DRC-2013-003854

December 30, 2013 CD13-0359

Mr. Rusty Lundberg
Director
Utah Division of Radiation Control
195 North 1950 West
P.O. Box 144850
Salt Lake City, UT 84114-4850

Re: Utah Radioactive Material License (RML UT2300249) Updated Site-Specific Performance Assessment; Response to Round 1 Request for Information

Dear Mr. Lundberg:

On 7 June 2013, Energy*Solutions* received from the Division a Round 1 Request for Information regarding the updated site-specific Performance Assessment (originally submitted 9 October 2012). Following receipt of the Request, Energy*Solutions* met with Division staff on 16 July 2013 and 29 August 2013 to discuss and clarify the requests and appropriate form for response. As a result, attached is revision 1 of the updated site-specific Performance Assessment. Where necessary, the Report has been revised in response to the Division's request and detailed interrogatory responses provided.

Revision 0 of the updated site-specific Performance Assessment originally included the Neptune Modeling Report as its Appendix B. Preparation of revision 1 of the updated site-specific Performance Assessment has not resulted in a need for Energy*Solutions* to revise Neptune's original model (as previously submitted). Therefore, all references to Appendix B or Neptune's Performance Assessment, reference Appendix B, as submitted with revision 0.

While the Energy*Solutions* Class A West Embankment has been sited, designed, and operated for the disposal of Class A waste, revision 1 of the site-specific Performance Assessment specifically confirms that:

- The embankment is suitably sited and licensed for the disposal of large quantities of blended ion-exchange resins (in excess of 40,000 $ft^3$ per year) at or near the Class A limits;

- Disposal of waste in the Containerized Waste Facility provides inherent additional intruder protection;

- Protection of an inadvertent intruder is provided even though there are no credible intrusion scenarios;

- The proposed alternative evapotranspirative cover design meets the required performance objectives of UAC R313-25; and

- Consumption of the groundwater will not result in a dose that exceeds standards, even though the groundwater is not potable.

In conclusion, Energy*Solutions* finds that disposal of large volumes of blended resins will continue to have no significant environmental impacts unaddressed by prior licensing actions. Furthermore, the proposed alternative evapotranspirative cover design will perform as modeled. If you have any questions regarding this request, please contact me at 801-649-2000.

Sincerely,

Daniel B. Shrum
Senior Vice President, Regulatory Affairs

cc: John Hultquist, DRC

ENERGY*SOLUTIONS*

# UTAH RADIOACTIVE MATERIAL LICENSE (RML UT2300249)

# UPDATED SITE-SPECIFIC PERFORMANCE ASSESSMENT

**(Revision 1)**

**December 30, 2013**

**For**
**Utah Division of Radiation Control**
195 North 1950 West
Salt Lake City, UT 84114-4850


**Energy*Solutions*, LLC**
423 West 300 South, Suite 200
Salt Lake City, UT 84101

## EXECUTIVE SUMMARY

Energy*Solutions*, LLC (Energy*Solutions*) operates a low-level radioactive waste (LLRW) disposal facility west of the Cedar Mountains in Clive, Utah. On 14 February 2011, Energy*Solutions* requested concurrence from the Utah Division of Radiation Control that previous licensing activities allowed for the receipt and disposal of processed ion-exchange resin waste on a large-scale at the Clive facility (Shrum, 2011a and Shrum, 2011b). The Division reviewed Energy*Solutions*' request and determined that Energy*Solutions* could receive processed ion-exchange resin waste up to 40,000 cubic feet per year. In order to receive processed ion-exchange resin waste at volumes greater than 40,000 cubic feet per year, Energy*Solutions* would be required to conduct an updated site-specific Performance Assessment that includes prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways. In accordance with these directives, an updated site-specific Performance Assessment was submitted to the Division on 8 October 2012. On 7 June 2013, Energy*Solutions* received from the Division a Round 1 Request for Information regarding the updated site-specific Performance Assessment. Where necessary, this report has been revised in response to the Division's request and detailed interrogatory responses provided.

The updated site-specific Performance Assessment utilizes the HYDRUS and RESRAD platforms, replacing the previous HELP, UNSAT-H, and PATHRAE platforms. In addition, updated climate, weather patterns, temperature records, wind reports, precipitation measurements, evaporation records, geology characteristics, hydrology logs, surface water observations, groundwater measurements, and ecologic field studies were used as input into the calculations. Two alternate cover designs were analyzed (in comparison to the site's traditional rock armored cover) and the list of Class A nuclides expanded by 19.

The updated site-specific Performance Assessment demonstrates continued protection of the general public following embankment closure through consideration of possible contaminant transport via the atmosphere, site soils, groundwater, surface water, vegetation, and burrowing animal pathways. Similarly, the impact of viable inadvertent intrusion is demonstrated to be well below regulatory limits.

Doses to the general public during operations continue to be monitored and controlled according to Energy*Solutions*' Radiation Protection Program, Environmental Monitoring Program, and ALARA Program. Because of these administrative controls, inclusion of additional volumes of blended ion-exchange resins up to 100 percent of the waste inventory does not compromise the Embankment's performance or reduce protection of the general public from plant or animal driven migration of contaminants during operations.

Energy*Solutions* has demonstrated in previous licensing activities that the disposal site, disposal site design, land disposal facility operations, disposal site closure, and post-closure institutional control plans are adequate to protect the public health and safety. Design features and operational practices do not require alteration to accommodate the disposal of processed ion-exchange resin waste in excess of 40,000 $ft^3$, annually.

The updated site-specific Performance Assessment also demonstrates that, because of the very low infiltration rates associated with the alternative evapotranspirative cover designs, no water that infiltrates through the covers will reach the point of compliance within 10,000 years. Therefore, no radionuclide contamination will arrive at the point of compliance well within the 10,000 year assessment period. As such, disposal of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the groundwater resource.

The design of the Containerized Waste Facility (CWF) exceeds regulatory requirements for disposal of Class A waste and provides intruder barriers for wastes above the Class A classification (e.g., engineered facility, disposal unit stability, and at least 5 meters depth to waste). Therefore, the CWF design, operation, and license support demonstrate protection of inadvertent intruders from the disposal of larger volumes of Class A blended resins.

Therefore, this updated site-specific Performance Assessment and the resulting findings demonstrate that Energy*Solutions*' proposed evapotranspirative cover system and methods for disposal of blended ion-exchange resins in excess of 40,000 $ft^3$ annually will ensure that future operations, institutional control, and site closure can be conducted safely, and that the site will comply with the Division's radiological performance criteria contained in UAC R313-15 and UAC R313-25.

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ENERGYSOLUTIONS

# 1. INTRODUCTION

Energy*Solutions*, LLC (Energy*Solutions*) operates a low-level radioactive waste (LLRW) disposal facility west of the Cedar Mountains in Clive, Utah. Clive is located along Interstate-80, approximately 3 miles south of the highway, in Tooele County. The facility is approximately 50 miles east of Wendover, Utah and approximately 75 highway miles west of Salt Lake City, Utah. The facility sits at an elevation of 4,275 (ft) above mean sea level (amsl).

## 1.1 Purpose

On 14 February 2011, Energy*Solutions* requested concurrence from the Utah Division of Radiation Control (the Division) that previous licensing activities allowed for the receipt and disposal of processed ion-exchange resin waste on a large-scale at the Clive facility (Shrum, 2011a and Shrum, 2011b). The Division reviewed Energy*Solutions*' analysis supporting this request and determined that Energy*Solutions* could receive processed ion-exchange resin waste up to 40,000 cubic feet per year. However, in order to receive processed ion-exchange resin waste at volumes greater than 40,000 cubic feet per year, Energy*Solutions* would be required to conduct a new performance assessment analyses that include

> "*prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways*" (Lundberg, 2011).

While the ultimate quantity of disposed processed ion-exchange resin waste is unknown, Energy*Solutions* further recognizes that UAC R313-25-8(1)(c) supports the Division's requirement for an updated site-specific Performance Assessment (in the event that the total disposal volume of processed ion-exchange resin waste "*will result in greater than 10 percent of the total site source term over the operational life of the facility*" [UAC R313-25-8(1)(c)]. In compliance with these requirements, Energy*Solutions* submitted to the Division on 8 October 2012 an updated site-specific Performance Assessment, which included:

- Analysis of additional subsurface fate and transport of LLRW contaminants leached from the Embankment via contact with precipitation that has infiltrated through two possible embankment cover designs, and transported to a well at the point of compliance 90 feet from the outside edge of the LLRW material in the disposal cell;

- Modeling of expected groundwater well concentrations and comparison to groundwater protection levels (GWPLs) for a Time of Compliance of 500 years following embankment closure, projected peak groundwater well concentrations for each radionuclide for a Performance Period of 10,000 years following embankment closure, and projected peak doses to the general public due to ingestion of well water for a Performance Period of 10,000 years following embankment closure;

- Modeling of expected exposures and resulting doses to hypothetical inadvertent intruders within a Time of Compliance of 1,000 years following embankment closure; and

- Evaluation of additional radionuclides that were not included in prior Class A Performance Assessments conducted in support of Clive licenses (see Table A-1 of Appendix A).

On 7 June 2013, Energy*Solutions* received from the Division a Round 1 Request for Information regarding the updated site-specific Performance Assessment. Where necessary, this report has been revised in response to the Division's request and detailed interrogatory responses provided. Revision 0 of this updated site-specific Performance Assessment included the Neptune Modeling Report as its Appendix B. Preparation of revision 1 of this updated site-specific Performance Assessment has not resulted in a need for Energy*Solutions* to revise Neptune's original model (as previously submitted). Therefore, all references to Appendix B or the updated site-specific Performance Assessment herein, reference Appendix B, as submitted with revision 0.

### 1.2 Other Associated Performance Assessments

In 2010, the Utah Radiation Control Board (the Board) promulgated a new rule (UAC R313-25-8, "Technical Analysis") that required Energy*Solutions* to conduct a site-specific Performance Assessment before disposing of large volumes of depleted uranium (URCB, 2010). In compliance with the Board's directive, Energy*Solutions* submitted a new depleted uranium site-specific Performance Assessment to the Division, based upon the GoldSim Platform (McCandless, 2011). The depleted uranium Performance Assessment evaluated quantitative doses to 10,000 years and qualitative effects out to geologic time frames to account for the far-future uranium chain in-growth influences. This Report's updated site-specific Performance Assessment does not project the fate and transport through geologic time periods nor does it replace the depleted uranium Performance Assessment.

In 2012, Energy*Solutions* requested that the Division amend Radioactive Material License # UT 2300249 and Ground Water Quality Discharge Permit No. UGW450005 to combine the Class A and Class A North disposal embankments into one embankment (termed *Class A West*), (McCandless, 2012). To support this request, Energy*Solutions* utilized the same PATHRAE, UNSAT-H, and HELP methodology that was employed for previous Clive embankment licensing efforts, updating it to reflect the new Class A West geometry. Potential groundwater impacts from the Embankment with a traditional rock-armored cover system were similarly evaluated using the methodology consistent with previous groundwater models performed for other Clive facility embankments (Whetstone, 2011). While the updated site-specific Performance Assessment described herein is consistent with and supports the assessment conducted in justification for the embankment combination request, it has been prepared to address the disposal of blended resin volumes in excess of 40,000 $ft^3$.

