materials contain approximately 30% gravel. This group is represented by samples W2-B1/2 and W5-B1/2 because they bracket the particle size distribution for the plastic soil samples, and by sample W8-B1/2 to represent the non-plastic soil samples.*

- *Group U: These materials are more uniformly (U) graded with some plasticity, and represent approximately 47% by volume of the existing stockpiles. On average, these materials contain approximately 2% gravel. This group is conservatively represented by sample W9-B1/2 because it contains the highest amount of gravel for the soil samples within Group U. The topsoil samples fall within Soil Group U and are represented by sample E1-A1/2 which has a measured plasticity index (PI) equal to the average of the PI values for all the topsoil samples and the gradation of the sample represented the average gradation of the topsoil samples; and*

- *Group F: These materials are fine textured (F), plastic, and represent approximately 5% by volume of the existing stockpiles. On average, these materials contain approximately 0.5%*

gravel. This group is conservatively represented by sample E3-A1/2 because it contains the lowest amount of fines for the clay samples.

EFR then categorized the results of the Phase II program to bracket the range in hydraulic properties. The hydraulic characterization tests identified three hydraulic classification groups for the cover soils as summarized in Table 02/1/1-1, the results of which were used to parameterize the cover model:

- *High hydraulic conductivity and low storage. This group would be considered as an upper bound scenario since water flow through the cover should be higher, and storage should be low, compared to the other soil samples. This group is represented by sample W2-B1/2.*
- *Intermediate hydraulic conductivity and storage. This group would be considered as a base case (average) scenario since water flow through the cover should be intermediate compared to the other soil samples. This group is represented by an average of the soil sample test results (W2-B1/2, W5-B1/2, W8-A1/2, and W9- B1/2).*
- *Low hydraulic conductivity and high storage. This group would be considered as a lower bound scenario since water flow through the cover should be slower, and storage should be high, compared to the other soil samples. This group is represented by sample W9-B1/2.*

EFR indicated that the topsoil samples are represented by sample E1-A1/2.

EFR used the hydraulic classification groups to parameterize the cover model for the proposed ET cover. The erosion protection layer was represented by sample E1-A1/2, the water storage layer was represented by the samples identified above, and the radon barrier layer and grading layer were represented by the samples identified above after applying a correction factor to account for a decrease/increase in the saturated water content. The correction factor was calculated from the anticipated change in porosity for the different compaction efforts. In the model, the values for alpha and n were not changed to maintain a conservative approach for simulation of the radon barrier layer.

While increasing compaction would lower alpha by reducing the largest pore size, and lower n by making a more uniform pore size distribution, keeping these parameter values constant will simulate a soil that releases water more readily than a soil at higher compaction (Tinjum et al., 1997). Additionally, the Ks values for the radon layer were assumed to equal that for the water storage layer to maintain a conservative approach.

EFR stated that the Ks of the radon barrier layer will be lower near term and perhaps long term, and assuming a higher Ks is conservative. Parameter values for the grading layer were assumed to equal those for the water storage layer. EFR concluded that effects on the grading layer, *which has a lower relative compaction compared to the water storage and radon barrier layers, are not anticipated to affect the model results since this layer is located below the terminal root zone and low permeability radon barrier layer. The three scenarios and corresponding input values are summarized in Table 02/1/1-2 for the proposed ET cover design. The material layering and thicknesses of the cover design are based on those determined to be in compliance with radon emanation at the surface as evaluated by the RADON model (Denison 2012b):*

- *The erosion protection layer will be placed at 85% standard Proctor at optimum water content and will include 25% gravel as add-in to the topsoil materials;*
- *The water storage layer will be placed at 85% standard Proctor at optimum water content and will include variable gravel contents based on the material distribution for the soils;*
- *The radon barrier layer will be placed at 95% standard Proctor at optimum water content and will include variable gravel contents based on the material distribution for the soils; and*
- *The grading layer will be placed at 80% standard Proctor at optimum water content and will include variable gravel contents based on the material distribution soils.*

EFR indicated that soil cover layers and their respective hydraulic and physical material properties potentially could be affected by wet/dry, freeze/thaw, and other pedogenic processes as suggested by Benson et al. (2011). EFR also indicated, however, as noted in Benson et al. (2011), that potential changes to the cover can be minimized by designing the cover system to be as close as practical to the anticipated equilibrium state under long-term conditions; EFR noted furthermore, that Benson et al's 2011 study also noted that long-term changes are more prone to occur for less permeable soils compared to more permeable soils.

EFR concluded that the hydraulic test results for the soils stockpiled at White Mesa are within the range of parameter values anticipated to occur long-term as noted by Benson et al. (2011), indicating that the hydraulic properties used as input are likely to represent long-term conditions. EFR noted that, for example, soil that will be used to construct the water storage layer reported a range of values as follows:

- *The hydraulic conductivity values at White Mesa range between 35 and 130 cm/day (cm/d) while those reported by Benson et al. range between 0.86 and 43 cm/d (with a recommended value equal to 4.3 cm/d).*
- *The saturated volumetric water contents at White Mesa range between 0.23 and 0.40 while those reported by Benson et al. range between 0.35 and 0.45 (with a recommended value equal to 0.40).*

- *The alpha values at White Mesa range between 0.0073 and 0.022 cm^{-1} while those reported by Benson et al. range between 0.001 and 0.033 cm^{-1} (with a recommended value equal to 0.02 cm^{-1}).*

- *The n values at White Mesa range between 1.26 and 1.32 while those reported by Benson et al. 2011 range between 1.1 and 1.5 (with a recommended value equal to 1.3).*

EFR, based on the above comparison, and the relatively permeable nature of the soils, concluded that corrections to account for potential pedogenic processes are not warranted at this time because the physical and hydraulic properties at the emplaced conditions are such that post-construction changes should be minimal. Furthermore, the soil properties for the water storage layer are similar to data collected at the Monticello site for long-term conditions that accounted for pedogenic processes (Ks of 13 cm/d; saturated volumetric water content of 0 41; alpha of 0.0021 cm-1; and n of 1.30) as reported in Benson et al. (2008).

Table 02/1-1. Identified Hydraulic Classification Groups and Scenarios for the Soils Used to Parameterize the Cover Model

Scenario	*ID*	*Soil Type*	*Storage (cm)*	*Ks (cm/d)*	*Gravel (%)*
Upper Bound	*WB2-B1/2*	*B*	*11.2*	*130 (1.5×10^{-3} cm/s)*	*41*
Base Case (Average)	-	*B & U*	*18.1*	*62 (7.2×10^{-4} cm/s)*	*15*
Lower Bound	*W9-B1/2-*	*U*	*21.7*	*35 (4.1×10^{-4} cm/s)*	*0*

Note: Storage or available water content was computed at the difference between the volumetric water content at field capacity and wilting point tensions multiplied by the thickness for the erosion protection and water storage layers. Storage accounts for reduced capacity from the amount of gravel calculated using the approach suggested by Bouwer and Rice (1984). The amount of gravel for the upper bound scenario was taken as measured. The amount of gravel for the base case scenario was based on a weighted average for the material volumes and percentage of gravel for the B, U, and F soil types. The amount of gravel for the lower bound scenario was assumed to equal zero based on previous geotechnical results.

Table 02/1-2. Parameter Values Used to Parameterize the Cover Model for the Three Hydraulic Scenarios Modeled Using the van Genuchthen-Mualem Functions

Cover Layer	Purpose	Thickness (cm)	θ_r (-)	θ_s (-)	α (1/cm)	n (-)	K_s (cm/d)	I (-)	ρ_b (g/cm^3)
Upper Bound Soils									
1	*Erosion Control*	*15*	*0.02*	*0.32*	*0.0080*	*1.35*	*11*	*0.5*	*1.70*
2	*Water Storage*	*107*	*0*	*0.23*	*0.022*	*1.32*	*130*	*0.5*	*1.85*
3	*Radon Barrier*	*110*	*0*	*0.16*	*0.022*	*1.32*	*130*	*0.5*	*2.07*
4	*Grading*	*76*	*0*	*0.26*	*0.022*	*1.32*	*130*	*0.5*	*1.74*
Base Case Soils (Average)									
1	*Erosion Control*	*15*	*0.02*	*0.32*	*0.0080*	*1.35*	*11*	*0.5*	*1.70*
2	*Water Storage*	*107*	*0*	*0.34*	*0.011*	*1.30*	*62*	*0.5*	*1.67*
3	*Radon Barrier*	*110*	*0*	*0.27*	*0.011*	*1.30*	*62*	*0.5*	*1.87*
4	*Grading*	*76*	*0*	*0.37*	*0.011*	*1.30*	*62*	*0.5*	*1.58*
Lower Bound Soils									
1	*Erosion Control*	*15*	*0.02*	*0.32*	*0.0080*	*1.35*	*11*	*0.5*	*1.70*
2	*Water Storage*	*107*	*0*	*0.40*	*0.0073*	*1.26*	*35*	*0.5*	*1.56*
3	*Radon Barrier*	*110*	*0*	*0.33*	*0.0073*	*1.26*	*35*	*0.5*	*1.75*
4	*Grading*	*76*	*0*	*0.43*	*0.0073*	*1.26*	*35*	*0.5*	*1.47*

Note: The saturated and residual volumetric water contents for the erosion protection and water storage layers were corrected for the amount of gravel calculated using the approach suggested by Bouwer and Rice (1984). The base case scenario was obtained by averaging the B and U soil samples: the saturated/residual volumetric water contents, n, and ρ_b were arithmetically averaged while α and K_s were geometrically averaged.

<u>*Cover Design Sensitivity Analyses Using Revised Cover Soils Properties*</u>

IN ITS RESPONSE, EFR indicated the following:

- *"The purpose of Appendix E (cover design sensitivity analysis) in the Revised ICTM Report was to compare the potential performance of different conceptual cover designs based on model results assuming as-built material properties; and*

- *MWH does not believe that inclusion of additional sensitivity analyses is warranted for the four different conceptual cover designs assuming weathered material properties.*

<u>*Revised ET Cover Sensitivity Analyses*</u>

For the proposed ET cover, the analysis presented above suggests that the soils will be constructed in a manner that is close to the anticipated equilibrium state under long-term conditions, and that correcting the material properties to account for pedogenic processes is not warranted at this time. Rather, additional sensitivity analysis assuming various scenarios for the soil material properties, and vegetative conditions, has been completed for the proposed ET cover design. These updated model results are discussed below.

<u>*Soil Properties*</u>

The model-simulated water flux rate through the tailings cell cover during the anticipated 57-year climate record (between 1932 and 1988) is shown on Figure 02/1/1-2 for the upper bound and lower bound hydraulic scenarios. These climatic conditions are the same as those applied in the Revised ICTM Report. The base case scenario is also plotted and compared to the departure from the average amount of winter precipitation (November through February).

The average water flux rates predicted for the above scenarios are summarized below:

- *The upper bound hydraulic scenario had an average water flux rate equal to approximately 6.0 mm/yr or about 1.9% of the average annual amount of precipitation;*

- *The base case scenario had an average water flux rate equal to approximately 2.8 mm/yr or about 0.9% of the average annual amount of precipitation; and*

- *The lower bound hydraulic scenario had an average water flux rate equal to approximately 2.4 mm/yr or about 0.8% of the average annual amount of precipitation.*

These rates are approximately 5 to 12 times higher than the value reported in the Revised ICTM Report (Denison 2010) The higher values are attributed to the laboratory Ks results which were on the order of 80 cm/d ($9x10^{-4}$ cm/s) while the value used in the previous model was on the order of 8 cm/d ($9x10^{-5}$ cm/s) for the water storage layer. In actuality, the water flux rates could be slightly lower than modeled depending on the Ks value assumed for the radon barrier layer. In the model, the K_s value for the water storage and radon barrier layers were assumed to be equal. Because the radon barrier layer will be compacted to 95% standard Proctor compaction the material would be expected to have a lower permeability than used in the model. EFR indicated that additional data may be collected to evaluate the K_s values at 95% compaction. EFR indicated that, overall, these simulated values are slightly higher than measurements collected at the Monticello site for the last 12 years (average percolation rate of 0.63 mm/yr with a minimum and maximum rate of 0 and 3.8 mm/yr).

Vegetation Properties

EFR performed sensitivity analyses to predict water flux rated through the tailings cell cover during the anticipated 57-year climate record (between 1932 and 1988) for the upper bound and lower bound vegetation scenarios assuming 30% and 40% cover (base case hydraulic scenario). Results of those simulations are provided on Figure 02/1/1-3 of the Response.

The upper bound scenario assumed a reduced root biomass distribution as presented in Table 01/1/3-1. The lower bound vegetation scenario assumes a lower wilting point pressure head equal to -30,000 cm, and a minimum surface pressure head equal to - 150,000 cm. The water stress response function for grass was selected from the default database in HYDRUS. The database does not distinguish between different species of grass, and transpiration is assumed to cease at soil water pressures below the assumed wilting point of -8,000 cm. However, plants in semiarid environments, many of which were selected for the ET cover, commonly maintain transpiration at significantly lower (more negative) soil water pressures. For example, crested wheatgrass can survive in soil water conditions where the soil water pressure ranges between -20,000 and -40,000 cm (Chabot and Mooney, 1985; Brown, 1995). Unless otherwise noted, all simulations assume the default wilting point of -8,000 cm and a minimum surface pressure head of - 15,000 cm.

Results of the sensitivity analysis simulations indicate the following average water flux rate based on an assumed 40% vegetated cover:

- *The upper bound vegetation scenario had an average water flux rate equal to approximately 4.9 mm/yr.*
- *The lower bound vegetation scenario had an average water flux rate equal to approximately 0.7 mm/yr.*

The average model-predicted water flux rate predicted assuming 30% vegetation cover was as follows:

- *The upper bound vegetation scenario had an average water flux rate equal to approximately 5.1 mm/yr; and*
- *The lower bound vegetation scenario had an average water flux rate equal to approximately 0.9 mm/yr."*

Possible Future Climate Conditions and Impacts on Infiltration Rates through Cover

IN ITS RESPONSE to the interrogatory item requesting further justification be provided for the assumed range of future climate conditions at the White Mesa site, EFR reviewed selected published studies related to past and predicted future climate simulations to further develop an estimate of the range of potential future climate conditions that might exist at the White Mesa site during the next 200 to 1,000 years.