### 1.3 Blended Ion-Exchange Resins

Spent resins from ion-exchange systems at nuclear power plants are low-level radioactive waste and require disposal at a licensed facility. Energy*Solutions,* in a joint venture with Studsvik LLC known as SempraSafe, uses the THermal Organic Reduction (THOR) process to blend low-activity resins with small amounts of higher-activity resins using heat to significantly volume-reduce spent resins into a solid-phase, compact, homogeneous, chemically and environmentally stable waste form known as processed ion-exchange resin waste (Shrum, 2011a and Shrum, 2011b).

NRC issued direction encompassing disposal of processed ion-exchange resin waste in the form of a Staff Requirements Memorandum (SRM), to direct the Commission's current position be risk-informed and performance-based through a combination of rulemaking and guidance. In its analysis of the disposal of processed ion-exchange resin waste, NRC staff expressed concern that the disposal of large quantities of waste at or near the Class A limit may not have been evaluated fully in the development of the initial regulations for the disposal of LLRW in 10 CFR 61. However, the staff acknowledged that actual disposal practices for such wastes were far more robust than the disposal techniques analyzed when the initial regulations were developed. In particular, staff recognized that current disposal at the Clive facility includes engineered barriers and increased depths that provide significant protection for an inadvertent intruder. Specifically, staff stated in their recommendation,

> *"The staff's preliminary independent analysis indicates that current practice at . . . disposal facilities may safely accommodate an increase in the amount of disposed waste at or just below the Class A limits. Site-specific intruder analyses could be used to confirm protection of individuals from inadvertent intrusion at these sites."* (NRC, 2010, pg. 19).

NRC also stated its position that large-scale LLRW blending may be conducted when it can be demonstrated to be safe, (NRC, 2010, pg. 36).

Historically, Energy*Solutions* has directly disposed of processed ion-exchange resin waste from utility customers and THOR-processed resins under its current license from the Division. However, to address the disposal of a processed ion-exchange resin waste-stream in volumes greater than 40,000 cubic feet per year, Energy*Solutions* has prepared the updated site-specific Performance Assessment described herein.

### 1.4 Regulatory Context

In the context of disposal of radioactive waste, a performance assessment is a quantitative evaluation of potential releases of radioactivity from a disposal facility into the environment, and assessment of the resultant radiological doses. Energy*Solutions* conducts performance assessments to demonstrate that the Clive Disposal Facility meets its performance objectives throughout the required period of performance.

#### 1.4.1 UAC R313-15-401: Periods of Performance versus Times of Compliance

Analysis of the appropriate Periods of Performance and Times of Compliance applicable to this updated Site-Specific Performance Assessment includes the following promulgated requirements for disposal of Class A waste.

1. 500 YEARS: Energy*Solutions'* Class A West Embankment is subject to performance limits on the release of groundwater contamination, as required by UAC R317-6-2 (delineated in Clive's Ground Water Quality Discharge Permit). However, UAC R317-6-3 classifies Clive's groundwater as Class IV, *"non-potable, saline ground water."* Because of this, the

Period of Performance for protection of Clive's groundwater resources from further degradation is 500 years, following the Class A West Embankment closure.

2. 1,000 YEARS: In addition to preservation of the current non-potable condition of the groundwater resource, Energy*Solutions* is also required

> "*When calculating the total effective dose equivalent to the average member of the critical group, the licensee shall determine the peak annual total effective dose equivalent dose expected within the first 1000 years after decommissioning.*" [UAC R313-15-401(4)].

While specifically referencing a time duration following decommissioning, these requirements specifically, "*apply only to ancillary surface facilities that support radioactive waste disposal activities,*"[UAC R313-15-401(1)] and not the Class A West Embankment itself. As such, the 1,000 year Total Effective Dose Equivalent (TEDE) limit is a Time of Compliance and not applicable to the specific Period of Performance of the closed Class A West Embankment.

Furthermore, no specific Period of Performance of the closed Class A West Embankment has been promulgated in UAC R313-25-20, as related to the protection of a hypothetical inadvertent industrial intruder. However, NRC guidance has historically assessed intruder scenarios for a time period equivalent to that indicated in UAC R313-15-401(4), (e.g., 1,000 years after facility closure), (NRC, 1986). Embankment performance for 1,000 years for the protection of an inadvertent industrial intruder is also supported by the precedent time periods required by 10 CFR 20, Subpart E (for decommissioned sites), 10 CFR 40, Appendix A (for uranium mill tailings), and DOE Order 435.1.

The 500-year Period of Performance for engineered barriers used to limit inadvertent intrusion (e.g., 10 CFR 61.42) is not the same as the promulgated Period of Performance for protection of the general population from releases of radioactivity (e.g., 10 CFR 61.41). As such, NRC deemed the engineered barriers and concentration limits inherent with the Class A classification were sufficient to demonstrate protection of an inadvertent intruder.

3. 10,000 YEARS: UAC R313-25-8(5)(a) includes reference to a 10,000-year Period of Performance. However, this citation only applies to "*any facility that proposes to land dispose of significant quantities of concentrated depleted uranium,*" [UAC R313-25-8(5)(a)], and as such, is not applicable to the updated Site-Specific Performance Assessment. Similarly, neither the Division's nor NRC's low-level waste disposal regulations specify a Period of Performance (UAC R313-25 and 10 CFR 61). However, NRC's environmental impact statement for 10 CFR 61 recognizes the need for a Period of Performance, "*commensurate with the persistence of the hazard of the source,*" (NRC 1981a; NRC 1982; NRC 2000).

Energy*Solutions* recognizes that a Period of Performance of 10,000 years was evaluated as part of the NEPA analysis in the Draft Environmental Impact Statement (DEIS) for 10 CFR 61 (NUREG-0782). Similarly, NRC's Performance Assessment Working Group (formed to provide information and recommendations on performance assessment methodology required by 10 CFR 61.41) also recommended a 10,000-year Period of Performance, considering it

> "*sufficient to capture the risk from the short-lived radionuclides (the bulk of the activity disposed) and the peaks from the more mobile long-lived radionuclides, which tend to bound the potential doses at longer timeframes,*"(NUREG-1573).

The Division has required that an updated Site-Specific Performance Assessment be conducted that includes

> "*prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways,*"

before being able to dispose of processed ion-exchange resin wastes at volumes greater than 40,000 cubic feet per year, (Lundberg, 2011).

Separate from requirements to preserve the groundwater resource for a 500-year Time of Compliance, the Utah Division of Drinking Water and U.S. EPA have promulgated radionuclide concentration limits (e.g., maximum contaminant levels of MCLs) in drinking water, based on the associated health effects from ingestion. EPA has developed MCLs for four groupings of radionuclides: (A) Ra-226 and Ra-228; (B) man-made beta and photon emitters; (C) gross alpha, excluding uranium isotopes and radon; and (D) U-234, U-235 and U-238, based on a maximum committed effective dose equivalent (CEDE) of 4 mrem/year. This dose standard is reflected in Division's requirement UAC R313-25-19, which states "*No greater than 0.04 mSv (0.004 rem) committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater.*"

In compliance with these regulatory requirements, Energy*Solutions* has addressed applicable requirements and guidance in revision of the Periods of Performance and Times of Compliance assessed in this updated Site-Specific Performance Assessment, as follows:

1. <u>500 YEARS</u>: In compliance with groundwater resource protection standards of UAC R317-6, the updated site-specific Performance Assessment projects expected groundwater well concentrations for a Period of Performance of 500 years, following Class A West Embankment closure.

2. <u>1,000 YEARS</u>: Consistent with federal guidance and precedence, the updated site-specific Performance Assessment projects expected exposures to a reasonable inadvertent intruder within a Time of Compliance of 1,000 years, following Class A West Embankment closure.

3. <u>10,000 YEARS</u>: In compliance with federal guidance and precedence, Energy*Solutions* has maintained the original 10,000-year Period of Performance for demonstration of protection of the general public. Similarly, in compliance with the Division's directive, the updated site-specific Performance Assessment projects peak isotopic groundwater well concentrations for a Period of Performance of 10,000 years, following Class A West Embankment closure.

   While the Division is on record agreeing that the groundwater classification, level of its totally dissolved solids, and other naturally-occurring contaminants create completely non-potable groundwater, (thereby eliminating all reasonable possibility of any member of the public from receiving such a groundwater dose), Energy*Solutions* has revised the updated site-specific Performance Assessment to demonstrate that no members of the general public still alive following consumption of the Clive's natural groundwater will receive a CEDE in excess of 4 mrem/year within a 10,000-year Period of Performance.

### 1.4.2 <u>UAC R313-25: Performance Objectives</u>

NUREG-1573 has been developed as a key NRC guidance document for conducting performance assessments (NRC, 2000), with more recent guidance contained in NUREG-1854, (NRC, 2007). The guidance NRC has issued to assist applicants and licensees in applying standards has been incorporated in this updated site-specific Performance Assessment. This updated site-specific Performance Assessment demonstrates compliance with the performance objectives described below.

#### 1.4.2.1 *UAC R313-25-19: Protection of the General Public*

The key endpoints of this updated site-specific Performance Assessment are estimated future potential doses to members of the public. The performance objectives required in UAC R313-25-19 (e.g., 10 CFR 61.41) are the following:

> *"Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants or animals shall not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any member of the public. No greater than 4 mrem committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater. Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable, (ALARA)."*

However, NRC based these performance objectives on the dated International Commission on Radiological Protection (ICRP) 2 dose methodology (ICRP, 1959). By comparison, current health physics practices follow the dose methodology used in 10 CFR 20 (e.g., UAC R313-15), which are based on ICRP 30 methodology (ICRP, 1979). For consistency, NRC recommends, "*that the performance assessment be consistent with the methodology approved by the NRC in Part 20 for comparison with the performance objective [of 10 CFR 61.41]*" (NRC, 2000). Since UAC R313-15 establishes a TEDE limit, rather than the whole body dose, NRC notes in NUREG-1573, *"As a matter of policy, the Commission considers 0.25 mSv/year (25 mrem/year) TEDE as the appropriate dose limit to compare with the range of potential doses represented by the older limits that had whole-body dose limits of 0.25 mSv/year (25 mrem/year) (NRC, 1999, 64 FR 8644; see Footnote 1). Applicants do not need to consider organ doses individually because the low value of the TEDE should ensure that no organ dose will exceed 0.50 mSv/year (50 mrem/year)."* (NRC, 1999, 64 FR 8644; see Footnote 1).

This approach was also taken for Yucca Mountain in 10 CFR Part 63, NUREG-1854 and NUREG-1573, and in the NRC Decommissioning Criteria for West Valley. Therefore, while this updated site-specific Performance Assessment does not specifically consider organ doses individually, comparison to a more conservative value of the TEDE ensures that no organ dose will exceed the promulgated limitations of UAC R313-25-19.

In this updated site-specific Performance Assessment, Energy*Solutions* also demonstrates compliance with the performance objective requiring that no members of the general public following consumption of Clive's natural groundwater receive a CEDE, in excess of 4 mrem/year within a 10,000-year Period of Performance.

1.4.2.2 *UAC R313-25-20: Protection of the Inadvertent Intruder*

UAC R313-25-20 requires assurance of protecting individuals from the consequences of inadvertent intrusion into disposed waste. An inadvertent intruder is someone who is exposed to waste unintentionally and without realizing it is there (after loss of institutional control). This is distinct from an intentional intruder, who might be interested in deliberately disturbing the site, or extracting materials from it, or who might be driven by curiosity or scientific interest.

*"Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."* [UAC R313-25-20]

Another important term to define in evaluation of this Performance Objective is an intruder barrier:

*"A sufficient depth of cover over the waste that inhibits contact with waste and helps to ensure that radiation exposure to an inadvertent intruder will meet the performance objectives set forth in this part, or engineered structures that provide equivalent protection to the inadvertent intruder."* [UAC R313-25-2]

Energy*Solutions* licensed its Containerized Waste Facility (CWF) disposal design to manage radioactive waste shipments with activity concentrations nearer to the Class A limit (but with relatively low volumes) in contrast to the Class A waste typically disposed at Clive (higher volumes of low activity waste). As detailed below, the CWF disposal design is based on the added safeguards of disposal practices for wastes above the Class A classification. Therefore, it inherently provides improved barriers prerequisite for protection of an inadvertent intruder and is an ideal location for disposal of blended resins.

Currently, typical processed ion-exchange resin wastes are disposed in either plastic or metal liner (high integrity container) and placed in the center of the disposal embankment. Note that neither this nor previous performance assessments take credit for the high integrity container itself in demonstrating long-term performance. This disposal methodology exceeds the intruder barrier requirements of UAC R313-25 in the following ways.

- Resin liners are placed in either the first or second layer of the CWF. The containers are placed in a honeycomb pattern of concrete silos and backfilled with sand. At some interior locations in the CWF, the containers are placed in a temporary steel silo. The silo is used to administratively ensure the honeycomb spacing pattern, including minimum distances between adjacent containers, is achieved. After the steel silo is removed, voids around the containers are filled with the sand backfill. Once a specific area of containerized disposal is filled, additional compacted layers of sand and clay are placed above the container to complete and close the specific area.

- An engineered facility is an important component in intruder protection. Reliance on engineered features is based on the assumption that an intruder encountering the barrier would recognize it as something out of the ordinary and cease attempts at construction or agriculture (thereby reducing their exposure to radiation). The combination of the liner and CWF structure protects an intruder from penetrating the site and contacting the waste.

- The design and operation of the CWF provides more stable disposal than is required by UAC R313-25 for Class A waste. The placement of containerized waste, the sand backfill, the compacted sand, and clay above the containers, the placement and compaction of bulk waste above the layers of containerized waste, and the cover combine to form a stable disposal configuration. The CWF design provides stability to ensure the long-term compaction combine to resist slumping and differential settlement, which limits infiltration and reduces the potential for dispersion of the waste over time. In addition to improving the performance of the disposal site, this provides inherent protection for the inadvertent intruder, since it provides a "*recognizable and nondispersible waste*" as contemplated in UAC R313-15-1009.

- Energy*Solutions*' Class A Radioactive Material License (UT 2300249) requires that containers are placed in either the first or second layer of the CWF and covered with multiple layers of compacted waste. The result is that even the top layer of processed ion-exchange resin waste is a minimum of 5 meters below the cover, which would be sufficient to satisfy disposal requirements for waste classified above Class A. The 5 meter thick barrier also inhibits access by an inadvertent intruder. This barrier is composed of earth, lower activity waste, and other similar materials.

Although UAC R313-25-20 requires that an inadvertent intruder be protected, NRC staff acknowledged that applicants and licensees are not expected to perform specific intruder dose analyses, because the waste classification itself and segregation requirements were developed to inherently provide inadvertent intruder protection, (NRC, 2000). Even so, this updated site-specific Performance Assessment demonstrates protection of inadvertent intruders. While an unlimited number of hypothetical inadvertent intruder scenarios could be developed, Division requirements limit such development to include, "*Identification of the known natural resources at the disposal site whose exploitation could result in inadvertent intrusion into the wastes after removal of active institutional control.*" UAC R313-25-7(8). Of similarly sentiment, NRC's Performance Assessment Working notes that,

> "*the overall intent [of exposure scenario development guidance] is to discourage excessive speculation about future events and the PAWG does not intend for analysts to model long-term transient or dynamic site conditions, or to assign probabilities to natural occurrences. . . The parameter ranges and model assumptions selected for the LLW performance assessment should be sufficient to capture the variability in natural conditions, processes, and events. . . Therefore, PAWG recommends that new site conditions that may arise directly from significant changes to existing natural conditions, processes, and events do not need to be quantified in LLW performance assessment modeling . . . With respect to human behavior, it may be assumed that current local land-use practices and other human behaviors continue unchanged throughout the duration of the analysis. For instance, it is reasonable to assume that current local well-drilling techniques and/or water use practices will be followed at all times in the future.*" (NUREG-1573).

NRC further supports the importance of selecting appropriate inadvertent intruder scenarios that reflect current practices and site environments in its guidance to Regulators reviewing performance assessments to,

> "*[1] verify that conceptual models for the biosphere include consistent and defensible assumptions based on regional practices and characteristics (i.e., conditions known to exist or expected to exist at the site or surrounding region); [2] verify that intermediate results (e.g., fluxes, travel times) are physically reasonable;. . . [3] evaluate the types of scenarios . . . considered in the intruder analysis and confirm that the scenarios considered are appropriate for the site; [4]verify that assumptions and parameters used in defining the exposed intruder, including location and behavior of the intruder, timing of the intrusion, and exposure pathways,* ***are consistent with the current regional practices*** *[emphasis added]; and [5] if a garden is assumed in the scenario [implying it is not always required], verify that the garden size is appropriate and consistent with regional practices*" NRC (2007).

Traditional generic exposure scenarios typically evaluating potential inadvertent intruder doses (in compliance with UAC R313-25-20) are described in NRC's draft Environmental Impact Statement supporting 10 CFR 61 (NRC 1981a) and the Update of Part 61 Impacts Analysis Methodology (NRC 1986). The methodology described therein includes evaluation of exposure pathways within a group of four inadvertent intruder scenarios including intruder discovery, intruder drilling, intruder construction, and intruder agriculture. These inadvertent intrusion scenarios represent a potential series of events that are initiated by the successful completion of a water supply well. However, NRC further notes that,

> "*it would be unreasonable to expect the inadvertent intruder to initiate housing construction at a comparatively isolated location before assuring that water for home and garden use will be*

*available. Thus, this scenario (intruder-driller) is assumed to precede the following three scenarios*" (NRC, 1986).

The intruder-drilling scenario is assumed to be an initiating event for the intruder-construction and intruder-agriculture scenarios (NRC 1986, Section 4.1.1.1). This scenario assumes that waste is brought to the ground surface in a mixture with cover material, unsaturated zone material, and drilling mud and is then contained in a mud pit used by the driller. The driller (a separate individual from that in any subsequent exposure scenario) may be exposed by direct gamma radiation from the waste mixture in the mud pit (NRC, 1986). Attributes of this scenario such as the dimensions of the mud pit and depth of water above the cuttings are described in Section 4.2.1 of NRC (1986).

The intruder-discovery scenario described in Section 4.2.3 of NRC (1981) involves external exposure to discoverable wastes that are clearly distinguishable from natural materials. The dose assessment methodology described in NRC (1981) was updated in NUREG/CR-4370 (NRC, 1986). Exposure to the intruder-discoverer is assumed to be limited to the topmost waste layer, since the intruder "*would likely stop excavating before digging too deep into the rest of the waste*" (NRC 1986, Section 4.2.3). The intruder-discovery scenario for stable waste streams in the first 500 years after closure is assumed to preempt the intruder-agriculture scenario (and, presumably, the intruder-construction scenario) because construction and inhabitation of a home will not occur once the waste has been discovered and recognized (NRC 1986, Section 4.2.3).

The intruder-construction scenario involves direct intrusion into disposed wastes for activities associated with the construction of a house {(e.g., installing utilities, excavating basements, and similar activities [as described in Section 4.2.2 of NRC (1986)]}. However, because there is no historic evidence of prior residential construction at the Clive site, the extreme salinity of Clive's soils, the non-potable groundwater , the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-construction scenario is not considered "reasonable" for the Clive site nor included in this updated site-specific Performance Assessment.

The intruder-agriculture scenario assumes an individual is living in the home built under the intruder-construction scenario, and is also exposed from gardening activities involving the waste/soil mixture excavated during construction (NRC 1986, Section 4.2.4). As with the inadvertent intruder-construction scenario, the lack of historic evidence of prior residential agriculture at the Clive site, the extreme salinity of Clive's soils, the non-potable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-agriculture scenario is not considered "reasonable" for the Clive site no included in this Report's site-specific Performance Assessment.

As part of an unrelated investigation, NRC staff specifically asked the Division to "*provide further information on its position that the onsite residential and agricultural intruder pathways for the [EnergySolutions] site are unrealistic.*" In response, Division staff

"*stated that onsite residential and/or farming scenarios at the [EnergySolutions] facility are unrealistic for several reasons. First, the site conditions of low precipitation (i.e., approximately*

*5-6 inches/year) and high evapotranspiration rates (i.e., approximately 40 - 50 inches/year). Also, there is a lack of suitable irrigation water . . . and the soil is extremely saline. Secondly, Tooele County has designated this part of the county as Heavy Industry and Hazardous Waste Zones which bars any such residential and/or farming uses*" (NRC, 2005).

The Division's judgment of the unrealistic nature of farming or residential intruder scenarios is consistent with the requirements of UAC R313-25-7(8).

An archeological survey of the Clive area was performed in 1981, as part of the siting criteria used for the Vitro disposal cell (AERC, 1981). This survey found no evidence of long-term residential or agricultural resource sites. A similar cultural and archaeological resource survey was conducted in 2001 on a land adjacent south to Section 32 (Sagebrush, 2001). In addition to the new survey, Sagebrush's (2001) report also summarized five additional cultural resource inventories performed within a mile of the subject area, between the original 1981 and 2001 studies. In all surveys, Sagebrush reported no paleontological, prehistoric, or historic resources were discovered in the survey area. In fact, no evidence has been discovered that suggests the Clive facility has ever been inhabited or developed for agriculture by permanent residents in the past (probably due to unfavorable conditions for human habitation).

In compliance with UAC R313-25-20 and Division directive, Energy*Solutions* has included credible inadvertent industrial intrusion scenarios in its updated site-specific Performance Assessment. However, since (1) Clive's groundwater is not potable and will not support a residence or agriculture, (2) the expense of treating Clive's groundwater with conventional technologies as well as low aquifer yield is preventing current industrial occupants from using such treatment; (3) Clive's geology holds no mineral resources of value, and (4) Clive's current practices and county-zoning limit use of the area to only industrial purposes, Energy*Solutions* has revised this updated site-specific Performance Assessment to only include scenarios of inadvertent intrusion that may result from industrial pursuits (e.g., similar to those apparent with Energy*Solutions'* current developed neighbors).

The Intruder-Drilling scenario assumes that waste is brought to the ground surface in a mixture with cover material, unsaturated zone material, and drilling mud and is then contained in a mud pit used by the driller. Subsequent to the drilling activity, this updated site-specific Performance Assessment assumes an industrial worker begins working at the site of the drill cuttings, being exposed by direct gamma radiation from the waste mixture in the mud pit for 2,000 hours per year (scenario assumed to be equivalent to the Intruder-Industrial Driller scenario at the longer annual exposure of 2,000 hours/year). This behavior is similar to activities currently observed by Energy*Solutions'* industrial Clive neighbors.