EFR's evaluation of future climate changes/conditions focused on discussion of results of certain recent climate and hydrological model simulations (e.g, Seager et al. 2007; Seager and Vecchi 2010; Cayan et al. 2010) that suggest that continued warming and drought conditions may be expected to occur in the southwestern U.S. through the latter half of the current (21st) century EFR also provided additional discussion regarding expected plant response to future climatic conditions, including big sagebrush, one species that EFR indicates could invade a portion of the ET cover during the early portion of its post-closure design life.

EFR included a summary of previous long-range future climate forecasts done for the Four Corners region (e.g., Waugh and Peterson 1995) but concluded that due to the magnitude of the uncertainties involved (including the large range of temperature and precipitation ranges developed) that "it becomes extremely difficult and highly unreliable to make predictions on future changes in vegetation for the White Mesa Mill site or any waste facility", and that "the analog approach in combination with climate models may be the most effective path forward, but further work is needed before these tools can be applied with a reasonable degree of confidence". EFR concluded that "based on the preceding review [the discussions provided in Attachment G], the most consistent view of climate change in the southwest U.S. is for warmer conditions and greater evaporative loss of water"... and the "it also appears likely that winter precipitation may decrease and summer precipitation may increase, with an accompanied shift in the water balance from winter storage to pulse dominated"...

Based on the paleoclimate and paleorecharge studies summarized above, and EFR's assessment of forecasted conditions that may occur in the future as a result of climate change EFR concluded that "the assumption of applying the maximum annual or winter precipitation value *for a ten year period does not appear to be justified. Rather, repetition at a lower frequency for one of the wetter (and drier winter seasons is a more practical approach to determine if the ET cover will have sufficient storage capacity to minimize percolation during a period of climatic stress. Based on this conclusion, EFR performed the following additional infiltration model sensitivity analyses:*

- *To simulate an increased precipitation scenario we used the Blanding 1993 winter precipitation (296 mm) and PET data repeated for a five year period as part of the 57-year simulation incorporated in the Revised ICTM Report. The January and February measurements recorded during the 1993 winter season correspond to the maximum and second highest measured values recorded during the period of record, respectively. The winter precipitation during 1993 corresponds to the 4th wettest year and the 97th percentile, and is anticipated to be similar to a Holocene wet climate scenario (up to about 13,000 years ago) based on information presented by Waugh and Peterson (1995); and*

- *To simulate a decreased precipitation scenario we propose using the Blanding 1977 winter precipitation (39 mm) and PET data repeated for a five year period as part of the 57-year simulation incorporated in the Revised ICTM Report. The winter precipitation during 1977 corresponds to the 7th driest year and the sixth percentile, and is anticipated to be similar to a short-term drought.*

EFR stated that this approach is functionally similar to the approach incorporated to design the

Monticello repository, and therefore is considered appropriate for this semiarid site in the same region.

Results of these additional sensitivity analysis simulations indicated model-simulated water flux rate through the tailings cell cover for the upper bound and lower bound climate scenarios is shown on Figure 02/1/1-4 (base case hydraulic scenario, 40% cover, anticipated root biomass, and default wilting point). The average water flux rate is summarized below:

- *An upper bound climate scenario having an average water flux rate equal to approximately 6.4 mm/yr; and*

- *A lower bound climate scenario having an average water flux rate equal to approximately 2.6 mm/yr.*

<u>Revised Bathtubbing Analysis</u>

IN ITS RESPONSE to the interrogatory item relating to the bathtubbing analysis, EFR provided a revised bathtubbing analysis using a revised base case estimated tailings porosity of 47%. EFR *also conducted sensitivity analyses calculations using a range of estimated porosity values (44% to 51%. In its revised analyses, EFR assumed a saturated tailings thickness in Cells 2 and 3, and in Cells 4A and 4B, of 1.1 m (3.6 ft), and 0.3 m (1 ft), respectively. An average water flux rate through the cover of 2.8 mm/yr (0.11 inches/yr), based on the revised infiltration modeling described above, and 50% saturation (volumetric water content of 22% to 26%) of the cover soil materials were used in the revised bathtubbing analysis. Results of the revised analyses suggested that equilibrium levels of leachate in the tailings cells would not result in the occurrence of bathtubbing in any of the tailings cells within a 1,000-year period following tailings cell closure. The response provide by EFR also included (in Attachment A to its May 31, 2012 Response to the Round 1 Interrogatories on the Revised ICTM Report) the information inadvertently omitted from Attachment E-1in the revised ICTM Report.*

2.3 Division's Assessment of EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 02/1

2.3.1 Properties of Soils Proposed for Use in Cover Construction/ Infiltration Sensitivity Analyses

The hydraulic conductivity results from the August 2012 on-site soils testing provide useful information. However, EFR should provide additional information to allow the Division to further assess whether the parameterization of the hydraulic conductivity soil properties for use in the revised infiltration simulations is representative of long-term eover hydraulic conductivities that may occur in the cover during the postclosure period. Additional information provided should include the following:

- **For the Phase II soil sample testing to determine hydraulic conductivity, provide information on the diameter of, and the thickness of the prepared (recompacted) soils samples tested in the laboratory testing device (flexible-wall permeameter) that was used, and the specific ASTM D5084 Method testing procedure used in the testing; and**
- **Provide additional explanation and rationale to allow the Division to further assess whether the tested samples and tested sample sizes, and the soil samples themselves, may be considered as providing representative samples for estimating expected in-place long-term constructed conditions in the cover system proposed to be constructed using such soils. Consider the fact that the samples received by the testing laboratory were disturbed soil samples in 20-L buckets (Attachment B supporting EFR's Response to the Round 1 Interrogatory 02/1 on the Revised Reclamation Plan/Benson and Wang 2012), i.e., disturbed samples were used. Disturbed soil samples were used in the laboratory testing, rather than, for example, large (≥ 0.30 m- (12-inch-) diameter, ≥ 15 cm (6 inch-) thick undisturbed block samples of soil from an on-site compacted Test Pad constructed to simulate conditions in the cover system from which a large block undisturbed sample of compacted soil, if such a Test Pad were available, could have been collected for use in the testing.**

In supplying additional supporting information, EFR should consider relevant guidance such as that contained in Benson et al. 1994 and Benson et al. 1997, which recommend that small- diameter soil samples not be used in laboratory soil sample testing for hydraulic conductivity, and that for obtaining the most representative test results, laboratory testing should be conducted on undisturbed block soil samples of compacted soils (e.g., carved from oversized block samples excavated from an on-site compacted soil cover Test Pad) having a minimum diameter of 0.30 m (12 inches) and a minimum soil sample thickness of 15 cm (6 inches), and that ASTM D5084 [Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter], Method C procedures should be followed. These recommendations are intended to capture macropore characteristics of compacted clayey soil layers. Pending receipt and confirmation of testing results of samples performed using such procedures, the Division will consider that the April 2012 sample hydraulic conductivity testing results as preliminary and provisional and subject to unquantified uncertainty.

Based on review of EFR's Responses to the specific issues addressed in the first of this interrogatory, the Division has determined the following:

- **Additional information regarding details of the laboratory soil sample testing performed on the April 2012 soil samples needs to be provided for review to permit the Division to be able to independently evaluate whether the soil conditions assumed in the revised ET cover sensitivity analyses may or may not conservatively represent (bound) degraded soil cover conditions in the proposed ET cover [see the discussion provided in boldface text under '<u>Cover Soil Layer Properties</u>' above];**

- **EFR's finding that "...overall, these simulated values are slightly higher than measurements collected at the Monticello site for the last 12 years (average percolation rate of 0.63 mm/yr with a minimum and maximum rate of 0 and 3.8 mm/yr)" is not useful for corroborating the "reasonableness" of the revised predicted infiltration results. For instance, EFR has made no specific comparison between the in-situ soil conditions present at the subsurface infiltration test sites installed at the Monticello site and the soil conditions expected to occur within the degraded ET cover soils at the White Mesa site; and**

- **In the revised ET cover infiltration analyses, EFR has not conducted and/or has not provided model output or details regarding an infiltration sensitivity case involving a scenario where water ponds on the proposed ET cover as a result of potential flattening of the cover surface due to future differential settlement within one or more areas of the tailings management cells [see the discussion provided under '<u>Revised Bathtubbing Analysis'</u>, in Section 3.3 under "Moisture Storage Capacity of Cover", and in Section 3.4, Other Cover Design-Related Issues, under "Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions" below].**

EFR has conducted additional cover sensitivity analyses to assess effects of different assumed percentages of vegetation on the cover on predicted infiltration rates through the

cover. However, EFR has not provided or supported sufficient details regarding the characteristics of the cover vegetation assumed in the revised infiltration sensitivity analyses. For example, the Division has concerns regarding the estimated root biomass (root density) values listed in Table 01/1/3-1 in EFR's September 10, 2012 Response to Rd Interrogatory 01/1 Item No.3 (see Section 1.3 above). Additionally, the ICTM report (or the Reclamation Plan) needs to provide: (1) definition of clear, concise, and measurable revegetation acceptance goals/criteria for the vegetation establishment on the tailings cell cover system, (2) a description of how EFR will conduct periodic post-closure monitoring and reporting to the Division of the vegetation community health, viability, success, and sustainability, (3) a description of proposed action plans, schedules and deadlines for remedial actions if/when needed to effectuate plant community success, and (4) similar follow-up monitoring of the plant community/cover system to ensure successful performance before release of the facility's surety bond and/or transfer of title to DOE. EFR should describe specific, quantitative goals for sustained shrub establishment (including rooting depths and minimum acceptable shrub cover percentages) that consider the need for deeper rooted plants to remove water that may accumulate lower in the cover profile in response to an exceptionally wet year or successive wet years. If that water is not removed, then it would be available for subsequent downward movement into the waste. At the same time, however, protection against biointrusion by roots of the compacted lower portion of the cover or the waste is required (see additional discussion below under "Potential Plant Root Penetration Depths"). The Division has concern that attempting to balance these competing objectives effectively in a cover system that has no capillary barrier would be very difficult or problematic. A capillary barrier, or a thorough justification for not incorporating one, is required by the Division. In developing the descriptions, plans, and goals for the vegetation establishment on the tailings cell cover, EFR should consider and address lessons learned from the post-closure monitoring and maintenance activities and corrective revegetation measures required at the Monticello, Utah tailings repository and other similar facilities in this regard (e.g., Waugh 2008; Sheader and Kastens undated, circa 2007; U.S. DOE 2007). EFR should assess the potential applicability and benefits of using vegetation health monitoring tools/metrics such as the Cover Vegetation Index recently implemented at the Monticello Repository (U.S. DOE 2009).

Corrective measures that may be needed to address/correct issues related to establishment of undesirable species, e.g., colonization by certain undesired grass/weedy species that may have more limited water stress tolerance than initially seeded grass species (e.g., Smesrud et al. 2012), seed or sprout predation following seeding/reseeding efforts, possible low success rates resulting from for shrub establishment efforts, etc., should be described.

Estimated costs for conducting these post-closure activities and corrective actions, and for reporting, once approved by the Division, will need to be incorporated in the financial surety estimate.

EFR also has not considered (as part of a possible upper bounding [reasonably worst-case] set of conditions), a scenario that includes no shrub vegetation on the cover (or alternatively, if adequately justified based on data available for ET cover revegetation activities conducted at other similar sites, an assumed grass vegetation cover percentage value lower than the 30% lower bound value currently assumed). Such a scenario would be consistent with cover infiltration scenarios that have been performed in infiltration sensitivity analyses completed for other, similar facilities (e.g., for a proposed uranium mill tailings facility in Colorado [Kleinfelder 2009]). The Division also views this type of conservative scenario as appropriate and consistent with information provided in Sections 4.3.1 and 4.3.3 of U.S. DOE 1989 which indicate that "desert climates usually do not provide enough moisture to support plant reproduction except once every few years", and "...At very arid sites, vegetation on the cover may be sparse or absent (in the case of a sustained drought)".

Additionally, the soils proposed by EFR for use in constructing the ET cover are extremely low in natural organic matter (OM) content, e.g., compared to soils used for constructing the Monticello Tailings Repository cover system e.g., zero to about 0.4 % according to Table D-5 in Appendix D of the Revised ICTM Report, compared to a recommended minimum OM content of from approximately 1.5 to 3.0%). These factors indicate that, given the natural climate conditions at the site (which could include possible prolonged (e.g., decadal to multi-decadal) future drought periods likely to create conditions unfavorable for sustaining plant growth in the cover), and without substantial and extensive OM enhancements incorporated into the soils prior to cover construction and possible periodic active post-closure intervention/maintenance measures such as reseeding, possible irrigation of the cover, etc..., the on-site soils tested to date appear to be unfavorable for use in constructing the ET cover. Use of such soils could result in a cover that is detrimental for vegetation growth and sustainability, especially during possible future drought periods.

The Division requests that EFR provide the additional information requested in the discussion under '<u>Cover Soil Layer Properties</u>' above and conduct the additional infiltration sensitivity analyses discussed in Section 3.3 under '<u>Revised Bathtubbing Analysis</u>', under "Moisture Storage Capacity of Cover", and in Section 3.4, Other Cover Design-Related Issues, under "Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions" below. Based on the results of developing and providing this additional information and completing these additional sensitivity analyses, EFR should revise their conclusions and interpretations and proposed technical approach and/or revise the currently proposed cover design accordingly to reflect the new information/modeling results.

<u>Potential Plant Root Penetration Depths</u>

Aspects of EFR's response to this interrogatory related to cover infiltration sensitivity analyses do not sufficiently address the Division's concerns with respect to the potential

impacts on the cover from future plant root penetration. Assumptions made by EFR regarding the potential depth of bioinvasion by plants do not appear to be supported and do not appear to be accurate.

Jackson et al. (1996) discussed plant root depths in grasslands, deserts and other biomes. They reported on studies showing that plant roots can penetrate earthen materials very deeply, even in compact clay, hard pan or rock, and emphasized that many plants send tap roots down to great depths if needed to reach the groundwater table. They reported such depths to be up to 7 m for trees, 5 m for shrubs, 2.5 m for herbs, and 2 m for crops.

Goodwin (1956), according to Tabler (1964), indicated that Big Sagebrush roots apparently can penetrate indurate layers by slow vertical extension.