The performance standard for protection of individuals from inadvertent intrusion (UACR313-25-20) requires "*...protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste.*" However, these regulations are silent on the specific dose standard to apply. Since UAC R313-25 has been issued, the standard used by NRC (and included in the pending revisions to 10 CFR 61) and others for low-level radioactive waste disposal licensing has been an intruder standard of 500 mrem/yr. The 500 mrem/yr standard is also used in DOE's waste determinations implementing the 10 CFR 61 performance objectives (NUREG-1854). It is noted that 500 mrem/yr was also the standard proposed in 10 CFR 61 in 1981 (46 FR 38081, July 24, 1981). The Statement of Considerations for the final rule did not object to the number. It was removed apparently at the request of EPA, because of its concern of how one would monitor it or demonstrate compliance with it, but not because EPA disagreed with it (47 FR57446, 57449, December 27, 1982). A dose standard of 500 mrem/yr is also used as part of the license termination rule dose standard for intruders (10 CFR 20.1403). Consequently, this updated site-specific Performance Assessment uses a 500 mrem/yr threshold for the intruder dose for purposes of applying the performance standard for protection of individuals from inadvertent industrial intrusion.

1.4.2.3 *UAC R313-25-21: Protection of Individuals During Operations*
UAC R313-25-21 states that

> "*Operations at the land disposal facility shall be conducted in compliance with the standards for radiation protection set out in R313-15 of these rules, except for release of radioactivity in effluents from the land disposal facility, which shall be governed by R313-25-19.*"

Historical records submitted annually to the Division demonstrate that Energy*Solutions*' existing operations have impacts that are maintained by administrative controls within the applicable regulatory limits. Furthermore, personnel and environmental monitoring data confirm that the applicable limits are met on a continuing basis. Since there is no change being proposed as part of this updated site-specific Performance Assessment in the types of waste or necessary administrative controls that will be managed, protection of individuals during operations will continue.

UAC R313-25-21 also states that "*every reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable, ALARA.*" The Clive Radiation Protection Program ensures that all reasonable actions are taken to reduce radiation exposures and effluent concentrations to levels that are considered, "As Low As Reasonably Achievable" (ALARA). Since there are no changes being proposed in the waste types and classifications that are being disposed of in the Embankment, the current ALARA Program will not require revision as part of this site-specific Performance Assessment.

1.4.2.4 *UAC R313-25-22: Stability of the Disposal Site After Closure*
To help achieve stability, NRC notes that to the extent practicable the waste should maintain gross physical properties and identity over 300 years, under the conditions of disposal. NRC believes that the use of design features to achieve stability is consistent with the concept of ALARA and the use of the best available technology. NRC also notes that a site should be evaluated for at least a 500-year time frame to address the potential impacts of natural events or phenomena.

Consequently, Energy*Solutions* has implemented a disposal site and cover designs that provides reasonable assurance that long-term stability will be achieved and that the use of the best available technology in setting design standards in the range from 200 up to 1,000 years is appropriate to provide site stability to the extent practicable. Because the longevity of the cover designs demonstrate protection, this updated site-specific Performance Assessment does not trigger the need to conduct additional stability analysis.

1.4.2.5 *Groundwater Protection Limits*

In addition to these radiological criteria, the State of Utah imposes limits on groundwater contamination, as stated in the Ground Water Quality Discharge Permit (Energy*Solutions*, 2013). Part I.C.1 of the Permit specifies that GWPLs shall be used for the Embankment. The Permit specifies general mass and radioactivity concentrations for several constituents of interest to Class A waste disposal. These GWPLs are derived from Ground Water Quality Standards listed in UAC R317-6-2 Ground Water Quality Standards. Exceptions to values in that table are provided for specific constituents in specific wells, tabulated in Table 1B of the Permit.

It is important to note that according to the Permit, groundwater at Clive is classified as Class IV, saline ground water, according to UAC R317-6-3 Ground Water Classes, and is highly unlikely to serve as a future water source. The underlying groundwater in the vicinity of the Clive site is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses, and is not potable for humans. Analysis conducted by the World Health Organization in 2003 suggested associations between TDS concentrations in drinking water and the incidence of cancer, coronary heart disease, arteriosclerotic heart disease, cardiovascular disease, and total mortality rates in studies conducted in Australia and the former Soviet Union (WHO, 2003). In the study in Australia, it was determined that mortality from all categories of ischemic heart disease and acute myocardial infarction was increased in a community with high levels of soluble solids, calcium, magnesium, sulfate, chloride, fluoride, alkalinity, total hardness, and pH when compared with one in which levels were lower. Similarly, the results of an epidemiological study in the former Soviet Union indicated that the average number of cases of inflammation of the gallbladder and gallstones over a 5-year period increased with the mean level of dry residue in the groundwater.

Since the background water quality of the groundwater renders it unsafe for human consumption, groundwater protection standards are applied at the Clive site as a non-degradation, or Best Available Technology (BAT), standard. No dose is possible through the groundwater pathway, since its consumption is impossible without extensive treatment. The BAT standards for groundwater do not provide any additional protection in terms of human health.

This updated site-specific Performance Assessment calculates estimates of groundwater concentrations at a virtual point of compliance well near the Embankment for comparison with these GWPLs. The period of compliance for GWPLs, consistent with the established licensing basis for the Clive facility and with BAT, is 500 years. Even though groundwater concentrations beyond 500 years are calculated to inform the site-specific Performance Assessment, it is recognized that no dose can be realized from the groundwater pathway based on the background water quality.

### 1.5 Report Scope

This Report documents the updated site-specific Performance Assessment, conducted in compliance with UAC R313-25-8. Analysis includes evaluation of potential groundwater migration of contaminants to a Point of Compliance well for a period of 500 years following embankment closure, projected peak groundwater well concentrations and general public doses for a period up to 10,000 years following embankment closure, doses to reasonable hypothetical individuals who have inadvertently intruded into the waste within 1,000 years following embankment closure, and an expanded source term of isotopes not considered in previous site-specific performance assessments.

This Report describes the methodology for achieving these objectives and the results of the analyses, including:

- Developing a long-term climate record representative of the site;
- Representation of near-surface processes that affect net infiltration, such as evaporation, runoff, and plant water uptake;
- Representation of movement of water through the cover layers, waste, and liner;
- Release of radionuclides and transport through the vadose zone to the saturated zone;
- Transport of radionuclides in the saturated zone to the point of compliance;
- Evaluation of groundwater concentrations over time at the point of compliance; and
- Evaluation of radiation dose for hypothetical inadvertent human intruder scenarios occurring upon the disposal embankment.

The results of the updated site-specific Performance Assessment include:

- A description of the calculations and basis for the estimate of a steady-state infiltration rate applied in the transport model;
- A description of the transport model used to calculate groundwater concentrations over time;
- Identification of groundwater concentrations (and associated general public doses from its ingestion) at the time of highest concentrations within 10,000 years, and comparison of groundwater concentrations within 500 years of site closure to groundwater protection limits; and
- Evaluation of dose for hypothetical inadvertent intruder scenarios within 1,000 years of embankment closure.

# 2. UPDATED SITE-SPECIFIC PERFORMANCE ASSESSMENT COMPONENTS

This updated site-specific Performance Assessment includes analysis of the influences of alternative evapotranspirative cover designs on subsurface contaminant transport, modeling of expected exposures and resulting doses to reasonable inadvertent intruders, and evaluation of additional radionuclides not included in previous site-specific Performance Assessments. Components of this updated site-specific Performance Assessment include a current long-term climate record representative of the Clive site; improved representation of near-surface processes that affect net infiltration, such as evaporation, runoff, and plant water uptake; representation of movement of water through improved evapotranspirative cover designs; and evaluation of radiation dose for inadvertent industrial intruder scenarios occurring following the disposal embankment closure.

## 2.1 Site Characteristics

Energy*Solutions*' low-level radioactive waste disposal facility is located west of the Cedar Mountains in Clive, Utah. Clive is located along Interstate-80, approximately 3 miles south of the highway, in Tooele County. The facility is approximately 50 air-miles east of Wendover, Utah and approximately 75 highway miles west of Salt Lake City, Utah. The facility sits at an elevation of approximately 4,275 feet above mean sea level (amsl) and is accessed by both highway and rail transportation. The Clive facility is adjacent to DOE's above-ground disposal embankment used for disposal of uranium mill tailings that were removed from the former Vitro Chemical company site in South Salt Lake City between 1984 and 1988.

The Clive facility receives waste shipped via truck and rail. Class A low-level radioactive waste is disposed in a permanent near surface engineered disposal embankment that is clay-lined with a composite engineered cover. The disposal embankment is designed to perform for a minimum of 500 years based on requirements of 10 CFR 61.7(a)(2), which provides long-term disposal with minimal need for active maintenance after site closure.

### 2.1.1 Climate

Energy*Solutions* has operated a weather station at Clive since July 1992. The station monitors wind speed and direction, 2-m and 10-m temperatures, precipitation, pan evaporation and solar radiation. A 19-year Summary Report from January 1, 1993 through December 31, 2011, provided to the Division on February 23, 2012, has been incorporated into this updated site-specific Performance Assessment (MSI, 2012). This was the most recent data available at the time the models were performed. Since the Embankment is located entirely within Section 32, this information adequately characterizes the site. Furthermore, the Embankment has no significant effects upon the meteorological conditions or air quality of the region.

### 2.1.2 Weather Patterns

The Clive region is in the Intermountain Plateau climatic zone that extends between the Cascade-Sierra Nevada Ranges and the Rocky Mountains and is classified as a middle-latitude dry climate or steppe. Hot dry summers, cool springs and falls, moderately cold winters, and a general year-round lack of precipitation characterize the climate. Mountain ranges tend to restrict the movement of weather systems into the area, but it is occasionally affected by well-developed storms in the prevailing regional westerlies. The mountains act as a barrier to frequent invasions of cold continental air. Precipitation is generally light during the summer and early fall and reaches a maximum in spring when storms from the Pacific Ocean are strong enough to move over the mountains. During the late fall and winter months, high pressure systems tend to settle in the area for as long as several weeks at a time.

### 2.1.3 Temperature

Regional climate is regulated by the surrounding mountain ranges, which restrict movement of weather systems in the vicinity of the Clive facility. The most influential feature affecting regional climate is the presence of the Great Salt Lake, which can moderate downwind temperatures since it never freezes (NRC, 1993). Frequent invasions of cold air are restricted by the mountain ranges in the area. Data from the Clive facility from 1992 through 2011 indicate that monthly temperatures range from about -2°C (29°F) in December to 26°C (78°F) in July (MSI, 2012).

### 2.1.4 Winds

In the 19-year period of time (July 1993 through December 2011) the most frequent (and predominant) winds were from the south-southwest direction, with the second most frequent direction being the east-northeast, followed by the south. Wind Rose data incorporated into this updated site-specific Performance Assessment has been obtained from the on-site weather station and checked for accuracy by a certified meteorologist (MSI, 2012).

### 2.1.5 Precipitation

The Clive site receives an average of 8.62 inches of precipitation per year. Measurements taken at the Clive site showed that the lowest monthly precipitation recorded was 0 inches in May 2001. The highest recorded monthly precipitation was 4.28 inches, in May 2011 (MSI, 2012).

### 2.1.6 Evaporation

Pan evaporation measurements are taken from April through October when ambient temperatures remain above freezing. Maximum hourly evaporation values usually occur in July. The 17-year average annual evaporation at the Clive site is 52.73 inches (excluding 2 years of reported instrument malfunction) (MSI, 2012).

### 2.1.7 Geology

The Energy*Solutions* Clive site is located on the eastern fringe of the Great Salt Lake Desert. The Clive site is located in, and is bounded by, the Great Salt Lake Desert to the west at approximate elevations of 4,250 to 4,300 feet amsl. Also to the west, low-lying hills rise 50 to 100 feet from the desert floor. To the east and southeast, the site is bounded by the north-south trending Lone Mountains, which rise to a height of 5,362 feet amsl. At the base of the Lone Mountains alluvial fans slope gently toward the west at a gradient of approximately 40 feet per mile. The site has topographic relief of approximately 11 feet over one mile, sloping in a southwest direction at a gradient of approximately 0.0019. The most recent characterization of the site geology and hydrogeology is reported in the Revised Hydrogeologic Report (EnergySolutions, 2012).

The Clive site rests on Quaternary lakebed deposits of Lake Bonneville. Site subsurface logs indicate that lacustrine deposits extend to at least 500 feet underneath the site. The underlying Tertiary and Quaternary age valley fill is composed of semi-consolidated clays, sands, and gravel where it comes in contact with bedrock. Although the exact depth to and relationships of various bedrock units are unknown, the presence of nearby outcrops and the regional block-faulted basins suggest that the valley-fill deposits are several hundred feet thick within the area of the site. Estimated down-dip projections from bedrock outcrop on the southwest corner of Section 31 and bedrock found at depth in Clean Harbors wells suggest that the contact may dip to the east about three degrees.

To the north of the site are the Grayback Hills, composed of limestone and quartzite mapped as Permian-Pennsylvanian Oquirrh Formation, which is as much as 10,000 feet thick in western Utah. Igneous extrusives form a resistant cover on the Grayback Hills, and are mapped as Pliocene-age basalt/rhyolite.

Geomorphic processes at the site are limited to micro processes that occur in the soil. For example the Great Salt Lake Desert is located in a semiarid to arid region where precipitation is less than evaporation. When the soil water evaporates, dissolved mineral matter is precipitated and forms calcium carbonate, gypsum and alkali (sodium and potassium carbonates) in the soil. Macro geomorphic processes are almost nonexistent where the general rate of weathering is very slow. This is due to the low amounts of precipitation, the lack of fluvial activities and the lack of relief at the site.

### 2.1.8 Hydrology

Alluvial and lacustrine sediments that fill the valley floor are estimated to extend to depths of greater than 500 feet with unconsolidated sediments ranging from 300 to over 500 feet. North-south trending mountains and outcrops define the hydrogeologic boundaries for the aquifer system. Lone Mountain located two miles east of the site, rises approximately 950 feet above the valley floor. The Grayback Hills located to the north and outcropping features to the west rise 500 feet and 230 feet respectively above the valley floor (Envirocare, 2004).

Four hydrostratigraphic units have been delineated in the unsaturated zone and shallow aquifer system at the Clive Facility, consisting of upper silty clay/clayey silt (Unit 4), upper silty sand (Unit 3), middle silty clay (Unit 2), and lower sand/silty sand (Unit 1). The site aquifer system consists of a shallow unconfined aquifer that extends through the upper 40 feet of lacustrine deposits. A confined aquifer begins around 40 to 45 feet below the ground surface and continues through the valley fill. Due to the low precipitation and relatively high evapotranspiration, little or no precipitation reaches the upper unconfined aquifer as direct vertical infiltration. Groundwater recharge is primarily due to infiltration at bedrock and alluvial fan deposits which then travels laterally and vertically through the unconfined and confined aquifers. Groundwater flow in this area is generally directed north to northeasterly.

Fresh water from the recharge zones along the mountain slopes develops progressively poorer chemical quality in response to dissolution of evaporate-minerals during its travel through the regional-scale flow systems. The groundwater quality in the unconfined aquifer at the Clive Facility is considered saline with concentrations of several chemical species (sulfate, chloride, total dissolved solids, iron, and manganese) significantly exceeding the EPA secondary drinking water standards.

### 2.1.9 Surface Water

The area containing the Clive facility lies within the Great Basin drainage, a closed basin having no outlet. The site drains into the normally-dry Ripple Valley depression on the eastern fringe of the Great Salt Lake Desert.

The nearest usable body of water east of the Clive site is 28.1 miles away. At this location, a perennial stream flows from Big Spring (1,000 feet south of I-80) to the Timpie Springs Waterfowl Management Area, about 2,000 feet north of I-80. Activities at the Energy*Solutions* Clive Facility have no effect on surface-water quantities or quality at the Clive site. There are no perennial surface-water systems associated with the Clive site. Water necessary for construction is provided by existing wells in the vicinity requiring transport to the site, or impounded water.

No surface water bodies are present on the Clive site. The nearest stream channel ends about two miles east of the site and is typical of all drainages along the transportation corridors within 20 miles of the site. Stream flows from higher elevations evaporate and infiltrate into the ground before reaching lower, flatter land. The stream channel reduces until there is no evidence of a stream. The watershed up-gradient of the site covers approximately 46 square miles.

### 2.1.10 Groundwater

Local groundwater recharge from meteoric sources is generally limited, since pan-evaporation greatly exceeds precipitation (NRC, 1993). Recharge is more likely to occur in areas adjoining the surrounding mountain ranges, moving as subsurface flow to the center of the basin. Given the strong evaporation potential at the site, it is expected that some unsaturated zone (vadose zone) groundwater may actually moves upward. An upward gradient is not only due to evaporation of water at the ground surface, it is also driven by the transpiration of plants, which pull water from the ground and release it to the dry atmosphere. The coupled effect of these two processes, or evapotranspiration, serves to keep near-surface soils dry enough that precipitation often does not penetrate to lower soils.

Groundwater at the Clive site is found within a low-permeability saline aquifer starting near the bottom of the Unit 3 stratigraphic unit, and saturating the Unit 2 stratigraphic unit. The depth to groundwater is between approximately 20 and 30 feet bgs at an approximate elevation of 4,250 ft amsl (Brodeur, 2006). The regional (saturated) groundwater system flows primarily to the east-northeast toward the Great Salt Lake (Envirocare 2004) and the local shallow groundwater follows a slight horizontal gradient to the north-northeast. Occasional transient shallow aquifer mounding occurs due to infiltration of surface water.

The underlying groundwater in the vicinity of the Clive site is of naturally poor quality because of its high salinity and, as a consequence, is not suitable for most human uses (NRC, 1993). Groundwater beneath the Clive site ranges in total dissolved solids (TDS) from 30,000 mg/L to 100,000 mg/L, with a site-wide average TDS content of 40,500 mg/L. The majority of the cations and anions are sodium and chloride, respectively. This is not potable for humans. For comparison purposes, sea water typically has a TDS content of 35,000 mg/L, thus the salinity content at the site is higher than average sea water.

2.1.11 Ecology

Ecological exploratory field studies were conducted in 2012 to examine biogeography, bioturbation, and biological communities near the Clive site (SWCA, 2012). These studies observed average plant species cover consist of 14.3% black greasewood, 5.9% Sandberg bluegrass, and approximately 3% cover each of shadscale saltbrush and gray molly occurring in low densities with 1.6% and 1.3% cover, respectively. Ground cover is dominated by 79.2% biological soil crust cover.

Field studies also included small mammal trappings, with 83 deer mice and one kangaroo rat trapped. Small mammals were observed to have concentrated in the north of the Clive facility. Borrows of deer mice, kangaroo rats, ground squirrels, and badgers were also observed during the field studies.

Nineteen ant mounds were recorded and measured, with an average of 24 ant mounds observed per hectare. The average individual ant mound area estimate was approximately 2,683 $cm^2$ and 28,348 $cm^3$, respectively. The belowground area of the excavated ant mounds was found to be sparsely distributed, with most of the ant nests within 0.6 meters of the surface.

Analyses of plant species cover, small mammal densities, animal burrow volumes, ant mound volumes, and soil chemistry and nutrition parameters identified several relationships between the variables under consideration. Positive correlations were witnessed between total vegetation cover, mammal densities, and burrow volumes. In contrast, no correlation was observed between total vegetation cover and ant mound area or volume. There were also strong positive correlations between ant mound area, mound volume, and cover of weedy species. There was also a strong, negative correlation between ant mounds and soil silt, and somewhat strong negative correlations between animal densities, burrow volumes, and soil clay content. Field studies concluded that the high soil pH did not appear to be limiting for any of the native or weedy plant species observed. However, plant cover, particularly of shadscale saltbrush, showed strong, negative correlations with high soil salinity.

In support of the evapotranspirative cover designs under consideration, the field studies pointed to several key design features for the Clive site:

- The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses.

- Although a vegetation community of sufficient diversity and density is desired to maximize transpiration from the soil, vegetation density was positively correlated with small mammal and burrowing activity. As such, bioturbation should be expected to increase with increasing vegetation. Furthermore, the presence of badgers and a large family of burrowing owls indicates that the biota can potentially move large volumes of soil. Because of this, the bank-run borrow material layer has been included in both of the evapotranspirative cover designs as a bio-intrusion and bioturbation barrier (also serving to minimize the penetration by ants through the cover layers).

- Soils were mostly silty clay loams with elevated pH, elevated salinity, and low organic matter.

SWCA also examined the root density and maximum rooting depth of dominant plant species on the Clive Facility. Observed root densities were higher near the surface of the soil, where roots were mostly fibrous with few woody structures. A few large, woody roots were encountered in deeper soils. Rooting depths were shallower than expected, with the maximum rooting depth of dominant woody plant species ranging from 16 to 28 inches. Woody plant species maximum rooting depths were proportional to aboveground plant mass with an above-ground height root depth ratio of 1:1 and an above-ground width root depth ratio of approximately 1.4:1. The halogeton-disturbed plot had higher ratios of plant height and width to maximum rooting depth (1.4:1 and 1.7:1, respectively). The low proportion of roots to above-ground biomass is expected for annual plants, which invest the bulk of their energy in reproduction and little energy in root systems.

## 2.2 Embankment Cover Designs

Principle design features of the embankment provide long-term isolation of disposed waste, minimize the need for continued active maintenance after site closure, and improve the site's natural characteristics in order to protect public health and safety. The environment, site personnel, and the public are protected both during and after active disposal operations from unsafe levels of radiation. Long-term stabilization of the Embankment is accomplished through erosion control and flood protection. The controlled areas of the Embankment are fenced both during construction and after operation to prevent public access. Additionally, Embankment custodial maintenance and surveillance are performed to assure continued long-term compliance with applicable regulatory standards.

The Embankment cover design is a critical component in the isolation of waste from the leaching potential of infiltration. DOE's Vitro Embankment and Energy*Solutions*' LARW Embankment use a traditional rock armor cover design as a percolation barrier. However, as part of this updated site-specific Performance Assessment, the Division requested Energy*Solutions* evaluate alternative cover designs that more efficiently maximize the amount of time that precipitation is available for evapotranspiration within the alternative cover designs (DRC, 2012). These cover designs, combined with the natural climate system (with ten times the evaporation potential as annual precipitation), ensure that infiltration to the waste is minimized.

### 2.2.1 COVER DESIGN 1: Traditional Rock Armor

A rock armored cover is the design used at Clive's LARW embankment and DOE's neighboring Vitro embankment. It was also included in the initial design approved for the Class A West combined Embankment. In the rock armor cover design, the top slope consists of the following, from top to bottom:

- **Rip Rap cobbles**. Approximately 24 inches of Type-B rip rap will be placed on the top slopes, above the upper (Type-A) filter zone. The Type-B rip rap used on the top slopes ranges in size from 0.75 to 4.5 inches with a nominal diameter of approximately 1.25 to 2 inches. Engineering specifications indicate that not more than 50% of the Type B rip rap would pass a 1 1/4-inch sieve.