Schenk and Jackson (2002) indicated that the 90% range for root-system depth for forbs and semi-shrubs in areas of low water availability extends to 3.7 meters, with some significant percentage of other forbs and semi-shrubs penetrating to deeper depths. They also indicated that the 90% range for root-system depth for shrubs in areas of low water availability extends to 7.2 meters, with some significant percentage of shrubs penetrating deeper, with many tree roots tending to grow considerably deeper into soils, with the 90% range extending down to nearly 17 meters, with a maximum depth of about 58 m. these documented root-system depths far exceed the currently modeled one-meter root depth. Schenk and Jackson (2002) indicate that ""...root channels and macro-pores are likely to act as conduits for water recharge deeper than predicted by simple infiltration models."

Hakonson (2002) suggested that most plants, including common plants as well as phreatophytes, are capable of sending down roots much more deeply than is generally anticipated if it is necessary for plants to do so to reach and acquire water. With respect to 2-m thick cover system in New Mexico, he indicated that"most 'shallow rooted' plant species have the capability to send roots *much deeper* than the couple of meters of cover proposed."

In an extreme case in fractured terrain, Phoenix (1955) reported that in the interior of Calamity Mesa, Colorado, miners encountered roots in fractures at depths of about 50 feet.

In contrast to the 1.8 meters assumed in the response, others have reported greater maximum rooting depths for big sagebrush. Cook and Lewis (1963) indicated that roots of big sagebrush were found in their study down to depths of 183 cm (6 feet). Sturges (1977) reported root depths of big sagebrush down to 213 cm. Campbell and Harris (1977) stated that roots of big sagebrush species have been found to extend to depths greater than 3 meters. Reynolds and Fraley (1989) reporedt big sagebrush root depths in their study down to 2.25 meters.

Others have reported even deeper rooting depths for big sagebrush. For example, Cook and Lewis (1963) reference work by Weaver and Clements (1938) who indicated Big Sagebrush roots extending to depths of 5 to 11 feet.

Figure 2 of Plate XLIV of Kearney et al. (1914) is said to be a copy of a photograph of Big Sagebrush at the edge of a stream near Nephi, Utah, where some of the stream banks had, at the time the photo was taken, recently caved in. The photo shows a Big Sagebrush taproot extending downward a great distance along the remaining cut bank edge. The figure caption states the distance is about 11 feet, while the text describes the distance as over 15 feet. Both depths are significantly large.

Tabler (1964) references work of Shantz and Zon (1924) who reported Big Sagebrush roots extending to depths of 4 to 18 feet. Foxx and Tierney (1984; 1985) claimed documentation in their database of reports of Big Sagebrush putting down roots to 914 centimeters (30 feet).

Please further address issues associated with plant bioinvasion of the cover system, including additional infiltration sensitivity analysis, to account for the potential for deeper-rooted plant penetration based on this and possibly other additional published information. Note that Big Sagebrush has been reported to send roots down deeper than 3 meters (9.84 feet), which, according to the Revised ICTM Report, is deeper than the base of the White Mesa cover system soil package, as currently planned in the Revised ICTM report, and as described for some areas of the cover and depicted on Sheet TRC-7 from the Revised Reclamation Plan (Denison Mines 2011).

2.3.2 Range of Possible Future Climate Conditions at White Mesa Site

Based on the review of the Response and the information provided in Attachment G, and selected published information, the Division has concern that EFR has not adequately addressed uncertainties associated with future climate conditions that may occur at the White Mesa site during the closed tailings embankment's required service life (200 to 1,000 years). The Division has concern , that EFR has consequently not adequately addressed the types and ranges of plant responses that might occur for vegetation that would be established on the ET cover and in the surrounding terrain as a result of the potential changes in climate conditions during that required service period. Rather, EFR has primarily focused on the results of selected climate models/ hydrological model simulations which have several associated uncertainties and that are limited to timeframes of on the order of about 100 years, and has attempted to extrapolate findings from those selected climate model simulations to apply to, and to be representative of, conditions over a much longer time period than for which those simulation results were intended to apply. In so extrapolating those findings, EFR has not provided supporting technical justification, described what assumptions are involved, or quantified what uncertainties are involved in attempts to project those findings/assumed conditions over that much more extended time period.

As part of the review of this Response, the Division conducted a preliminary literature review of additional published information on climate models, and in particular, of some of the uncertainties associated with the use of such climate models. A summary of some of the uncertainties associated with such model, based on this review, is provided in the inset text below.

Discussion of Some Uncertainties Associated with Current Climate Models

Climate model practitioners and investigators acknowledge that there are several uncertainties associated with current climate models of the types that were cited in EFR's response and described in further detail in Attachment G of the Response. For example, MacDonald (2010) indicated that Cayan et al. 2010 considered the warming that has occurred during the Early 21st - Century Drought as part of the basis for their conclusions, but that although the warming that has occurred during that period is consistent with the warming that occurred during other periods of regional aridity in portions of the southwestern U.S. in the 20th century (e.g., 1900-9014; 1924-1936; 1953-1964, and 1988-1991), the amount of warming and the magnitude and prolonged nature of the high temperatures of the Early 21st-Century Drought have no analog in the 20th century. Woodhouse et al. 2010 used paleoclimatic records to show that the current warming in the Southwest may exceed any other warming episode experienced over the past 1,200 years.

Seager and Vecchi (2010) suggest that the great North American droughts of the past 200 years were caused by very small sea surface temperature (SST) anomalies in the eastern Pacific Ocean. They indicate that there has been a general cooling trend in the eastern Pacific following 1979 and that such cooling typically is associated with drought in the North American Southwest (NASW). MacDonald (2010) indicates that the drivers of such SST anomalies remain poorly understood, as does the potential impact of increasing greenhouse gasses on Pacific SSTs. Seager and Vecchi (2010) conclude that the general drying in recent decades and the 21st-Century Drought could be a result of natural decadal variability in Pacific SSTs.

In millennial-scale climate model simulations, Coats et al. (2012) found that the climate forecast model they used, although capable of simulating megadroughts through a persistent anomalous SST forcing in the tropical Pacific (e.g. the late 6th-century drought in the control run and the late 13th-century drought in the forced run), indicated that other mechanisms in the model could produce similarly extreme moisture anomalies in the NASW. Coats et al. (2012) noted a number of other uncertainties associated with the climate models being currently in use such as: (i) In the observational record, persistent droughts in the NASW have been tied to cool tropical Pacific SSTs but it is not known if this relation holds for the entire last millennium; (ii) There is observational evidence that warm tropical Atlantic SSTs can create a tendency towards dry conditions in the NASW (Seager et al. 2008; Kushnir et al. 2010; Nigam et al. 2011); and (iii) Longer records of proxy estimated tropical Pacific SST are needed to assess the state of El Nino Southern Oscillation (ENSO) during megadroughts and to determine how coherent previous NASW drought and ENSO variability may have been prior to the observational record.

As noted in Coats et. al. 2012, Cook et al. (2009) also indicated that although IPCC [AR4] climate models robustly predict a shift towards dry conditions in NASW, there is no agreement on the future state of the tropical Pacific, despite the strong connection between ENSO and NASW hydroclimate. Hunt (2011) also analyzed global multi-year drought and pluvial occurrences in a 10,000- year control run of the CSIRO AOGCM and found that persistent hydroclimate features can result from internal climatic variability, with stochastic atmospheric variability playing an important role.

Coats et al. 2012 indicated that model intercomparison employing multiple coupled Atmosphere Ocean General Circulation Models (AOGCMs) is needed to determine if stochastic atmospheric variability similarly influences NASW drought occurrences in the most recent generation of AOGCMs.

In summary, there are numerous uncertainties and complexities associated with the use of all regional climate models with regard to their ability to reliably forecast longer-term future climate conditions in the NASW and at the White Mesa Site. The above discussion appears to corroborate an earlier assessment of the uncertainties associated with future climate modeling as developed and discussed in U.S. NRC 2003b. For this reason, attempts to extend the results from climate model predictions forecasting climate conditions through the end of the 21st century to timeframes of 200 to 1,000 years will likely result in further compounding of these uncertainties and is likely to result in highly unreliable predictions.

The above discussion is also generally consistent with previous assessments of the uncertainties associated with future climate modeling completed for the proposed Yucca Mountain Repository as described in NRC 1997 and by the Center for Nuclear Waste Regulatory Analysis (CNRWA) 2005. Those assessments provide some useful guidance and insights with respect to the forecasting potential future climate change at Yucca Mountain and for other sites. These assessments are summarized in the following paragraphs.

NRC staff, when evaluating methods for estimating future climates at Yucca Mountain in an Issue Resolution Status Report in 1997 (NRC 1997), concluded that careful consideration of indicators of past climatic conditions provides adequate information to bound the likely range of future climate conditions. The NRC staff also concluded that although anthropogenic influences on climate (i.e., emission of greenhouse gases such as carbon dioxide and methane) could overwhelm natural climate cycles inferred from the past 1 to 2 million years, the anthropogenic influences on climate are likely to diminish over the next few thousand years, allowing natural cycles to be reestablished. This conclusion was found to be consistent with the results of an expert elicitation study on future climate (Dewispelare, et al. 1993) in which three of the five participating experts believed that the principal effects of greenhonse gas emissions would dissipate in 3,000 to 5,000 years. The other two experts believed that the effects would last much longer.

The 1997 NRC review also commented on the role of mathematical climate models in estimating future climate. Based on the state of the art at the time, the NRC staff believed that "...attempts to use GCMs [global circulation models] to predict climate changes over tens of thousands of years would almost certainly remain controversial, leading to debate over the competence of one model and data set vs. another" (NRC 1997, p. 13). The help resolve this concern about mathematical climate models, NRC provided (1997) the following acceptance criterion:

- The staff will not require climate modeling to estimate the range of future climates. If DOE uses numerical climate models, determine whether such models were calibrated with paleoclimate data before they were used for projection of future climate, and that their use suitably simulates the historical record (NRC, 1997, p. 6).

Subsequent work by the NRC (NRC 2003b) and a 2005 independent review report (CNRWA 2005) reexamining the NRC 1997 evaluation of methods for estimating future climate change (at Yucca Mountain) found that, in terms of the characteristics of future climates (i.e., mean annual precipitation and temperature, seasonal weather patterns, and storm intensities), the characteristics inferred from paleoclimate reconstructions and present day analog records may represent the range of climate conditions that will occur in the future, even if the timing of these climates cannot be reliably estimated. The greatest uncertainty in future climate conditions relates to anthropogenic effects that may result in climates in southern Nevada that do not have analogs with present or Pleistocene climates, such as prolonged El Niño conditions. The nature, likelihood, and duration of such nonrepresentative climate conditions cannot be reliably assessed based on current research. Over longer time periods, the range of conditions inferred from the Pleistocene paleoclimate record reasonably bounds future climate during the period of geologic stability.

A primarily concern that was identified with respect to use of mathematical climate models was that such models could predict a prolonged period of semi-arid conditions at Yucca Mountain (at least over the next 10,000 years) that would not lead to a reasonably conservative estimate of net infiltration. The acceptance criterion that was established in the Yucca Mountain Review Plan (NRC 2003b) to address this concern is (CNRWA 2005):

- "Verify that paleoclimate information is evaluated [over the past 500,000 years for the Yucca Mountain Repository case] as the basis for projections of future climate change." *For example, confirm that numerical climate models, if used for projection of future climate, are calibrated based on such paleoclimate data (NRC 2003b, p. 2.2-58) [Italics added]."*

The preferred approach that was selected by the NRC for characterizing future climate conditions in assessing the performance of the potential repository was to rely on paleoclimate data to estimate the likely range of future climate conditions.

In addition to the above considerations, the EFR Response and the discussion in Attachment G do not specifically adequately address the known, *long-term recurrent* nature of pluvial (anomalously wet periods) climatic events. Persistent, multi-decadal drought and multi-decadal pluvial events have been a recurrent feature of North American hydroclimate since at least the time of the Medieval Climate Anomaly (e.g., see Cook et al. 2010; Schwinning et al. 2008). For example, the early twentieth century pluvial period (1905–1917), briefly described in EFR's Response (p. 12 of 70) in general terms as an early

20th century wetter period, was likely one of the largest pluvial events in the last thousand years (Woodhouse et al. 2005), where the climate in almost the entire western region of the U.S. was wetter than normal. The major wet anomaly for this pluvial period extended along an axis from the southwest and into the northern Great Plains (Cook et al. 2010). The time period for this pluvial event exceeds 10 years.

Peterson (1994) also evaluated paleoclimate and paleocultural information to define a Little Climate Optimum or Medieval Warm Period (A.D. 900 to A.D. 1300) as having occurred in the northern Colorado Plateau region of the southwestern U.S. During the height of that period, the region was characterized by greater winter and greater summer precipitation than today.

For the above reasons, EFR's choice to simulate an increased precipitation scenario by repeating the Blanding 1993 winter precipitation of 296 mm and PET data for a five-year period as part of the 57-year infiltration simulation [using climate data spanning the years 1932-1988]), as discussed above, is not clearly and transparently supported or demonstrated.

Based on the above considerations, the Division requests that EFR:

- Reevaluate and further define an appropriate reasonably conservative upper bounding future climate condition using a method that is consistent with that described in the guidance outlined in NRC 1997 and NRC 2003b. Specifically, please provide additional information demonstrating, as appropriate, that any numerical climate models or results derived from any such models, if used as a basis for projecting future climate conditions at the White Mesa site be clearly calibrated to paleoclimate data; and
- Provide additional information, as appropriate, to support the contention made in this Response that "the 1993 winter precipitation of 296 mm and PET data for a five-year period as part of the 57-year infiltration simulation [using climate data spanning the years 1932-1988]) is anticipated to be similar to a Holocene wet climate scenario (up to about 13,000 years ago) based on information presented by Waugh and Peterson (1995)".

Porosity of Tailings (Item No. 2 of Interrogatory 02/1)

The Division views the base case and range of porosity values used in the revised analyses to be reasonable and consistent with porosity values assumed in radon emanation analyses competed for similar facilities in Utah (e.g., NRC 2008) and is similar to the default porosity value of 0.40 (40%) recommended for tailings for use in radon emanation modeling in Regulatory Guide 3.64 (NRC 1989). For evaluating potential for bathtubbing, a lower tailings total porosity value is more conservative than a higher porosity value (e.g., porosity estimate of 57% previously assumed).

The tailings dewatering systems in Cells 2 and 3 are known to be much less efficient at dewatering the tailings in those cells than the tailings dewatering systems in Cells 4A and

4B are expected to be (based on calculations). The Division interprets the current low efficiency of the tailings dewatering systems in Cells 2 and 3 as indicating that significantly longer amounts of time will be required to dewater tailings in Cells 2 and 3 compared to the time (estimated to be on the order of 5 ½ years) needed to dewater tailings in Cells 4A and 4B. Greater uncertainty exists regarding final thicknesses of the saturated portions of the tailings in Cells 2 and 3 when final cover placement would take place over these cells. Consistent with the intent of guidance contained in Sections 2.1 and 4.1 of NRC 2003a, more conservative upper bound saturated thicknesses should be estimated and evaluated in the bathtubbing analysis, based on extrapolation of current dewatering system rates, more detailed tailings dewatering analyses (see below) and that reflect the degree of uncertainty associated with the future dewatering of tailings in Cells 2 and 3.

Additionally, EFR needs to provide additional information and details regarding the specific range of in-situ tailings properties and conditions used in the tailings dewatering analysis for Cells 2 and 3, including the range and distribution of hydraulic conductivity values (related to the range of possible distributions of sand vs. slimes tailings) assumed in the analysis. The analysis provided by EFR does not adequately reflect the variable tailings conditions that may exist in Cells 2 and 3, the dewatering model for Cells 2 and 3 appears to be overly simplistic, and the input parameters for the tailings properties used in the analysis appear to be estimated values and not based on site-specific testing of the tailings. The absence of *in situ* testing of the tailings properties is not consistent with guidance contained in Sections 2.1.2 through 2.1.4 of NRC 2003a. The possible maximum saturated thicknesses of tailings in Cells 2 and 3 prior to cover placement need to be estimated in more conservative manner (and incorporated accordingly into sensitivity analyses) to account for uncertainties associated with the continued effectiveness of the dewatering systems in Cells 2 and 3. A conservative range of possible in-situ residual tailings hydraulic conductivity conditions/distributions in Cells 2 and 3 needs to be considered in the analysis.

<u>Revised Bathtubbing Analysis</u>

~~Additionally, for assessing the potential for bathtubbing, the Division recommends that the~~ value of infiltration used in the bathtubbing analysis scenario be the highest average infiltration rate obtained from the full range of model infiltration sensitivity analysis scenarios considered. The Division recommends that the same analysis scenario include a combination of: (i) maximum (upper bound) assumed hydraulic conductivities for the cover soils; (ii) an assumption of no grass vegetation on the ET cover; (iii) a flattened topslope inclination (unless the topslope inclinations in the current proposed cover design are increased to a minimum of 2 to 3 %); and (iv) an assumption that liner conditions in the tailings cells have the lowest defect sizes and frequencies and least permeable soil/GCL underliner values (effectively yielding the lowest overall calculated leakage rates) that EFR determined in its cell liner leachate leakage analyses.

Additional information needs to be provided on effects of expected higher infiltration rates through the (rock riprap-covered) sideslope areas on bathtubbing under such assumed reasonably worst-case conditions as described in the previous paragraph. Specifically,

EFR needs to provide additional information on infiltration rates through the sideslope portions of the proposed cover and the potential effects (depending on geometric relationship of sideslope areas relative to areas covered by the cell liners) of such infiltration on bathtubbing, under the reasonably worst-case assumed conditions described in the above paragraph.

Missing Information in Attachment E-1

EFR provided the information was inadvertently omitted from Attachment E-1 of Appendix E of the Revised ICTM Report. The missing information was submitted as part of EFR's Response to the Rd 1 Interrogatories on the Revised (Rev 5.) Reclamation Plan (submitted to the Division on August 31, 2012),

3.0 Moisture Storage Capacity of Cover

3.1 Round 1 Interrogatory White Mesa Revised ICTM Report ; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1: Moisture Storage Capacity of Cover

Interrogatory White Mesa Rev ICTM; R313-24-4; 10 CFR40 Appendix A, Criterion 6(1); INT 03/1: "Moisture Storage Capacity of Cover": Referencing Appendix F of the Revised ICTM Report, THE INTERROGATORY REQUESTED that EFR:

- Redefine and further justify the critical meteorological design event (or sequence of contiguous events) used in the bathtubbing analysis;
- 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; and the 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 ;
- Identify the month(s) of the year that would be expected to comprise the most critical percolation period; and
- 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.

THE INTERROGATORY REQUESTED, referencing Appendix F of the Revised ICTM Report, that EFR also:

- Provide additional details regarding the assumed gradient at the soil cover/atmosphere interface, including the possibility of the gradient exceeding unity due to matric suction gradients that might be greater than unity;
- 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; and
- 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.

3.2 EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1: <u>Moisture Storage Capacity of Cover</u>

IN ITS RESPONSE, EFR recommended that Appendix F be eliminated from the next revision of the ICTM Report and provided additional information intended to address these requests. EFR indicated that this information would be incorporated (instead) into the next revision of Appendix G to the ICTM Report.

IN ITS RESPONSE, EFR indicated that a gradient of unity was not assumed for the soil cover/atmosphere interface, and that the upper surface boundary condition representing the air-soil interface follows a system-dependent boundary condition. The soil surface boundary condition within the model may change from prescribed flux to prescribed head type conditions and vice-versa. EFR also indicated that in the model presented in the 2010 Revised ICTM Report, a maximum surface ponding depth of five centimeters was assigned. EFR stated that localized surface ponding, if it were to occur, would act to increase hydraulic gradients along the air-soil interface resulting in greater amounts of water that could infiltrate into the cover until the surface pond reservoir was depleted.

EFR also stated that the infiltration modeling was updated to account for an increased precipitation scenario; and this scenario was selected to correspond to the most critical time period for which percolation through the cover could occur during its required performance life. EFR stated that such an evaluation would be presented in another appendix (e.g., Appendix G) because it is not applicable to the original intent of Appendix F, and because Appendix F would be deleted from the next revision of the ICTM Report.

3.3 Division's Assessment of EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1

Based on review of the EFR Response to the items addressed in this Rd 1 interrogatory on the ICTM Report and the EFR Response to the Round 1 Interrogatories on the Revised (Rev 5.0) Reclamation Plan to infiltration rates through the proposed ET cover, the Division finds the information provided in the Response regarding the gradient parameterization incorporated into the infiltration modeling to be acceptable. However, the Division has concern that the infiltration analyses presented in the Revised ICTM Report and described in the Response to the Round 1 Interrogatories on the Revised ICTM Report and on the Rev 5.0 Reclamation Plan are not sufficiently conservative to bound the uncertainty associated with possible future flattening of the cover topslope inclination (see the discussion under Section 3.4, Other Cover Design-Related Issues, under "Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions" below). Additionally, similar to the assessment for potential for bathtubbing, the Division recommends that the value of infiltration used in the infiltration sensitivity analysis scenario for evaluating the cover soil moisture holding capacity be the highest average infiltration obtained from the full range of model infiltration scenarios considered, and that the same scenario include the following additional assumptions: (i) assumed maximum (upper bound) assumed hydraulic conductivities for the cover soils; (ii) the assumption of no grass vegetation on the ET cover; (iii) the assumption of a flattened topslope inclination (unless the topslope inclinations in the current proposed cover design are increased to a minimum of 2 to 3 %). Additional information needed from EFR in order to resolve these concerns related to the soil moisture storage capacity of the cover is provided in the table attached to this Technical Memorandum and in the "Technical Memorandum, Revised (Rev. 5.0) Reclamation Plan Review".

3.4 Other Cover Design-Related Issues (Related to Rd Interrogatories 02/1 and 03/1)

3.4.1 Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions

3.4.1.1 Round 1 Interrogatory White Mesa Revised ICTM Report ; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1: Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions

As described above, INTERROGATORY 02/1 on the Revised ICTM Report included an item (Item No. 1) addressing the erosion protection layer for the proposed ET cover. INTERROGATORY 08/1 on the Rev 5.0 Reclamation Plan – "Erosion Stability Evaluation" REQUESTED THAT EFR address long-term erosion and filter layer criteria for the proposed ET cover layers.

3.4.1.2 EFR Responses to Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions

IN ITS RESPONSE to the above interrogatory items, EFR included revised calculations and text discussing the results of the revised calculations.

3.4.1.3 Division's Assessment of EFR Responses to Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions

Information presented in the EFR Responses to the above interrogatory items and a discussion of the content of the revised calculations are described in detail in the document entitled "Technical Memorandum, Revised (Rev. 5.0) Reclamation Plan Review". However, the erosion protection analyses methodology used by EFR to support the proposed cover design is based on assumptions that EFR has not yet demonstrated valid assumptions for the proposed ET cover design for the tailings management cells area. Based on the Division's review of the information provided by EFR to date, EFR has not adequately demonstrated to the Division's satisfaction that flattening of the proposed ET cover surface would not occur (due to post-closure differential settlement). Based on this consideration, the Division has concern that the infiltration analyses presented in the Revised ICTM Report and described in the Response to the Round 1 Interrogatories on the Revised ICTM Report and on the Rev 5.0 Reclamation Plan are not sufficiently conservative to bound the uncertainties associated with predicting whether such cover topslope flattening might occur following construction of the (currently proposed) cover. Additional information needed from EFR in order to resolve concerns related to the current erosion protection technical basis justification and future cover infiltration rate - related uncertainties is provided in the table attached to this Technical Memorandum and in the "Technical Memorandum, Revised (Rev. 5.0) Reclamation Plan Review".

3.4.2 Suitability of/Impacts from Using Soils Tested in April 2012 for Constructing ET Cover

3.4.2.1 Round 1 Interrogatory White Mesa Revised ICTM Report ; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1:Suitability of/Impacts from Using Soils Tested in April 2012 for Constructing ET Cover

As described above, INTERROGATORY 02/1 on the Revised ICTM Report included an item (Item No. 1) REQUESTED THAT EFR provide additional information to justify the assumed cover soil layer properties.

3.4.2.2 EFR Responses to Suitability of/Impacts from Using Soils Tested in April 2012 for Constructing ET Cover

IN ITS RESPONSE, as described previously, EFR provided and discussed results of additional testing of stockpiled on-site soils proposed for use in constructing the ET cover, completed in April 2012.

3.4.2.3 Division's Assessment of EFR Responses to Suitability of/Impacts from Using Soils Tested in April 2012 for Constructing ET Cover

The results of April 2012 soil testing suggest that the on-site soils tested appear to be suitable for establishment of vegetation cover, with the use of soil amendments as discussed in Attachment G submitted by EFR in its Response. However, the Reclamation Plan, and specifically, Attachment G, do not provide sufficient information on the types, amounts, sources, methods of application, estimated costs, and limitations of the potential amendments that are discussed to demonstrate that use of the on-site soils will be suitable and cost-effective. The Revised ICTM Report, and the Rev 5.0 Reclamation Plan and Appendix G also do not provide sufficient details regarding future contingency measures that would be implemented for rectifying cover revegetation problems if they occur.

The Division requests that EFR provide additional information in the Reclamation Plan, and specifically, in Attachment G to allow the Division to determine that sufficient information has been provided on the types, amounts, sources, methods of application, estimated costs, and limitations of the potential soil amendments and soil amendment practices to demonstrate that use of the on-site soils will be suitable and not cost-prohibitive. EFR should provide additional details regarding the soil amendment procedures to further substantiate/demonstrate that use of the on-site soils will be adequate for facilitating sustainable performance of the cover with respect to the establishment and sustainability/longevity of vegetation on the cover for promoting evapotranspiration throughout the cover performance period (200 to 1,000 years). The Division also requests that EFR provide additional details regarding contingency measures for rectifying cover and provide information demonstrating that such proposed future remedial measures, if required, are reasonable and reflective of cover revegetation remedies that have been required and shown to be effective for other similar facilities (e.g., Monticello tailings repository – e.g., see U.S. DOE 2007; Waugh et al. 2008).

Alternatively, EFR should explain a plan for use of alternate soils and/or the possible need for bentonite amendment of these higher-K_{sat} soils, if necessary, for constructing the cover, in order to satisfy applicable long-term cover design (e.g., infiltration reduction) objectives, considering results of additional infiltration sensitivity analyses using these amended soils that include more conservative assumptions regarding the effects of potential long-term changes in properties of these amended soils in the completed cover.

3.4.3 Cover Design Safety Factor

3.4.3.1 Round 1 Interrogatory White Mesa Revised ICTM Report ; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1 Cover Design Safety Factor

INTERROGATORY 03/1 also REQUESTED, referencing Appendix F of the Revised ICTM Report, that EFR 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).

3.4.3.2 EFR Responses to Cover Design Safety Factor

IN ITS RESPONSE, EFR indicated that the inclusion of a factor of safety (FOS) to the design of the cover is not appropriate considering the conservative nature of the assumptions used to evaluate the cover design and performance.

3.4.3.3 Division's Assessment of EFR Responses to Cover Design Safety Factor

Based on review of this Response, it appears to be acceptable to not include a specific FOS into the cover design to specifically address the above-identified uncertainties. In a preliminary review of peer-reviewed literature, no published guidance documents specifically addressing this matter were identified by URS or by the Division. However, during its review of the information provided by EFR, the Division/URS evaluated the information to determine whether an appropriate, and adequately justified, reasonably conservative range of input conditions and parameter values have been assumed by EFR, and that sufficient sensitivity analyses have been included as part of all modeling simulations and calculations that incorporate the full range of these assumed conditions and parameter values. All analyses and model sensitivity analyses have also been reviewed to determine whether they have been performed in accordance with applicable NRC guidance and other applicable and relevant criteria and accepted industry practices. Results of that evaluation are applied to other specific interrogatory items that are addressed in this document. Therefore no further action is required of EFR with respect to

the request that a specific safety factor be applied to the projected infiltration design or performance of the cover.