- **Filter Zone (Upper).** Six inches of Type-A filter material, will be placed above the sacrificial soil in the top slope cover. The Type-A filter material ranges in size from 0.08 to 6.0 inches, with 100% passing a 6-inch sieve, 70% passing a 3-inch sieve, and not more than 10% passing a no. 10 sieve (0.079 inch). The Type-A size gradation corresponds to a poorly sorted mixture of coarse sand to coarse gravel and cobble, according to the Universal Soil Classification System.

- **Sacrificial Soil (Frost Protection Layer).** A 12-inch layer consisting of a mixture of silty sand and gravel will be placed above the lower filter zone to protect the lower layers of the cover from freeze/thaw effects. The sacrificial soil material ranges in size from <0.003 to 0.75 inches, with 100% passing a 3/4-inch sieve, 50.2% passing a no. 8 sieve (0.093 inch), and 7.6% passing a no. 200 sieve (0.003 inch).

- **Filter Zone (Lower).** Six inches of Type-B filter material will be placed above the radon barrier in the top slope cover. This filter material ranges in size from 0.2 to 1.5 inches, with 100% passing a 1 1/2- inch sieve, 24.5% passing a 3/4-inch sieve, and 0.4% passing a no. 4 sieve (0.187 inch). The Type-B size gradation corresponds to a coarse sand and fine gravel mix, according to the Universal Soil Classification System.

- **Radon Barrier.** The top slope cover design contains an upper radon barrier consisting of 12 inches of compacted clay with a maximum hydraulic conductivity of $5 \times 10^{-8}$ cm/sec and a lower radon barrier consisting of 12 inches of compacted clay with a hydraulic conductivity of $1 \times 10^{-6}$ cm/sec or less.

The design for the traditional rock armored side slope cover is different, but similar to the top slope, (except for the thickness of the waste layer and the material used in the rip rap layer). The layers used in the Embankment side slope cover consist of the following, from bottom to top:

- **Rip Rap cobbles.** Approximately 24-inches of Type-A rip rap will be placed on the side slopes above the Type-A filter zone. The Type-A rip rap ranges in size from 2 to 16 inches (equivalent to coarse gravel to boulders) with a nominal diameter of 12 inches. Engineering specifications indicate that 100% of the Type-A rip rap would pass a 16-inch screen and not more than 50% would pass a 4 1/2- inch screen.

- **Filter Zone (Upper).** (Same design as top slope.)

- **Frost Protection Layer (Sacrificial Soil).** (Same design as top slope.)

- **Filter Zone (Lower).** The thickness of the Type B filter in the side slope will be 18 inches. The Type B filter material in the side slope will have the same size specifications as the top slope.

- **Radon Barrier**. (Same design as top slope.)

2.2.2 COVER DESIGN 2: Evapotranspirative Cover Design A

Evapotranspirative covers are increasingly being employed as alternative cover designs for municipal solid waste, hazardous waste, uranium/thorium mill tailings, and LLRW sites in arid and semiarid climates. Unlike conventional rock armor cover systems, which use materials with low permeability to limit movement of water into waste, evapotranspirative cover systems minimize water percolation by storing and releasing water through evaporation from the soil surface and through transpiration from vegetation. The primary objective of evapotranspirative cover systems is to use the water balance components of soil and vegetation to hold precipitation and release it through soil surface evaporation or transpiration without allowing water percolation into waste layers.

The use of evapotranspirative cover designs is relatively new. Since the amendment of the Resource Conservation and Recovery Act Subtitle D (40 CFR 258.60) in March 2004, evapotranspirative cover systems and demonstration sites have been installed at hazardous and radioactive waste disposal facilities in the arid west, including Hill Air Force Base (Utah), Monticello Mill Tailings (Utah), Los Alamos National Laboratory (New Mexico), Sandia National Laboratories (New Mexico), Sierra Blanca (Texas), Rocky Mountain Arsenal (Colorado), and the Hanford Site (Washington) (Rock et.al, 2012). In addition to these facilities, evapotranspirative cover systems have been proposed for the U.S. Ecology Nevada Site (Nevada), the Molycorp Tailings Facility (New Mexico), and Clean Harbors (Utah).

The arrangement of the layers used for the Evapotranspirative Cover Design A are (beginning at the top of the cover):

- **Surface layer**. This layer is composed of native vegetated Unit 4 material with 15% gravel mixture. This layer is 6 inches thick. The functions of this layer are to control runoff, minimize erosion, and maximize water loss from evapotranspiration. This layer of silty clay used in both evapotranspirative designs provides storage for water accumulating from precipitation events, enhances losses due to evaporation, and provides a rooting zone for plants that will further decrease the water available for downward movement.

- **Evaporative Zone layer**. This layer is composed of Unit 4 material. The thickness of this layer is varied in the Performance Assessment from 6 inches to 18 inches, to evaluate the influence of additional thickness on the water flow into the waste layer. The purpose of this layer to provide additional storage for precipitation and additional depth for plant rooting zone to maximize evapotranspiration.

- **Frost Protection Layer**. This material ranges in size from 16 inches to clay size particles. This layer is 18 inches thick. The purpose of this layer is to protect layers below from freeze/thaw cycles, wetting/drying cycles, and inhibit plant, animal, or human intrusion.

- **Upper Radon Barrier**. This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This layer has the lowest conductivity of any layer in the cover system. This is a barrier layer that reduces the downward movement of water to the waste and the upward movement of gas out of the disposal cell.

- **Lower Radon Barrier**. This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This is a barrier layer placed directly above the waste that reduces the downward movement of water.

### 2.2.3 COVER DESIGN 3: Evapotranspirative Cover Design B

The only difference between Evapotranspirative Cover Designs A and B is the placement of a filter zone between the frost protection layer and the upper radon barrier. Six inches of Type-B filter material is placed below the frost protection material layer in Evapotranspirative Cover Design B. The filter material ranges in size from 0.2 to 1.5 inches. The Type-B size gradation corresponds to a coarse sand and fine gravel mix. This high conductivity layer is placed on the upper radon barrier which has the lowest conductivity of any layer in the cover system. The function of this coarse-to-fine interface is to collect water that has drained vertically from the layers above and direct it laterally to a surface drainage system.

## 2.3 Source Term

This updated site-specific Performance Assessment evaluates transport and human exposure to 260 isotopes, including the additional radionuclides that were not included in prior Class A Performance Assessments conducted in support of Clive licenses (see Table A-1 of Appendix A). The waste concentrations for each radionuclide were initially developed in 2000 from data supplied by the Manifest Information Management System (MIMS), a database managed by the Department of Energy (DOE) that summarizes national low-level radioactive waste disposal information. The list of radionuclides established from the MIMS database was then classified by R313-15-1009 and their respective maximum Class A concentrations determined. Those nuclides classified as Class A according to Tables I or II of UAC R313-15-1009 (or classified according to UAC R313-15-1009(2)(f) are listed in Table A-2 of Appendix A. Concentration limits for radionuclides not listed on Table I or Table II of R313-15-1009 are set at their respective specific activities (see Table A-3 of Appendix A).

### 2.3.1 Partitioning Coefficients ($K_d$)

The partitioning coefficient is the equilibrium ratio of the adsorbed contaminant concentration in soil or waste (mg/kg) to the concentration in the pore water or leachate (mg/l). Higher $K_d$ values indicate that the specific radionuclide is more likely to partition to the soil and less likely to be released into groundwater. A $K_d$ value of zero is used in the Performance Assessment as an extreme upper bounding value (where a $K_d$ of zero signifies no flow retardation).

### 2.3.2 Fractional Release Rate

The updated site-specific Performance Assessment treats the embankment contaminated zone as a single homogeneous source of changing thickness and radionuclide concentrations as the result of leaching, erosion, and in-growth and decay. Erosion or human activities result in redistribution of the contaminated soil that, in turn, creates new contaminated zones.

As natural precipitation infiltrates through the cover and into the contaminated zone, radionuclides are leached from the waste and transported through the unsaturated (vadose) zone and saturated zone (aquifer) to a down-gradient point of compliance. Fractional releases of contamination from the embankment into the groundwater pathway are characterized by a water/soil concentration ratio for each radionuclide, which is defined as the ratio of the radionuclide concentration in the water to the radionuclide concentration in the contaminated zone.

### 2.3.3 Waste Containers

While they provide enhanced intruder barriers, no other waste isolation due to containerization is considered in the updated site-specific Performance Assessment. The updated site-specific Performance Assessment model considers the time required for the water to percolate through the cover. Although the initial waste moisture contents cannot be known with certainty, due to the inherent variability in the waste and in climatic conditions while the embankment is open, previous open-cell modeling suggests that drying of the waste occurs and that the moisture content in the waste at the time of cell closure will be well below the levels reached at eventual pseudo-steady-state.

# 3. ANALYSIS OF EMBANKMENT PERFORMANCE

As documented in the modeling report included in Appendix A, the two software platforms used in this updated site-specific Performance Assessment include HYDRUS (Šimůnek and Šejna, 2011a; 2011b) and the RESidual RADioactivity (RESRAD) computer family, developed by Argonne National Laboratory (Yu, 2007; 2001). The HYDRUS platform was selected over the U.S. Environmental Protection Agency's Hydrologic Evaluation of Landfill Performance Model (HELP) (Schroeder et al. 1994a, 1994b) which has been used in previous site-specific Performance Assessments (including that supporting Energy*Solutions*' Class A West embankment with rock armored cover). HYDRUS was used because of its ability to simulate complex processes known to have a significant role in water flow in landfill covers in arid regions, including water flow in variably-saturated porous media, material hydraulic property functions, atmospheric surface boundary conditions including precipitation and evapotranspiration, root water uptake, and free-drainage boundary conditions. The HYDRUS platform uses daily values of climate parameters and the properties of the proposed cover designs to provide long-term net infiltration input for the RESRAD transport platform.

The RESRAD platform is used to model in-growth, decay, and transport of radionuclides in the environment and radiation dose to potential human receptors. The RESRAD platform offers advantages over the previous Performance Assessment platform (e.g., PATHRAE), which included the risk of underestimating radionuclide migration into the aquifer due to the lack of consideration of vertical dispersion in the unsaturated zone. The RESRAD platform is also cited in DOE Order 458.1 as an example of dose assessment models that meet DOE quality assurance requirements under DOE Order 414.1C.

## 3.1 Protection of the General Public

Even though the assumption that a member of the general public would build a residence near the edge of the Clive site and use local groundwater for potable needs is extremely unreasonable, the updated site-specific Performance Assessment evaluates exposure of the general population to releases of radioactivity via the air, soil, groundwater, surface water, plant uptake, and exhumation by burrowing animals pathways (following closure and institutional control of the Embankment). The analyses identify and differentiate between the roles performed by the natural disposal site characteristics and design features in isolating and segregating the wastes. The updated site-specific Performance Assessment includes analyses demonstrating that the performance objectives of UAC R313-25-8(1) will continue to be met, even with the disposal of large volumes of blended ion-exchange resins. The analyses also demonstrate a reasonable assurance that the exposures to humans from the release of radioactivity will not exceed the limits set forth in UAC R313-25-19.

### 3.1.1 Air Pathway

Analyses conducted in support of the Class A West License amendment application and the 2008 Radioactive Material License renewal demonstrate that after final placement of the waste and closure of the Embankment with a rock armored cover, the facility design prevents any further migration of radioactivity through the air pathway. Analysis of the longevity of the alternate evapotranspirative cover designs, which provide equivalent isolation of waste from the atmosphere, also demonstrates that no such air-related doses are projected following closure and institutional control. Inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the general public from doses via the air pathway.

#### 3.1.2 Soil Pathway

The design of the Embankment minimizes exposures to contaminated soil by members of the general public. After closure of the embankment, all waste is covered by a cover system designed to protect against erosion and losses of integrity due to waste settlement. Furthermore, administrative controls and design requirements have been developed to ensure that external radiation levels at the top of the final cover will be at or below background radiation for the site, so no such soil-related doses are projected. Inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the general public from doses via the soil pathway.

#### 3.1.3 Groundwater Pathway

The primary site characteristics that prevent public exposures via the groundwater pathway are the very poor groundwater quality at the site, the low population density, arid meteorology, and the low yield of the aquifers. The groundwater is not potable because of its very high concentration of dissolved salts. This characteristic alone prevents any consumption of the water by humans or livestock. Additionally, the horizontal groundwater flow velocity is approximately 0.5 meters per year, resulting in groundwater travel times of approximately 60 years from the toe of the side slope region of the Embankment to the Point-of-Compliance well. Water quality impacts associated with the components of this updated site-specific Performance Assessment are addressed below, within the context of protection of a natural resource degradation performance objective. The low-yield aquifers found beneath the Clive site also limit human consumption as numerous wells would need to be installed in order to provide sustainable water for a household. Even so, analysis of the Embankment's performance demonstrates protection of the general public from doses via the groundwater ingestion pathway.

The candidate cover systems allow very little water to flow into the disposed waste. This limits the contamination of the groundwater by minimizing the contact of water with the waste. Inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not further compromise the already poor groundwater quality or impact the Embankment's performance and protection of the general public from doses via the groundwater pathway.

#### 3.1.4 Surface Water Pathway

Due mainly to the natural site characteristics, there are no radioactive releases expected through the surface water pathway from non-intruder scenarios. The annual precipitation is low and the evaporation is high. No permanent surface water bodies exist in the site vicinity. In addition, the site is far from populated areas. The disposal embankment design features also minimize the potential for releases by the surface water pathway, including loss of cover integrity due to rill and gully erosion. Embankment design includes drainage ditches around the waste disposal areas. After precipitation events, these ditches divert runoff from the disposal embankment to areas away from the waste. Long-term surface water pathway doses are projected to be zero because of the absence of permanent surface water bodies at the site. Inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the general public from doses via the surface water pathway.

#### 3.1.5 Vegetation Pathway

The plant uptake pathway is not a viable exposure pathway at the embankment because of natural site characteristics and design features of the embankment. Exposure by the plant uptake pathway could occur by (1) the production of food crops in contaminated soil at the site, and (2) root intrusion into the waste by native plants that are subsequently consumed by humans or animals. The natural site's characteristics prevent exposures via the plant uptake pathway because there is insufficient water at the site for the production of food crops. In addition, saline soils present at the site limit the number and type of plant species that can tolerate such conditions. Additionally, there are few deep-rooted native plants in the site vicinity.

Vegetation analysis developed for the previous Class A West performance assessment evaluated the redistribution of soils, and contaminants within the soil, by native flora and fauna. The biotic models are consistent with flora and fauna characteristic of Great Basin alkali flat and Great Basin desert shrub communities. In these analyses, vegetation had two primary effects on the cover system: increasing the hydraulic conductivity of the cover material and root clogging of the lateral drainage layers of the rock armor design. After final placement of the cover, releases and doses from the plant pathway are negligible, limited by the site's natural characteristics, which include low rainfall, thin plant cover, and the presence of plants that are highly efficient at removing water from the soil and transpiring the moisture back to the atmosphere.

Design features of the facility also help limit exposures via the plant uptake pathway. The candidate thick covers include capillary break, biointrusion, and bioturbation barriers that make the waste less accessible to plant roots after closure of the facility. The overall scarcity of deep-rooted plant species in the site vicinity and the configuration of the earthen cover will offer an inhospitable environment for extension of these types of roots into the waste. Inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the protection of the general public from doses via the vegetation pathway.

#### 3.1.6 Burrowing Animal Pathway

In the arid environment of the Clive Facility, ants fill a broad ecological niche as predators, scavengers, trophobionts and granivores. Ants burrow for a variety of reasons but mostly for the procurement of shelter, the rearing of young and the storage of foodstuffs. How and where ant nests are constructed plays a role in quantifying the amount and rate of subsurface soil transport to the ground surface at the Clive site. Factors relating to the physical construction of the nests, including the size, shape, and depth of the nest, are key to quantifying excavation volumes. Factors limiting the abundance and distribution of ant nests such as the abundance and distribution of plant species, and intra-specific or inter-specific competitors, also can affect excavated soil volumes. Parameters related to ant burrowing activities include nest area, nest depth, rate of new nest additions, excavation volume, excavation rates, colony density, and colony lifespan. The updated site-specific Performance Assessment developed in support of the disposal of depleted uranium evaluated the impact of ant burrowing on the transport of contaminant and found no significant associated impact to the performance of the Embankment.

Other burrowing animals at the site include kangaroo rats, ground squirrels, badgers and coyotes, and any additional fossorial mammals with potential to occur on or near the Clive site. The first deterrent to burrowing animals is the rip-rap erosion barrier (of the traditional rock armor cover design) and bioturbation barriers described in Appendix C (of the alternate evapotranspirative cover designs). While these may be only partially effective in deterring animals, the primary protective barrier is the clay radon barrier. The burrowing species at the site are not known to dig to such a depth that their burrows could penetrate through the entire cover and into the waste. After final placement of the cover, the design features of the facility, primarily the thick soil cover that isolates the waste from burrowing animals, will control releases and doses. Because of this, the likelihood of any animals burrowing through the entire cover and exhuming waste materials is sufficiently low that it was not included in the safety assessment calculations. As such, the burrowing animal pathway is not projected to result in any exposures to humans. Additionally, inclusion of volumes of blended ion-exchange resins in excess of 40,000ft$^3$ annually does not compromise the Embankment's performance and protection of the general public from doses via the borrowing animal pathway.

### 3.1.7 Doses to the General Public

Because of the design components of the Embankment, inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 ft$^3$ annually does not compromise the Embankment's performance and protection of the general public.

This updated site-specific Performance Assessment includes projections of radionuclide transport in groundwater, assuming a 4 mrem/year general public protection groundwater ingestion dose criterion. The RESRAD platform calculated the release and transport of Class A radionuclides from the Embankment, through the unsaturated zone, and horizontally through the shallow unconfined aquifer to a compliance-monitoring well located 90 feet from the edge of the Embankment. Because of the very low infiltration rates associated with the alternate evapotranspirative cover designs, it is projected that no water that infiltrates through the cover at the beginning of the modeling period will reach the point of compliance within 10,000 years. Therefore, no class A radionuclide concentrations were predicted to arrive at or be ingested by members of the general public from the Point-of-Compliance well within the 10,000 year assessment period. Even so, Table A-11 of Appendix A estimates 100-percent mortality of all members of the general public that consume Clive's native groundwater. Therefore, any dose to the general public (where no members of the public remain living following consumption of Clive's native groundwater) will be below 4 mrem/year. Therefore, inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 ft$^3$ annually does not compromise the Embankment's performance and protection of the general public from ingestion of groundwater.

### 3.2 Protection of the Inadvertent Intruder

For purposes of demonstrating performance, it is important to note that occupation of the site by traditional inadvertent intruders after site closure is not likely due to a lack of natural resources in the area, particularly a lack of potable water. As such, contacting the waste after site closure by an onsite resident is highly unlikely due to the lack of natural resources (no reason to drill or dig) and the design of the embankment cover system. Additionally, the design features and operations minimize radiation dose to inadvertent intruders. Several design features provide the required protection. Overall features include:

- Site isolation and the resultant lack of nearby residential population;
- Embankment cover systems (rip-rap of the traditional rock-armor design, bioturbation/biointrusion barriers of the alternate evapotranspirative cover designs); and
- Granite markers

While onsite occupation is unlikely, the impact on Embankment performance of inadvertent industrial intrusion is modeled in this updated site-specific Performance Assessment (e.g., drilling activities). The RESRAD platform projects annual radionuclide-specific doses related to the Industrial Intruder scenario within the assessment period of 1,000 years following embankment closure, (but not occurring within the first 100 years of institutional control – as outlined in NRC, 1981). After the institutional control period, it is assumed that inadvertent industrial intrusion may occur at any time. Therefore, the modeling results of interest pertain to a model time period of 100 through 1,000 years. In principle, annual doses for viable industrial intrusion scenarios are compared to an annual dose limit of 500 mrem/yr, as described in Section 5.1.1 of NRC (1981). As a result of this analysis, compliance with a performance objective of protection of an inadvertent industrial intruder at levels well below 500 mrem/yr is clearly established for all three embankment cover configurations.

In this updated site-specific Performance Assessment, unit concentrations of radionuclides are evaluated to calculate ratios of dose per unit waste concentration (mrem/yr per pCi/g). Because dose is a linear function of radionuclide concentration, these ratios are then used to evaluate any proposed or actual radionuclide waste concentration to calculate scenario-specific doses as the product of the ratio and the waste concentration. Dose-to-source ratios are used for multiple model years in order to support evaluation of potential doses from varied waste receipt inventories of disposed radionuclides.

For the majority of Class A radionuclides and industrial intrusion exposure scenarios, the time of highest potential radionuclide-specific dose and its progeny (if any) occurs immediately following the end of the institutional control period (e.g., 100 years). However, for a small subset of radionuclides, the time of highest potential radiation dose occurs at the end of the modeling period due to in-growth of progeny. Therefore, nuclide-specific dose-to-source ratios are calculated for modeling times of 100 years and 1,000 years. Depending on the exposure pathways modeled for a scenario, there are a relatively few radionuclides for which the time of maximum dose occurs between 100 and 1,000 years. Dose-to-source ratios at these times are also of interest because they represent a potential point in time where radiation dose may be limiting if the radionuclide in question represents a significant component of a radionuclide inventory being evaluated for disposal.

Dose-to-source ratios for the Intruder-Industrial Driller and Intruder-Industrial worker scenarios are provided in Tables A-5 and A-6 of Appendix A. Exposure pathways evaluated for the industrial driller scenario include external radiation dose to a water well driller from drill cuttings in an open "mud pit" and industrial worker near the cuttings, where the source term is diluted to account for the proportion of cuttings, cover material, unsaturated zone material, and saturated zone material comprising the cuttings. In addition to ratios calculated at 100 and 1,000 years, dose-to-source ratios are also included at the time of highest potential dose for Cm-244 (150 yr), Pa-231 (220 yr), and Np-236 (770 yr). While not actively involved in continued drilling, the Intruder-Industrial Worker is assumed to be exposed to the same scenario parameters as is the Intruder-Industrial Driller, but for 2,000 hours per year.

Application of these dose-to-source ratios to the current disposed Class A inventory (listed in Table A-4 of Appendix A) results in the radionuclide-specific intruder doses listed in Tables A-7 and A-8 of Appendix A. Therefore, as currently performing, this updated site-specific Performance Assessment projects a maximum total effective dose equivalent of 0.0072 mrem/yr to the Intruder-Industrial Driller and 2.4 mrem/yr to the Intruder-Industrial Worker (both well below the 500 mrem/yr criteria). In fact, if the entire Embankment were assumed to be filled with blended ion-exchange resins, the maximum projected dose to the Intruder-Driller and Intruder Worker would only be 0.11 mrem/yr and 37 mrem/yr, respectively (see Tables A-9 and A-10 of Appendix A).