3.4.4 Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions

3.4.4.1 Round 1 Interrogatory White Mesa Revised ICTM Report ; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 03/1 Cover Long-Term Erosion Protection Design Basis/Justification and Differential Settlement Issues Related to Infiltration Modeling Assumptions

4.0 Evaluation of Flow Through Tailings Cell Liners

4.1 Round 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1: Evaluation of Flow through Tailings Cell Liners

EFR's Response to INT 04/1 on Revised ICTM Report Plan – "Evaluation of Potential Flow through Tailings Cell Liners": THE INTERROGATORY REQUESTED that EFR do the following:

1. Refer to Appendix L (Evaluation of Potential Flow through Tailings Cell Liners) of the Revised ICTM Report: Please provide the following:
2. Revise and provide justification for the value of saturated hydraulic conductivity assumed for the compacted foundation [liner bedding] layers (comprised of a compacted gravel-sand mixture derived from crushing of loose sandstone, possibly with washed concrete sand used in some areas) underlying the geomembranes in Cells 2 and 3;
3. 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
4. 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.

4.2 EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INTO 01/1: Evaluation of Flow Through Tailings Cell Liners

IN ITS RESPONSE, EFR provided analyses and a series of calculations to estimate flux rates (flow rates) and calculate estimated travel times for liquids to migrate vertically from the base of either Cell 2 or Cell 3 through the vadose zone to the perched groundwater zone underlying these cells. Analyses were conducted for a range of possible different assumed saturated zone values for the in-place bedding materials underlying the geomembrane liners and considered various geomembrane defect sizes and frequency scenarios. All calculation scenarios assumed a base-case pressure head value of 5.82 m (19.1 ft), based on the analysis provided in Appendix L of the Revised ICTM Report (Denison 2010). For calculation purposes, the footprint area of each of Cell 2 and Cell 3 was assumed to be 70 acres, and a vadose zone thickness of 12.8 m (42 ft) was assumed (the thinnest thickness determined for Cells 2 and 3 based on groundwater depth information from the nearest wells and information on the bottom depths of Cells 2 and 3, as described in the analysis provided in Appendix L of the Revised ICTM Report [Denison 2010).

EFR indicated that the material installed beneath the liners in Cells 2 and 3 consists of crushed Dakota sandstone that was compacted with a smooth drum roller, but in some locations, in which a smooth base grade was available, portions of the liner were placed over sections of in situ Dakota sandstone (H. Roberts, 2012). The Second Phase Tailings Management System Construction Report generally is consistent with this observation: Energy Fuels Nuclear Inc. (1983) noted that a gravel-sand mixture derived from crushing of loose [Dakota] sandstone, with some washed concrete sand in some areas, was used to construct the compacted bedding layer immediately beneath the liner in Cell 3; and that a similar process and materials were used for the liner bedding material in Cell 2.

Acknowledging that no estimates of the hydraulic conductivity for the in-place liner bedding ~~materials beneath Cells 2 and 3 are available for incorporation into the leakage analyses, EFR~~ referred to results of saturated hydraulic conductivity tests in the vertical direction (Ks) measured on intact core-samples of the Dakota sandstone using a flexible wall permeameter (Appendix B) of the 2010 Revised ICTM Report for use as a starting point to assess the potential Ks value for the liner bedding materials. EFR used intact core-sample intervals, measured in feet below ground surface (ft bgs) from the following monitoring wells (MWs), and the corresponding Ks measurements in meters per second (m/s) are as follows for the Dakota sandstone (Appendix B), to derive a corresponding geometric mean Ks value of 9.0×10^{-7} *m/s (*9.0×10^{-5} *cm/s):*

- *MW-30 35.5-36.0 ft bgs was measured at 8.1x10-6 m/s.*
- *MW-30 44.0-44.5 ft bgs was measured at 8.2x10-8 m/s.*

- *MW-23 55.5-56.0 ft bgs was measured at 1.1x10-6 m/s.*

This geometric mean value is approximately eleven times higher than the minimum value and nine times lower than the maximum value. EFR acknowledged that, in actuality, the Ks value for these materials could be higher or lower than the test measurements listed above indicate, based on the reported variability and because the liner underlay material consists of crushed Dakota sandstone which may have experienced some compaction from hydraulic loading and tailings deposition.

4.3 Division's Assessment of EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1

EFR discussed various lines of evidence to support their contention that their assumption that an appropriate Ks value for the crushed sandstone/washed gravel bedding layers underlying Cells 2 and 3 to use in the leakage analysis similar to the Ks value used in the December 2010 Revised ICTM Report (2 x 10^{-9} m/sec) and that the geomembrane defect sizes and frequencies assumed in the calculations presented in Appendix L of the Revised ICTM Report (Denison 2010) are reasonable and do not require revision. Evidence cited by EFR includes:

- **"No significant leakage indicated by the leak detection systems;**
- **No leakage indicated by mounding of the perched aquifer water table surface;**
- **No observations of contamination (e.g., acid leaching, dissolution of carbonates, gypsum precipitation, staining) in the bedrock core samples were recorded during drilling of monitoring wells installed adjacent to the cells during spring 2005 as noted during inspection of the core by MWH (Appendix C);**
- **Total uranium was detected at background levels in bedrock core samples collected while drilling monitoring wells adjacent to the cells as noted by analyses presented in Appendix A;**
- **No contaminants detected in groundwater at levels above natural background concentrations (INTERA, 2007a; 2007b; 2008). The lack of groundwater contamination is corroborated by the following:**
  - **The apparent groundwater age beneath the tailings cells is dominated by water that is at least approximately 55 years old as determined from measurements of tritium and helium in groundwater within the vicinity and downgradient of the mill (Hurst and Solomon 2008). In other words, recharge at the land surface occurred prior to 1952 (Schwartz and Zhang 2003) and takes at least 55 years to reach the perched aquifer.**
  - **Groundwater beneath the tailings cells is not influenced by more modern water that may have leaked from the tailings cells.**

- No contaminants detected in groundwater as evaluated through measurements of stable isotopes for oxygen and sulfate in groundwater within the vicinity and downgradient of the mill (Hurst and Solomon 2008) indicative that significant leakage from the tailings cells have not occurred."

Based on review of the above Response, in the opinion of the Division, the bullet points listed by EFR do not provide evidence that no significant leakage has occurred through the liner systems beneath Cells 2 & 3 over the past 30 years. The Division finds that the analyses and conclusions presented in this Response do not sufficiently bound and are not sufficiently conservative to represent the full range of site and liner conditions that likely exist at and beneath cells 2 and 3 to assess potential impacts associated with potential leakage of leachate from Cells 2 and 3.

The point that "no observations of contamination (e.g., acid leaching, dissolution of carbonates, gypsum precipitation, staining) were recorded during drilling of monitoring wells installed between and adjacent to the cells during spring 2005" is not evidence that "no significant leakage has occurred through the liner systems beneath Cells 2 & 3 over the past 30 years." Instead, this finding indicates that leakage was not observed at these well locations, but it still could exist elsewhere inside/directly below the footprint area of the contiguous tailings cells.

Average groundwater flow velocities in the Burro Canyon Formation downgradient of the tailings cells are indicated in the Revised ICTM Report (p. 2-12) to be on the order of 1.7 to 3.2 ft/yr. This would imply that a constituent in a hypothetical groundwater plume in the groundwater would have only moved approximately 102 feet (e.g., 32 years x 3.2 ft/yr) in the aquifer over the past 32 years. The distance between upgradient and downgradient edges of Cell 3, where upgradient and downgradient wells are located, is, by comparison, on the order of 1,000 feet. If a release source (e.g., the location of a defect in the cell liner) were situated near the northern margin of Cell 3, and the release resulted in a plume of capable of being detected in a downgradient monitoring well, it is unlikely that the contamination would have been detected in any of the monitoring wells (e.g., MW-39, MW-30, MW-31) installed along the downgradient edge of Cell 3 by the present time. Hence, groundwater contaminant detection at the present time may be more likely only in cases where the contaminant source is located just a short distance upgradient from one of these monitoring wells.

Additionally, analytical results of groundwater monitoring conducted during the 1st and/or 2nd Quarters of 2012 indicate that Groundwater Concentration Limits (GWCLs) for the constituents listed in the following table were exceeded for the monitoring wells listed in the table that are located immediately downgradient of the edge of either Cell 2 or Cell 3:

Well No./ Cell Downgradient of	Parameter Exceeding GWPL	GWCL	Concentration Detected
MW-29/ Cell 2	Manganese	5624 µg/L	6140 µg/L
MW-30/ Cell 2	Nitrate + Nitrite Uranium Selenium	5 mg/L 8.32 mg/L 34 µg/L	15 -18 mg/L 8.38 µg/L (March 2012) 35 – 39.1 µg/L
MW-31/ Cell 2	Nitrate + Nitrite TDS Chloride Sulfate	5 mg/L 1320 mg/L 143 mg/L 532 mg/L	20 -22 mg/L 1360 – 1460 mg/L 151 - 160 mg/L 538-547 mg/L
MW-5/ Cell 3	Uranium	7.5 µg/L	18.6 µg/L (Q1 2012)
MW-11/ Cell 3	Manganese	131.29 µg/L	154 µg/L; 132 µg/L
MW-12/ Cell 3	Selenium	25 µg/L	27.2 µg/L (Q1 2012)

Although the magnitudes of exceedance of applicable GWCLs for the constituents reported in the above table are typically small and/or might have only occurred once to date, these reported exceedances reflect more recent groundwater monitoring data than referenced in the EFR Response and indicate that EFR's argument that no contaminants have been released from Cell 2 and/or Cell that have been detected in groundwater monitoring wells above background concentrations is not, or may not be defensible.

Additionally, information provided by EFR in "Response 2 (May 31, 2012)" to this interrogatory indicates that substantial volumes (but at rates below specified Action Leakage Rate trigger levels) of leachate have accumulated in the Leak Detection Systems underlying the primary geomembrane liners in Cells 4A and 4B since the time of their installation. Because the liners in Cells 2 and 3 were installed using older liner technologies and materials than were used in Cells 4A and 4B, and the Cell 2 and Cell 3 liners are older than those in Cells 4A and 4B, it would be reasonable and conservative to assume that leakage rates through the liners in Cells 2 and 3 would be substantially higher than leakage rates occurring through the primary liners in Cells 4A and 4B. For example, estimates of failure time for PVC liners range from about two decades to possibly a century or more. However, there remains much uncertainty about PVC liner longevity, and actual lifetimes will vary depending on liner and leachate properties and other environmental characteristics. One manufacturer, for example, claims a lifetime for their PVC liners, when buried in the subsurface, of only up to 20 years (Enviroconsystems, 2012). Likewise, CLI (2010), a geosynthetic solutions provider, indicates that for landfill liners,... "in buried applications, PVC can provide a service life of over 20 years." AccuGeo (2012), another

liner manufacturer, indicates, "...buried PVC liners will have a life of 20 years or more" (AccuGeo, 2012).

For further evaluating potential leakage rates from Cells 2 and 3, the Division requests that EFR perform an uncertainty analysis relative to PVC liner longevity in its infiltration modeling, or justify not doing so. Uncertainty analyses should involve at least one model run for liner failure occurring after decades (e.g., 20 years), and at least one model run for failure at about 100 years, or some alternative timeframe as justified by EFR.

For evaluating the appropriateness of some of the evidence EFR provided in the Response to support EFR's contention that Cells 2 and 3 are not currently experiencing significant leakage, detailed calculations were not provided (with input parameter assumptions and information supporting those assumptions) directly calculating the vertical transport time of constituents potentially seeping from below the base of Cell 2 and Cell 3 through the in-situ vadose zone bedrock materials underlying the liners of these cells to the top of the perched water zone underlying those cells, but would have been useful.

Based on the considerations described above and the available information, the Division assumes that tailings Cells 2 and 3 have a higher probability of releasing leachate to the groundwater system than do tailings Cells 4A and 4B. This probability is further heightened due to the much lower tailings dewatering rate observed in these two cells compared to Cells 4A and 4B, which has resulted in a more prolonged duration of elevated leachate levels present in Cells 2 and 3 to the present time. The rate at which leachate head levels in Cells 4A and 4B are predicted to be reduced is considerably higher than the dewatering rate in Cells 2 and 3 due to the more modern and more extensive tailings dewatering systems installed in Cells 4A and 4B.

Conclusions presented by EFR in the current Response to this interrogatory are as follows:

- **The Ks value assigned to the liner underlay materials using the value assumed in Appendix L is considered to be a reasonable and appropriate assumption, and that an attempt to decrease this value would result in potential leakage rates that do not appear to be realistic (i.e., too conservative); and**
- **Therefore, a higher Ks for the liner bedding materials does not seem to be justified to represent potential in-place liner conditions beneath Cells 2 and 3 and the calculations presented in the 2010 Revised ICTM Report do not require adjustment.**

Based on review of the Response, the Division requests that EFR:

- **Revise the liner leakage calculations and resulting conclusions from those currently presented in the Response to reflect a more conservative range of assumptions and the results of revised analyses incorporating those more conservative assumptions, that coincide more closely with current site information and conditions (see additional discussion at the end of this section), and that are consistent with a postulation that the liners in Cells 2 and 3 could allow leakage rates higher than or**

equal to measured leakage flux rates currently occurring through the primary liners in Cells 4A and 4B;

- **Quantify the degree to which the revised analyses result in flux rates through the liner systems in Cells 2 and 3 indicate higher leakage rates than leachate flux rates currently observed through the primary liners in Cells 4A and 4B, under all comparable assumed operational conditions and all assumed liner defect frequencies; and**
- **Provide a detailed travel time calculation or calculations, analogous to those discussed on p. 38 of 70 in "Response 1 (May 31, 2012)", but that instead calculate the vertical transport time of constituents potentially seeping from directly below the base of Cells 2 and 3 through the in- situ vadose zone bedrock materials to the top of the perched water zone. Include information on the hydraulic conductivity value(s) assumed and the effective field porosity value assumed for the bedrock materials and provide a basis for the value assumed (i.e., field measurements). Alternatively, if no single value of effective porosity is available or appropriate for the site, provide a range of effective porosity values assumed and use this range of values in the travel time calculations. Compare the value(s) of effective porosity used to the default value of 10 percent recommended for use by NRC at Title I UMTRCA sites in Section 4.3.1.3.2 of NRC 1993 (considered by the Division to be a relevant conservative default value for this type of analysis).**

The Second Phase Tailings Management System Construction Report (Energy Fuels Nuclear Inc. 1983) noted that a gravel-sand mixture derived from crushing of loose [Dakota] sandstone, with some washed concrete sand in some areas, was used to construct the compacted bedding layer, where present, immediately beneath the liner in Cell 3; and that a similar process and materials were used for the liner bedding material in Cell 2. In some areas, liner was laid directly on compacted bedrock.

Table 5.5.1 of Bear (1972) differentiates between "gravel" and "clean sand or sand and gravel", and gives a range of values for hydraulic conductivity for sand and gravel between 10^{-3} and 10^{0} cm/sec. These values may approximate values of hydraulic conductivity for a crushed sandstone. USACE (1993) refers to a value for hydraulic conductivity of 1.4 x 10^{-3} cm/sec and indicates that "clean, washed concrete sand is usually about this permeable". Elsewhere, USACE (1993) refers to "clean washed concrete sand with a permeability [hydraulic conductivity] of 10 ft/day", which equates to 3.5 x 10^{-3} cm/sec. "Washed concrete sand" used in one project is reported by Dwyer (1998) as having a hydraulic conductivity of at least 10^{-2} cm/sec. A falling-head permeameter test of "Nova Scotia washed concrete sand" is reported as having indicated a hydraulic conductivity of the sand in the range of 1 x 10^{-4} to 2 x 10^{-4} m/s (Mooers and Waller,1997), equivalent to 1 x 10^{-2} to 2 x 10^{-2} cm/sec. All of these reported ranges of hydraulic conductivity values exceed (by a few to several orders of magnitude) the geometric mean value of 9.0 x 10^{-7} m/sec (9 x 10^{-5}

cm/sec) assumed for this underlay material by EFR in the revised calculations described in the Response (August 31, 2012) to this Rd 1 interrogatory.

Based on the above information, unless EFR can provide more conclusive data, the Division requests that these higher values be used for the hydraulic conductivity of the underlay materials, or, at a minimum, that EFR run additional sensitivity analyses that incorporate these higher hydraulic conductivity values, to assess the impact of these higher values on the Cells 2 and 3 leakage rate calculations.

5.0 Contaminant Transport Modeling

5.1 Round 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1: Contaminant Transport Modeling

EFR's Responses to INT WHITE MESA REV'D ICTM; R313-24-4-05/1: Contaminant Transport Modeling: THE INTERROGATORY REQUESTED that EFR provide the information requested in Items No. 1 through 11 as follows:

1. Refer to Revised ICTM Report, Section 2.2 Site Characteristics and Section 3.4 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 (O2/H2O) 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 shows 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, 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.

5.2 EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INTO 01/1: <u>Contaminant Transport Modeling</u>

IN ITS RESPONSE, EFR indicated the following:

"Response 1:

TECHNICAL MEMORANDUM

WHITE MESA MILLSITE – REVISED ICTM REPORT REVIEW

The potential occurrence of increased flow and transport from the presence and distribution of fractures and/or joints in the unsaturated zone of the Dakota sandstone and Burro Canyon Formation underlying the site area is not supported by geologic and hydrogeologic observations as summarized below:

- *The lack of faulting and lack of extensive jointing combined with the largely structurally intact and sub-horizontal dip of the geologic units should act to limit the downward movement of water within the bedrock vadose zone. Structural control of water movement is likely limited due to the absence of faults and the apparent low frequency of joints.*
    - *The Dakota sandstone and Burro Canyon Formation are nearly flat-lying with reported dips of less than 1 degree to the south (D'Appolonia, 1979).*
    - *No faults have been mapped or identified within the Blanding Basin (Kirby, 2008) or White Mesa area (D'Appolonia, 1979).*
    - *The Dakota sandstone and Burro Canyon Formation are relatively devoid of joints. Where present, primary joints are nearly vertical and north striking, and commonly several meters in length; secondary joints are oriented east-west and commonly terminate at the intersection with primary joint surfaces (Kirby, 2008).*
- *Observational data collected during a 1994 drilling program of three perched monitoring wells and four angled borings beneath Cell 3 and Cell 4A concluded that few fractures were present in the cores or observed in video logs. And where such features were present the fractures were closed and/or sealed with gypsum (Hydro Geo Chem Inc. [HGC], 2010a).*
    - *The potentiometric surface map in the vicinity and downgradient of the tailings cells resembles that of a perched aquifer system in that the projected and inferred lines of equipotential are nearly parallel to one another (Figure 2-5 of the 2010 Revised ICTM).*
- *Age dating of groundwater in the vicinity and downgradient of the tailings cells indicates that infiltration takes longer than 55 years to travel through the vadose zone except in the vicinity of the wildlife ponds (Hurst and Solomon, 2008). The recharge mound near the wildlife ponds, combined with the absence of tritium in groundwater beneath the mesa, imply that the bedrock vadose zone can generally be considered as recharge-limited rather than permeability-limited (Hurst and Solomon, 2008), which corroborates the assumption that recharge and flow through the bedrock vadose zone is predominately via matrix flow rather than through fracture flow.*

The potential occurrence of increased flow and transport from the presence of uncemented and/or higher permeability intervals in the unsaturated zone of the Dakota sandstone and Burro Canyon Formation underlying the site area is not supported by geologic and hydrogeologic observations as summarized below:

- *Sub-horizontal units of potentially more permeable lithologic units (e.g., conglomerate and sandstone with intermittent conglomeratic features) cannot be correlated as broad continuous lenses beneath the tailings cells (HGC, 2010b). However, these units can be correlated short distances between boreholes as thin discontinuous lenses of limited thickness.*

- *A poor correlation between conglomeritic intervals and enhanced permeability has been observed through interpretation of hydraulic testing (HGC, 2010a):*

    - *Hydraulic conductivity tests in the horizontal direction for conglomeratic lenses beneath Cell 4B (MW-16) were approximately 5.1x10-7 m/s which is within the middle of the range of values (2.9x10-7 to 9.1x10-6 m/s) reported for the more massive sandstone lithology (HGC, 2010a).*

    - *Hydraulic conductivity tests in the horizontal direction for conglomeratic lenses beneath Cell 3 (angled borings) were lower than 1x10-7 m/s for three tests and higher than 1x10-7 m/s for one test (HGC, 2010a).*

    - *The similar hydraulic behavior between the sandstone and conglomeritic lenses can be explained because the conglomerate matrix is represented by sandstone and the gravel-sized clasts within the conglomerate are generally present in low percentages (less than 30 percent).*

- *The presence of unidentified high permeability discontinuous conglomeritic layers of limited thickness within the vadose zone would likely result in more timely detection of any seepage that may occur; because these units, if present, could act to spread any seepage over a wider area, and make such fluids less likely to pass undetected between monitoring wells (HGC, 2010a).*

A discussion regarding the material presented above will be included in the next iteration of the ICTM Report to some extent within Sections 2.2 and 4.3."

"Response 2 (May 31, 2012):

A brief summary of the geochemical characteristics of the perched groundwater as it relates to the development of input assumptions for the vadose zone will be included in the next iteration of the ICTM Report. The following discussion is anticipated to be included in Appendix M, to support the reactive transport model for the next iteration of the ICTM Report.

The geochemical modeling requires input assumptions regarding (i) the chemistry of the tailings pore water, (ii) the chemistry of the bedrock vadose zone pore water, and (ii) the mineralogy of the bedrock vadose zone. The geochemical characteristics of the vadose zone pore water can be constrained by the solid phases present within the bedrock and the pore water chemistry within the perched aquifer. The conceptual model used to support the geochemical modeling input assumptions for the vadose zone is explained below, while the conceptual model used to support the geochemical modeling input assumptions for the tailings pore water seepage chemistry is explained in the response to Comment Six (6) below.

Recharge, especially from the unlined wildlife ponds east of the mill site, represents the dominant source of the perched groundwater beneath the mill (Hurst and Solomon, 2008). Recharge from water (percolation) within shallow portions of the bedrock is likely to be near atmospheric conditions with a concentration of dissolved oxygen (DO) on the order of 8 milligrams per liter (mg/L). As percolation continues to migrate through the bedrock, the oxidation of organic compounds is likely to consume a portion of the dissolved and gaseous oxygen through aerobic respiration because this process is the most energetically favorable redox reaction anticipated to occur within the oxic vadose zone (Langmuir, 1997). Redox reactions within the bedrock and resultant pore water chemistry will be controlled by the water to rock and microbial reactions that occur during transport through the vadose zone. The presence of iron hydroxides and carbonate minerals in the bedrock suggests that oxic conditions coincident with aerobic respiration at near neutral pH are likely to dominate within the vadose zone. Therefore, the vadose zone pore water is anticipated to contain DO at detectable concentrations that reflect oxic conditions consistent with the presence of hydrous ferric oxide (HFO) within the bedrock.

Additionally, as the percolation continues to migrate downward through the vadose zone, the recharge water will eventually mix with the perched groundwater and equilibrate with minerals present within the zone of saturation. While there are naturally-occurring concentrations of chloride, sulfate, uranium, and other trace elements in the vadose zone initially, the modeling assumed zero concentrations as a simplification Initial solution concentrations in the vadose zone pore water were estimated by assuming equilibrium of calcite with HFO (Appendix M), consistent with minerals observed in the bedrock, such that only calcium, carbonate, and dissolved oxygen were included as aqueous species initially present within the vadose zone pore water.

Dissolved Oxygen

The concentration of DO is not being measured for wells screened within the perched aquifer because this analyte is not required by the groundwater discharge permit. However, DO was measured at a subset of the monitoring wells as part of the evaluation completed by the University of Utah (G. Hurst, 2012). These measurements are summarized below (see Table 05/1/2-1). The concentration of DO within groundwater appears to be related to the vadose zone thickness such that a thinner vadose zone correlates with a higher DO concentration in groundwater. Therefore, taking the measurement reported for the minimum vadose zone thickness (MW-30) to be consistent with the numerical model, the concentration of DO within the vadose zone pore water is likely greater than the 5 mg/L concentration reported for groundwater at this monitoring location. Within the bedrock vadose zone, the partial pressure of oxygen was fixed in the geochemical model assuming a DO concentration of 2 mg/L in pore water. Therefore, this assumption appears to be valid for the bedrock vadose zone, based on measurements of DO in groundwater for the minimum vadose zone thickness, at least as an initial condition.

Redox

The study completed by the University of Utah (Hurst and Solomon, 2008) did not measure concentrations within groundwater for any complete pair of redox species. However, in spite of observations of pyrite at some locations in the aquifer matrix, the presence of DO within groundwater suggests that oxic conditions and aerobic respiration are likely to dominate redox reactions in the vadose zone and in groundwater influenced by seepage from the wildlife ponds. Therefore, the oxygen redox couple is anticipated to control redox reactions within the bedrock vadose zone and in groundwater, at least as an initial condition. Whether or not this assumption would hold true if potential tailings seepage water was transported through the vadose zone will be discussed in the Response to Comment Six (6) below."

Table for Response 2 (May 31, 2012):

Table 05/1/2-1. Dissolved Oxygen (DO) Measurements For a Subset of Wells Screened Within the Perched Aquifer

Well	Location	DO at Upper Measurement Point (mg/L)	DO at Upper Measurement Point (mg/L)	Vadose Zone Thickness (m)
MW-5	*Between Cell 3 and 4B*	*0.02*	*0.01*	*22.9*
MW-11	*Between Cell 3 and 4A*	*0.25*	*0.01*	*19.5*
MW-14	*South of Cell 4A*	*0.14*	*0.04*	*22.9*
MW-15	*Between Cell 4A and 4B*	*1.43*	*0.24*	*19.5*
MW-29	*Between Cell 2 and 3*	*0.41*	*0.03*	*22.6*
MW-30	*Between Cell 2 and 3*	*5.24*	*5.12*	*12.8*
MW-31	*Between Cell 2 and 3*	*8.33*	*9.10*	*13.1*

Notes: Data provided electronically by G. Hurst. Samples were collected during July 2007. Dissolved oxygen measurements were made at the depths at which the passive diffusion samplers (PDSs) were deployed. The PDSs were deployed approximately 1 meter above the bottom of the screened interval ~~and 1 meter below the top of the screened interval. In wells that did not have a fully saturated~~ screened interval (MW-5, 14, 15, 29, 30, 31), the top diffusion sampler was placed approximately 1 meter below the top of the water level. Vadose zone thickness taken as difference between cell depth and water table depth.

"Response 3 (May 31, 2012):

Aluminum was selected to obtain charge balance because it was not measured in the various solutions representing the input chemistry, and the solutions had a negative charge imbalance which suggested cation deficiency. This additional text will be added to Sections 3.4.4 and Appendix M of the next iteration of the ICTM Report.

"Response 4 (May 31, 2012):

The values used to compute the statistics were derived from arithmetic averaging of primary and duplicate sample results (where applicable) after rounding to the nearest whole number for the acid neutralization potential (ANP) data. Duplicate samples for materials submitted May 2009 were labeled as being blind (i.e., collected from MW-100 with arbitrary depth intervals). The following sample locations corresponded to the following sample labels:

- *MW-24 80.0-80.3 Duplicate labeled as MW-100 11.1-11.3. The primary and duplicate samples results for ANP were equal to 25 and 28 grams of CaCO3 per kilogram of rock (g CaCO3/kg rock), respectively.*
- *MW-24 56.0-56.2 Duplicate labeled as MW-100 16.0-16.2. The primary and duplicate samples had the same ANP results.*
- *TW4-22 69.8-70.0 Duplicate labeled as MW-100 19.8-20.0. The primary and duplicate samples results for ANP were equal to 10 and 29 g CaCO3/kg rock, respectively.*
- *MW-23 103.0-103.3 Duplicate was labeled as is to be consistent with the original sample labeling criteria for samples submitted to the laboratory during February 2007.*

Therefore the summary statistics presented in Appendix C are valid and do not require adjustment. Clarifying text will be included in Appendix C for the next iteration of the ICTM Report to avoid future confusion."

"Response 5 (May 31, 2012):

The dry bulk density of the bedrock was assigned to equal 2.0 grams per cubic centimeter (g/cm3). This value was based on the measurement reported for MW-23 (55.5-56.0 ft) to be consistent with the sample interval test results used to parameterize the bedrock hydraulic properties (Appendix C). The value assigned to the model is approximately equal to the arithmetic average (2.1 g/cm3) of the samples tested (Appendix B and C). Clarifying text will be included in Appendix M for the next iteration of the ICTM Report to avoid future confusion."

"Response 6 (May 31, 2012):

The presence of measured DO in groundwater suggests that oxic conditions and aerobic processes are likely to dominate redox reactions in groundwater and also in the vadose zone as discussed in the response to Comment Two in this interrogatory. Whether or not this assumption *would hold true if potential tailings seepage water was transported through the vadose zone is discussed below.*

The conceptual model used to support the geochemical modeling input assumptions for the tailings pore water seepage chemistry is based on the following observations and hypothesized processes anticipated to occur in tailings pore water at depth.

Concentrations of DO in the tailings pore water at depth are not available because this analyte is not required to be measured for the GWDP, license or tailings sampling plan.

Surface water or tailings pore water near the upper surface of the impoundment is likely to be near atmospheric conditions with a concentration of DO on the order of 8 mg/L. The concentration of DO at depth can only be estimated and bounded by the chemistry of the tailings solutions combined with potential redox reactions that may occur at depth within the impoundment. The tailings solutions are acidic and contain detectable concentrations of some organic compounds and elevated concentrations of chloride, nitrogen (nitrate plus nitrite and ammonium), sodium, and sulfate. The oxidation of minerals within the ore during acid leaching is the likely cause of elevated concentrations of iron and other ions in the tailings solutions.

Based on the chemistry of the tailings solutions discussed above the following redox reactions are anticipated to occur within the tailing pore water at depth to some extent.

The DO within the tailings pore water at depth is likely to be consumed to some extent if oxidation of organic compounds, ammonium, and ferrous iron occurs. If DO was completely consumed anoxic conditions would develop. Considering the solution chemistry of the tailings pore water, and the energetics of the reaction, nitrate reduction and ammonium oxidation would be the next most favorable anaerobic reaction to occur once DO is consumed. Therefore, considering the elevated concentrations of nitrogen species within the tailings pore water at depth, and thermodynamic constraints, measurements for the nitrogen species can be used to calculate redox (pE) conditions in the tailings pore water at depth. Redox conditions calculated from the nitrogen species can then be used to infer redox reactions and mineral stability within the iron system.

Using the chemistry for the tailings pore water at depth (Appendix K) but assuming a DO concentration of zero:

- *The redox value calculated by PHREEQC for the upper bound concentrations is approximately 629 millivolts (mV). Using the nitrogen calculated pe value iron would partition approximately 70% as ferrous iron. The saturation index for HFO is calculated to be 0.07, implying that the solution is at equilibrium with HFO.*

- *The redox value calculated by PHREEQC for the base case concentrations is approximately 631 millivolts (mV). Using the nitrogen calculated pe value iron would partition approximately 67% as ferrous iron. The saturation index for HFO is calculated to be 0.15, implying that the solution is slightly supersaturated with HFO, and HFO could precipitate barring any sort of kinetic constraints.*

- *The redox value calculated by PHREEQC for the lower bound concentrations is approximately 628 millivolts (mV). Using the nitrogen calculated pe value iron would partition approximately 72% as ferrous iron. The saturation index for HFO is calculated to be 0 02, implying that the solution is at equilibrium with HFO.*

For these redox conditions, the calculated pe of the tailings pore water at depth is approximately 10.6 and HFO is anticipated to be a stable phase within the tailings pore water at depth. These calculations are used to support an alternative conceptual model for conditions in which the iron redox couple is used to constrain redox conditions within the vadose zone during reactive transport. This conceptualization differs from the scenario presented in the 2010 Revised ICTM Report in that the concentration of DO was fixed to equal 2 mg/L in the tailings pore water. Originally, this assumption was incorporated into the model to maintain consistency with the DO concentration in the vadose zone as a simplification. The sensitivity of this assumption is evaluated and discussed below.

Sensitivity Analysis

The initial concentration of DO within the vadose zone was assigned to equal 2 mg/L, as supported by data presented in response two of this interrogatory. The oxygen couple was used to determine the redox of the initial solutions (a pE of 13.6) within the vadose zone. This is equivalent to the parameterization for the 2010 Revised ICTM Report.

The initial concentration of DO within the tailings pore water was assigned to be infinitely small (essentially 0 mg/L), and the iron couple was used to determine the redox of the seepage water (a pE of 10.6) and during reactive transport through the vadose zone.

Furthermore, for this sensitivity analysis, concentrations of DO within the vadose zone during reactive transport were not fixed but allowed to vary as a function of the geochemical reactions. Subsequent calculations did not assume a fixed Eh, rather redox conditions were allowed to change as a function of the geochemical reactions with redox being controlled by the iron couple. This is generally the preferred approach rather than fixing the Eh to a specific value that may have little to no quantitative meaning during reactive transport. Additionally, the mass of HFO initially present within the vadose zone was allowed to change based on changing redox conditions. To maintain geochemical conditions consistent with this alternative conceptual model, the mass of HFO available to participate in sorption was allowed to vary depending on *the simulated redox and geochemical conditions; the conceptual model incorporated into the 2010 Revised ICTM Report limited sorption to the mass of HFO initially present in the vadose zone. The simulated pH, redox, aqueous concentration of uranium, and sorbed concentration of uranium within the shallow vadose zone for these two conceptual models are plotted below* ***(see Figure 05/1/6-1 and 05/1/6-2) (Refer to EFR's response for these figures).***

The iron redox couple scenario has a slightly higher pH immediately beneath the liners compared to the oxygen redox couple scenario. This slightly higher pH is related to the mass of HFO that precipitates, which is slightly higher for the iron redox couple scenario: the precipitation of HFO consumes acidity which results in a slightly higher pH. Both scenarios show complete dissolution of calcite at about the same depth. The iron redox couple scenario has a lower pE immediately beneath the liners compared to the oxygen redox couple scenario. The slightly lower pE is based on the value input at the upper boundary. The lower pE at greater depths for the iron redox couple scenario is lower than the oxygen redox couple scenario; because DO that is originally present within the vadose zone is oxidized and consumes electrons.

The concentration of uranium in the shallow vadose zone is significantly lower for the iron redox couple scenario compared to the oxygen redox couple scenario. Decreased transport of uranium is attributed to increased sorption onto HFO for the iron redox couple scenario because more HFO is present within the vadose zone. The increased mass of HFO is consistent with the conceptualization that the mass of HFO available to participate in sorption was allowed to vary depending on the simulated redox and geochemical conditions."

"Response 7 (May 31, 2012):

The diffusion coefficient (Dw) for the solutes modeled was assumed to equal 1.75 centimeters squared per day (cm^2/d). The value for Dw was based on measurements for chloride at infinite dilution in water at 25°C, and do not represent measurements in seawater. The value of Dw for some of the more common aqueous species are summarized below (see ***Table 05/1/7-1****). The maximum value of Dw corresponds to the value for chloride while the minimum value of Dw corresponds to the value for uranium (uranyl ion).*

Diffusive transport was assumed to be species-independent as a necessary simplification because the model is not set-up to simulate multicomponent diffusive transport. Diffusive transport through the variably saturated porous media is simulated as an effective diffusion coefficient (De) that is calculated as a function of space and time as the product of Dw and tortuosity factor in the liquid phase (τw). While the value for Dw is constant, the model simulated values for De vary through space and time as a function of the simulated spatial variations in water content and resultant tortuosity.

In unsaturated porous media the value for De tends to increase as the degree of saturation increases because of the increased connectivity of the porous media (decreased tortuosity). For example, using the value for Dw referenced above (1.75 cm^2/d), if the VWCs were equal to 8 percent and 15 percent the corresponding values for De would equal approximately 0.14 and 0.62 cm^2/d, respectively. The calculated values for De are within the range of values presented in the literature:

- *Hu and Wang (2003) report values for De equal to approximately 0.13 and 0.22 cm^2/d for a sand soil at VWCs approximately equal to 8 percent and 15 percent.*

- *Badv and Mahmoundi (2009) report values for De from 0.30 to 0.60 cm^2/d for a silty sand soil at VWCs approximately equal to 19 percent and 37 percent.*

In part, the value for De represents an intrinsic property of the porous media such that a direct comparison with values reported in the literature should be completed with caution because diffusive transport will vary depending on the retention curve which influences the tortuosity factor.

Theoretically, a higher value for De will result in increased diffusion which will tend to increase mass spreading resulting in faster transport times for the migrating diffusive front during transport through the vadose zone. These postulated effects are confirmed by the following plot which illustrates the chloride concentration profile within the bedrock vadose zone using the maximum and minimum values for Dw reported in Table 05/1/7-1.

The concentration profiles using two different values for Dw are plotted after 240 years for the base case flow and transport scenario described in the 2010 Revised ICTM Report (see ***Figure 05/1/7-1****).*

The results presented above indicate that the higher value of Dw equal to 1.75 cm2/d based on measurements for chloride as implemented in the 2010 Revised ICTM Report result in increased diffusive transport (more conservative assumption) at the leading edge of the plume. Therefore, a sensitivity analysis for the value assigned to the diffusion coefficient at infinite dilution in open water (Dw) is not warranted."

"Response 8 (May 31, 2012):

Initial Pressure Heads

The initial pressure heads within the bedrock vadose zone were assigned to represent conditions prior to construction of the tailings cells. Initial values were based on an assumed pre-tailing-

cell recharge rate equal to 1 percent of the average annual amount of precipitation between 1932 and 1988. The assumption that 1 percent of the annual precipitation will occur as recharge generally is in agreement with recharge studies completed at other semiarid sites. For example, a synopsis of recharge measurements suggests that average recharge rates in arid and semiarid environments can vary between 0.1 to 5 percent of the long-term average annual amount of precipitation (Scanlon et al. 2006). The review paper authored by Scanlon et al. (2006) reported the following recharge rates for relatively comparable environments in the southwestern United States as compared to Blanding:

- *3 percent of precipitation for the Middle Rio Grande Basin in central New Mexico. This regional recharge rate (8.5 mm/yr) was estimated using a steady state, inverse groundwater model and carbon-14 age dating. Recharge occurs primarily in the surrounding mountain block and mountain front settings through ephemeral streams, with little or no recharge in inter-stream basin floor settings.*

- *0.4 percent of precipitation on the Pajarito Plateau of northern New Mexico beneath a pinon juniper cover within the shallow subsurface soils. This localized recharge rate (0.2 mm/yr) was estimated using cumulative chloride water plots. The major source of recharge at this location is derived from snowmelt and spring rains.*

- *0.02 to 2 percent of precipitation for the High Plains in the Texas panhandle. Vadose zone modeling studies found that focused higher recharge rates (11 mm/yr) occur beneath ephemeral lakes and playas while little to no recharge (<0.1 mm/yr) in inter-playa settings.*

- *1 to 6 percent of precipitation for the Black Mesa basin in northeastern Arizona. This regional recharge rate (5 to 20 mm/yr) was estimated using carbon-14 age dating combined with a coupled carbon-14 flow and transport model. This recharge rate was independently verified using chloride mass balance. The aquifer is recharged seasonally from precipitation in the highlands principally during the winter and spring, with less recharge at lower elevations.*

Based on the measurements reported above a recharge rate assuming 1 percent of the average annual amount of precipitation (approximately 3 mm/yr) is justified for use in determining the initial conditions of the bedrock vadose zone. This assumption is further supported by numerical modeling completed by Scanlon et al. (2003) for conditions of a single deep borehole located in the High Plains of Texas. Their model simulations suggest that water potential and chloride profiles at depth are out of equilibrium with current climatic forcing, and reflect Pleistocene climate conditions Current water fluxes in the shallow subsurface, which developed over thousands of years, currently are upward. Their simulations further suggest that the drying front was initiated during the Pleistocene/Holocene climate shift, and that chloride concentrations at *depth are low, which suggests that water fluxes during the Pleistocene were quite high on the order of 1.3 mm/yr while Holocene recharge rates are negligible at <0.1 mm/yr.*

Comparison of Water Content and Pressure Head Profiles

The volumetric water content throughout the vadose zone beneath Cells 2 and 3 during the operational, dewatering, and post-closure steady-state timeframes is plotted in Figure 4-4 of the 2010 Revised ICTM Report. A comparison between water contents and pressure head is plotted below (see Figure 05/1/8-1). The synoptic timeframes plotted correspond to maximum head conditions (13 and 23 years), the end of dewatering (33 years), and post-closure steady-state (100 and 240 years). The change in subsurface hydraulic conditions during the assumed maximum tailings seepage duration from 0 through 23 years is evident by the increasing VWC and decreasing pressure head within the shallow vadose zone (less than 5 meters depth). In response to dewatering and reduced potential seepages rates, the VWC and pressure head conditions within the vadose zone become drier and eventually reach steady state conditions. The nearly identical profiles after 100 and 240 years indicate that steady state flow conditions have developed in the bedrock vadose zone."

<u>"Response 9 (May 31, 2012):</u>

In the 2010 Revised ICTM Report sulfate is not transported as a conservative species. Sulfate is allowed to sorb onto HFO and precipitate as gypsum. Sulfate concentrations within the bedrock vadose zone are predominately dictated by mineral precipitation reactions, as noted in Figure M-3. Even though the precipitation of gypsum results in a faster transport rate compared to uranium, sulfate nonetheless, is retarded. Therefore, the most applicable conservative species for comparison of uranium sorption/retardation would be with chloride or fluoride.

<u>The distribution coefficient (Kd) in units of milliliters per gram (mL/g) and the corresponding</u> retardation factor (Rf) in dimensionless units, as calculated from the output of the reactive transport model after 240 years, are summarized below for the conditions represented in Figure M-4 ***(see Table 05/1/9-1)****. Data below 2.3 meters depth are not tabulated since the concentration of uranium in pore water was less than 0.005 mg/L.*

The calculated Kd values ranged between approximately 0.002 to 1.5 mL/g corresponding to calculated Rf values between approximately 1 and 41. The calculated Rf values suggest that uranium is moving at about the same rate as groundwater for acidic pH conditions and 41 times slower than groundwater for near-neutral pH conditions.

A comparison between calculated Kd values listed above, and those presented in the literature need to be made with some caution. This is because of the site-specific nature of the values calculated using the results of the reactive transport model may not directly correlate with other *studies. Krupka et al. (1999) summarized measured Kd values for uranium for the following pH values:*

- *pH 3 a minimum Kd of < 1 mL/g.*
- *pH 5 a minimum Kd of 25 mL/g.*
- *pH 7 a minimum Kd of 63 mL/g.*

Significant research has investigated Kd values at the Naturita site in Colorado for a variety of test conditions. For example, the geometric mean Kd value for measurements in Curtis et al. (2006) is approximately 1.6 mL/g covering a range between 0.55 and 12.5 mL/g for sediments suspended in wells at the Naturita field site at near-neutral pH. For comparison, the average Kd value for the reactive transport model at near-neutral pH is approximately 0.43 mL/g. The minimum Kd values presented by Krupka et al. (1999) are orders of magnitude higher than the Kd values calculated using the output of the reactive transport model, while the Kd values presented by Curtis et al. (2006) are approximately a factor of four higher. The model calculated Kd values for the iron redox couple scenario (defined in the response to comment six of this interrogatory) varies between calculated values hovering around 10 mL/g. Therefore, the sorption and attenuation of uranium is reasonably represented by simulations using the reactive transport model. Approximately 0.5 and 18 mL/g within the upper 0.75 meters with the majority of the calculated values hovering around 10 mL/g. Therefore, the sorption and attenuation of uranium is reasonably represented by simulations using the reactive transport model."

Table for Response 9 (May 31, 2012):

Table 05/1/9-1. Calculated distribution coefficients and retardation factors as a function of depth after 240 years.

Depth (m)	pH (s.u.)	Aqueous U Conc. (mg/L)	Volumetric Water Content (-)	K_d (mL/g)	R_f (-)
0 -0.15	*3.2*	*21*	*0.073*	*0.0015*	*1,.04*
0.20 - 0.45	*4.7*	*12*	*0.073*	*0.68*	*20*
0.50 - 0.70	*4.7*	*3.1*	*0.074*	*0.87*	*25*
0.75 - 2.15	*4.9*	*0.38*	*0.074*	*1.5*	*41*
1.0 - 2.15	*7.3*	*0.073*	*0.075*	*014*	*4.6*
2.2 - 2.3	*7.3*	*0.015*	*0.076*	*0.72*	*20*

Note: Values summarized above were calculated as the arithmetic average of simulated values within the noted depth interval for conditions represented by Figure M-4.

"Response 10 (May 31, 2012):

The results plotted in Figures M-3 and M-4 were meant to illustrate concentration profiles after various times, and not the source term concentration. The concentration at the upper boundary (0 centimeters depth) is a function of the applied boundary condition (mass flux rate equal to time variable flux multiplied by the concentration); therefore, plotting the source term concentration would be contradictory to the boundary condition implemented at the upper surface and likely would be a source of confusion. The initial source term concentrations are summarized in Table M-1, which the reader can easily transfer to Figures M-3 and M-4 if necessary.

"Response 11 (May 31, 2012):

The decrease in uranium concentration (approximately 0.7 mg/L) within the upper 15 centimeters from 50 years to 100 years is attributed to subtle differences in sorbed concentrations. The increase in uranium concentration from 100 years to 240 years (approximately 7 mg/L) is attributed to decreased sorption from increased surface site loading resulting from increased total mass released into the vadose zone.

5.3 Division's Assessment of EFR Responses to Rd 1 Interrogatory White Mesa Revised ICTM Report; R313-24-4; 10CFR40 Appendix A, Criterion 6(1); INT 01/1

Response 1

Based on a review of the EFR Response, the clarification regarding the primary and duplicate sample pairs is useful and the explanation regarding duplicates in this Response should be included in the revised ICTM report. However, the sample statistics, particularly ANP ranges derived from the geometric mean and standard deviation appears to be in error. The apparent error is based on a misconception concerning the use of the geometric mean and the geometric standard deviation in describing the spread or distribution of the data. EFR states on page C-7 of Appendix C that "to support the sensitivity analysis, and determine a range of values for the amount of ANP, the geometric mean plus one geometric standard deviation was selected for an upper bound, while the geometric mean minus one standard deviation was selected as a lower bound. The geometric mean plus one geometric standard deviation corresponds to approximately 68% of the observations." These are incorrect approaches to use with lognormally distributed data. To find the proper bounding limits, the geometric mean must be multiplied (or divided) by the geometric standard deviation. Naturally log-normally distributed data have an asymmetric distribution and different values for mode, median and mean.

Adding the same value on either side of the mean, as EFR has done, does not properly characterize the interval containing 68.3% of the data. Bleam (2011)[1] explains the concept: "Log-normal distributions are asymmetric about the geometric mean. The lower limit of a range covering 68.3% of the population is the geometric mean divided by the geometric standard deviation while the upper limit is the geometric mean multiplied by the geometric standard deviation." Thus, the approach used in the Revised ICTM Report is not statistically correct; it does not follow standard professional practice. The natural data need to be first transformed by taking their logarithms, the transformed data need to be tested for normality, the mean and standard deviation of the transformed data need to be calculated, and then these intermediate parameters need to be exponentiated to obtain the geometric mean (GM) and the geometric standard deviation (GSD). The value of the lower bound of the population interval containing the central 68.3% of the data is equal to the geometric mean divided by the geometric standard deviation (GM/GSD) ; the upper bound is equal to geometric mean multiplied by the geometric standard deviation (GM*GSD). A similar issue exists for the HFO data.

An example is provided for ANP at Well MW-24. There are 9 data points. Thus, N-1 = 8. As indicated in Table C-15, the arithmetic mean is 7. The standard deviation is 7.68. The geometric mean (GM) is 5.17. The geometric standard deviation (GSD) is 2.06. The geometric mean is an appropriate measure of central tendency for the data, assuming that the ANP data are lognormally distributed. The lower bound of the interior 68.3% data-dispersion interval is the quotient of the geometric mean divided by the geometric standard deviation. This quotient is equal to 2.51 mg $CaCO_3$/kg rock. The upper bound of the interior 68.3% data-dispersion interval is the product of the geometric mean and the geometric standard deviation. This product is equal to 10.7 mg $CaCO_3$/kg rock. Thus, again assuming log-normality, the interior 68.3% of the data in the actual population should statistically fall within the range 2.51 to 10.7 mg $CaCO_3$/kg rock. Within the sample population, six of nine values, or 67%, fall in that estimated range, which is in excellent agreement with the theoretical value for the population.

~~Thus, the results of ICTM model sensitivity runs for ANP are in error because they do not~~ account for a sufficiently wide distribution of data. Accordingly, please correct all incorrect statistical calculations, and re-run the model sensitivity analysis for ANP and HFO using the lognormal distribution and the correct distribution parameters. Alternatively, the most conservative (i.e., the lowest) ANP or HFO values can be used in the model. A value of the geometric mean divided by two geometric standard deviations can be used. This will give a limit or bound above which 95.5% of the data values in the population should exist. Only 4.4% of the data values in the population should be less. Revise, as appropriate, the text, tables, and figures in the revised ICTM report and Appendix C to correct any statistical

[1] Bleam, W.F.,2011, Environmental Soil Chemistry, Academic Press, 496 pp.

errors that may be present for ANP and HFO. Furthermore, revisit the statistics for any other data that have a lognormal distribution and determine the correct, as appropriate, upper and lower bounds of the data determined using geometric means and standard deviations.

As an aside, a minor editorial clarification is needed on page M-10 where it is stated that "the amount of ANP present in the bedrock vadose zone was reported as grams of calcite ($CaCO_3$) per kilogram or rock." Please note that the original data reported in Appendix A are not reported using these particular units, although the units reported are equivalent. The text should be revised to reflect the actual reported units and the subsequent conversion to equivalent units used to develop the model input parameters.

Response 2

Based on a review of the EFR Response, the approach discussed concerning the initial geochemical conditions in vadose zone pore water where only calcium, carbonate, and DO (2 mg/L) at concentrations representing equilibrium with calcite and HFO is reasonable and is supported by the solid phase data available for the vadose zone bedrock and DO data available for the underlying groundwater. An assumption that redox is controlled by the oxygen couple and the concentrations of other constituents is zero is also reasonable and provides for a conservative simulation of constituent transport. The discussion provided in the Response should be included in the revised ICTM report to justify the initial geochemical conditions assumed for the vadose zone pore water.

Response 3

Based on a review of the EFR Response, using aluminum to obtain a charge balance in the PHREEQC modeling appears to be reasonable for cation deficient solutions. The explanation provided in the Response should be included in the revised ICTM report for clarity.

Response 4

The Division request that EFR provide additional information regarding the potential locations and distribution of fractures in the area beneath and downgradient of the tailings management cells area based on the information discussed below.

The interpretation provided in EFR's response above is similar to that presented in previous correspondence submitted by the Licensee in response to Round 1 Interrogatories submitted by on the Cell 4B Environmental Report (DUSA 2009). In that Response, the Licensee provided a letter, dated November 10, 2009, from Hydro Geo Chem which indicated that the reported sub-horizontal, limonite-stained features interpreted in the 1978 ER (Dames & Moore 1978) as bedding plane fractures may not be actual fractures but may represent structurally weaker zones along bedding planes that appear as partings in core samples. According to the Hydro Geo Chem report, examination of core samples collected during drilling of angle borings beneath tailings Cells 3 and 4A indicate that where fractures were present in cores, they were cemented with gypsum. They indicated that open fractures significant enough to impact groundwater movement in the perched

zone were not identified in that investigation. Hydro Geo Chem also concluded that no fractures were reported in cores from MW-3A, MW-16, or MW-23, the existing wells adjacent to or at the current location of Cell 4B. Hydro Geo Chem concluded that this made it even less likely that potentially undetected fractures could significantly affect subsurface fluid flow in the vicinity of proposed Cell 4B, and that, should the sub-horizontal features reported in the 1978 ER actually represent fractures, their sub-horizontal nature would prevent them from acting as vertical conduits from the tailing cell to the perched groundwater.

The Licensee also previously referred to the same Hydro Geo Chem Letter Report dated February 8, 2010 ('HGC, 2010a') that provided additional information and also recommended the installation of new monitoring wells MW-33 and MW-34 in the area of Cell 4B. These wells, as proposed, would be screened across the perched zone. In a meeting with the Division on February 18, 2010, the Licensee agreed to install three new wells, including a third monitoring well, MW-35, adjacent to the western edge of Cell 4B. New well MW-35 was proposed to help further define subsurface conditions and potential groundwater migration patterns downgradient of proposed Cell 4B.

The Division incorporated a new Permit condition requiring that a minimum of three additional downgradient groundwater monitoring wells be installed near Cell 4B. The Division requests that additional geologic data available from the wellbores for these three wells (MW-33 through MW-35) be evaluated and interpreted with respect to the additional information that these wells borings provide regarding the potential occurrence and distribution of fractures and conglomeratic zones downgradient of the Cell4 B/tailings management cells area. EFR should supplement and/or revise the interpretation provided in the Response above to reflect the results of their evaluation of this additional wellbore data.

Response 5

Based on a review of the EFR Response, a question arises as to why a dry bulk density of ~~2.0 g/cm^3 was assigned. Additionally, Please provide further discussion of the rationale~~ used for selecting a bulk density value of 2.0 g/cm^3 for bedrock for use in converting ANP and HFO values from rock mass to rock unit volume. Discuss locations of core samples considered with respect to: (1) locations of core boreholes with respect to the different disposal cells; and (2) the depth intervals of the core sample intervals considered with respect to the thickness of the vadose zone at each core interval location. Further justify the value of bulk density chosen (or different bulk density values that may be selected for use at different locations), including need for excluding from consideration any core interval(s) that lie within the saturated zone (e.g., See Table C-3 in Appendix C of the Revised ICTM Report). Please revise any affected calculations, re-run the model, and revise the ICTM report, as appropriate.

Response 6

Based on a review of the EFR Response, the approach discussed concerning the DO concentration in the tailings pore water is reasonable and is supported by the geochemical data available for the tailings pore water. The results suggest that the fixed DO condition is likely more conservative as it predicts uranium to be transported to greater depths than redox value determined using nitrogen and iron species. The decreased uranium transport under the iron redox couple scenario is likely due to increased sorption on HFO precipitated in the vadose zone. The discussion provided in the Response should be included in the revised ICTM report to justify the initial DO concentrations selected.

Response 7

Based on a review of the EFR Response, the chloride diffusion coefficient selected to represent all solutes in the model is reasonable. The sensitivity analysis provided in the Response suggests that the selected diffusion coefficient likely overestimates the diffusive transport depth of most of the solutes simulated. The discussion provided in the Response should be included in the revised ICTM report to justify the diffusion coefficient selected.

Response 8

Based on a review of the EFR Response, the discnssion provided outlines recharge rates for relatively comparable environments to White Mesa and suggests that regional recharge rates can vary from 0.1 to 6 percent of average annual amount of precipitation. However, EFR's justification for assuming 1 percent of the average annual amount of precipitation is not clear. It appears based on the studies cited in the Response that the assumed 1 percent recharge rate used in the model is on the lower end of the recharge rates reported for similar sites. In fact, the recharge rate chosen for the model appears to be up to 5 times less than average annual recharge rates reported for similar sites located on the Colorado Plateau (Healy 2010[2]). Additional justification for selecting a recharge rate equal to 1 percent of the average annual amount of precipitation should be provided or sensitivity analyses varying the initial average annual recharge rate within a reasonable range (e.g., 1 to 5 percent) should be performed to demonstrate the sensitivity of the model results to the initial volumetric water contents and pressure head distributions.

The comparison of volumetric water content and pressure head profiles provided in the Response appears to reasonably demonstrate that the post-closure volumetric water contents and pressure heads reach steady state in about 100 years, given the assumed initial recharge rate of 1 percent, the assumed maximum head conditions estimated for the operation of Cells 2 and 3 and the subsequent estimated dewatering rate used in the model. The discussion provided in the Response, as well as any additional sensitivity analyses of

[2] Healy, R. W., 2010, Estimating Groundwater Recharge, Cambridge University Press, United Kingdom, 245 pp.

the assumed initial recharge rate, should be included in the revised ICTM report to justify the initial water content and pressure head distributions selected for the flow model.

Response 9

Based on a review of the EFR Response, the explanation provided is reasonable and should be included in the revised ICTM report for clarity. The revised ICTM report should further indicate

Response 10

Based on a review of the EFR Response, the explanation provided is reasonable and should be included in the revised ICTM report for clarity.

Response 11

Based on a review of the EFR Response, the explanation provided is reasonable and should be included in the revised ICTM report for clarity. Further discussion should be provided regarding the relative degree or percentage of loading predicted for the surface sites and its impact on sorption of uranium as well as other constituents.

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