### 3.3 Protection of Individuals During Operations

Energy*Solutions*' Radiation Protection Program that is required by UAC R313-15-101(1) outlines the facility's radiation protection program. Included therein are descriptions of Energy*Solutions*' ALARA program, including dose goals that are significantly below the regulatory dose criteria for workers. Additionally, Energy*Solutions*' Safety and Health Manual describes site safety, incident reporting, emergency response, equipment operation, personal protective equipment, respiratory protection, medical surveillance, exposure monitoring, hazard communication, confined space entry, and other safety related programs. Since its creation in the early 1980s, Energy*Solutions*' radiological control program has successfully maintained worker exposures at a fraction of the regulatory limit, as demonstrated by worker dosimetry records and calculation of CEDEs. Energy*Solutions* actively reviews work practices, performs operational radiological surveys and has a functional ALARA review committee.

Operation-related exposures from the soil pathway involve the potential exposure of the public to contaminated material from the facility. If an exposure occurs, doses for this pathway result from external radiation or ingestion of soil on dirty hands. The primary site characteristic that prevents the likelihood of such exposures during operations and institutional control is the site's remote location (the low population density in the site vicinity, and the lack of natural resources to provide for population expansion). During operation, the facility is monitored as described in Energy*Solutions*' Environmental Monitoring Program, to ensure that no releases or doses have occurred via the soil pathway. During operation, the facility is monitored to ensure that no releases or doses occur via the soil pathway. Because of these administrative controls, inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the general public from soil during operations.

Energy*Solutions*' engineering and operational controls also prevent the resuspension and dispersion of particulates during operations. Blended resins are shipped in containers and not dumped in bulk. They are disposed in the shipping container and then surrounded by clean sand backfill. Water spray is used in the cells as needed to prevent resuspension of radioactivity. Haul roads are also wetted and maintained to prevent the resuspension and dispersion of particulate waste. Polymers are spread on inactive, open areas to bind the surface and prevent resuspension. Energy*Solutions* also performs continuous air monitoring to identify excessive airborne releases that require corrective actions. Because of these administrative controls, inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the general public from atmospheric transport of contaminants during operations.

The nearest stream channel is greater than five miles east of the facility. Surface water from precipitation is directed away from the waste disposal embankment by drainage ditches and berms. During facility operations, possibly contaminated contact storm-water is recovered and conveyed to evaporation ponds where it is monitored and controlled. No contact storm-water is released offsite, thereby maintaining releases from surface water ALARA. During operation, the facility is monitored as described in Energy*Solutions*' Environmental Monitoring Program, to ensure that no releases or doses have occurred via the surface water pathway. Because of these administrative controls, inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the general public from the surface water pathway during operations.

## 3.4 Stability of the Disposal Site After Closure

As part of the Class A West license amendment application, Energy*Solutions* demonstrated that the disposal site, disposal site design, land disposal facility operations, disposal site closure, and post-closure institutional control plans are adequate to protect the public health and safety in that they will provide reasonable assurance of the long-term stability of the disposed waste and the disposal site and will eliminate to the extent practicable the need for continued maintenance of the disposal site through the compliance period following closure in accordance with the requirements of UAC R313-25. The basis for this affirmative finding is presented in the description and justification of the design of the principal design features planned for the disposal facility. These principal design features have been designed to perform their required functions over an appropriate period of time such that the facility will meet applicable performance objectives without the need for ongoing active maintenance following facility closure. The basis for this performance demonstration is presented under UAC R313-25-7(2) through UAC R313-25-7(5), UAC R313-25-8(4), and UAC R313-25-22(1). Design features do not require alteration to accommodate the disposal of processed ion-exchange resin waste.

The design and operation of the CWF provides more stable disposal that is required by 10 CFR 61 for Class A waste. The placement of containerized wastes, the sand backfill, the compacted sand, and clay above the container; the placement and compaction of bulk waste above the layers of containerized waste, and the cover combine to form a stable disposal configuration. The CWF design provides stability to ensure the long-term viability of the disposal unit cover. The use of containers, sand backfill, and compaction combine to resist slumping and differential settlement, which limits infiltration and reduces the potential for dispersion of the waste over time.

### 3.5 Protection of the Groundwater Resource

The Embankment analysis for the rock armored cover design projects that 0.09 cm/yr and 0.168 cm/yr of water will infiltrate through the traditional rock armored cover's top and side slope, respectively (Whetstone, 2011), with the differences in infiltration rates due to the top and side slope design differences. It further demonstrates that at these levels, the Embankment with a rock armored cover will satisfy all of the groundwater protection criteria for radionuclide concentrations limited by what is necessary for the waste to qualify as Class A.

In this updated site-specific Performance Assessment, net water infiltration through the two alternate evapotranspirative covers (as computed using the HYDRUS and RESRAD platforms) is projected to be several orders of magnitude lower than calculated for the traditional rock armored cover (as presented in Table A-12 of Appendix A). The new analysis also demonstrates an optimal maximum evaporative zone layer thickness of 30.5 cm (above which negligible improvement is seen with increased thickness).

Radionuclide transport, driven by the HYDRUS-calculated precipitation infiltration, was modeled with the RESRAD platform assuming a 4 mrem/year groundwater protection level. The RESRAD platform calculated the release and transport of Class A radionuclides from the Embankment, through the unsaturated zone, and horizontally through the shallow unconfined aquifer to a compliance-monitoring well located 90 feet from the edge of the Embankment. The groundwater modeling included many conservative assumptions that helped to ensure that the radionuclide concentrations at the compliance monitoring well were not underestimated. For example, no delay factors for waste container life were used to delay the onset of radionuclide releases from waste. Additionally, the thickness of the entire footprint of the contaminated zone was conservatively set as the maximum waste thickness at the center of the Embankment. In actuality, the waste thickness decreases with distance from the center of the embankment in proportion to the slope of the cover and reaches zero at the edges of the embankment. Also, longitudinal dispersivity in the unsaturated and saturated zones was set at a larger value than that suggested by RESRAD default values (where larger values of longitudinal dispersivity reduce the potential arrival time of contaminants at the Point of Compliance well). Conversely, lateral dispersivity was set to a very low value to eliminate this mechanism of contaminant dilution in the saturated zone.

The groundwater resource protection component of the updated site-specific Performance Assessment was conducted in a phased manner, with the first to determine whether any Class A radionuclide that may potentially be disposed in the Embankment could reach the well at the point of compliance within the 10,000-year modeling period. Because of the very low infiltration rates associated with the alternate evapotranspirative cover designs, it is projected that no water that infiltrates through the cover at the beginning of the modeling period will reach the point of compliance within 10,000 years. Therefore, no class A radionuclide concentrations were predicted to arrive at the Point-of-Compliance well within the 10,000 year assessment period. As such, inclusion of additional volumes of blended ion-exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the groundwater resource.

# 4. SUMMARY AND CONCLUSIONS

The Energy*Solutions* Embankment is sited, designed, and operated for the disposal of Class A waste. The proposed disposal of large quantities (i.e., greater than 40,000 $ft^3$ per year) of processed ion-exchange resin waste has been evaluated in this updated site-specific Performance Assessment, which confirms that this waste can be disposed of safely and in compliance with all applicable regulatory requirements. As such, it specifically demonstrates that:

- The embankment is suitably sited and licensed for the disposal of large quantities of blended ion-exchange resins at or near the Class A limits;
- Disposal of waste in the CWF provides inherent additional intruder protection;
- Protection of an inadvertent intruder is provided even though there are no credible intrusion scenarios; and
- Consumption of the groundwater will not result in a dose to the general public that exceeds standards, even though the groundwater is not potable.

Even though not required for the disposal of Class A waste, the design of the CWF exceeds regulatory requirements for disposal of Class A waste (including blended ion-exchange resins in volumes exceeding 40,000 $ft^3$ annually). Specifically, the CWF provides an intruder barrier (engineered facility, disposal unit stability, and at least 5 meters depth to waste) that meets requirements for radioactive waste in excess of Class A concentrations. Therefore, the CWF design, operation, and licensing demonstrate that it is safe for the disposal of blended ion-exchange Class A resins.

This updated site-specific Performance Assessment and the resulting findings demonstrate that Energy*Solutions*' proposed methods for disposal of blended ion-exchange resins will ensure that future operations, institutional control, and site closure can be conducted safely, and that the site will comply with the Division's radiological performance criteria contained in UAC R313-25.

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# APPENDIX A

## Dose-To-Source Ratio and Dose Tables

# LIST OF TABLES

## Table A-1

### Radionuclides Unanalyzed In Prior Performance Assessments

| Isotope | Disposed Activity (mCi) [1] |
|---|---|
| Ar-39 | 0.04 |
| Ba-137 | 0.00 |
| Bi-208 | 3.30 |
| Cm-250 | 0.00 |
| Co-59 | 0.01 |
| Eu-150 | 0.38 |
| In-113 | 0.10 |
| In-115 | 0.00 |
| Mo-93 | 0.63 |
| Np-236 | 0.00 |
| Pb-205 | 0.10 |
| Rb-87 | 0.01 |
| Sm-146 | 0.16 |
| Sm-147 | 0.01 |
| Sm-148 | 0.00 |
| Sm-149 | 0.00 |
| Sn-117 | 0.04 |
| Tc-98 | 0.04 |
| Te-123 | 0.43 |
| Zr-93 | 0.05 |

[1] In addition to those listed, a single curie of Gd-152 was reported in a single shipment (e.g., manifest number 0868-01-0030). Upon further evaluation, the generator determined that this manifested valued was a typographical error and the activity should have been assigned to Gd-153, which has a half-life of 241.6 days. Because Gd-153 is addressed within prior site-specific Performance Assessments, it is not included in this table. The generator requested that Energy*Solutions* correct the shipping manifest.

## Table A-2

## List of Radionuclide Inventories Classified as Class A According to UAC R313-15-1009

| ELEMENT | NUCLIDE | CLASS A CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Actinium | Ac-225 | 440,000,000 | 2.74E-02 |
| Silver | Ag-105 | 440,000,000 | 1.13E-01 |
| Silver | Ag-108 | 440,000,000 | 4.51E-06 |
| Silver | Ag-110m | 440,000,000 | 6.84E-01 |
| Silver | Ag-111 | 440,000,000 | 2.04E-02 |
| Americium | Am-241 | 10,000 | 4.32E+02 |
| Americium | Am-242 | 440,000,000 | 1.83E-03 |
| Americium | Am-242m | 10,000 | 1.41E+02 |
| Americium | Am-243 | 10,000 | 7.37E+03 |
| Americium | Am-244 | 440,000,000 | 1.15E-03 |
| Americium | Am-245 | 440,000,000 | 2.34E-04 |
| Arsenic | As-73 | 440,000,000 | 2.20E-01 |
| Arsenic | As-74 | 440,000,000 | 4.87E-02 |
| Gold | Au-195 | 440,000,000 | 5.10E-01 |
| Gold | Au-198 | 440,000,000 | 7.38E-03 |
| Gold | Au-199 | 440,000,000 | 8.60E-03 |
| Barium | Ba-140 | 440,000,000 | 3.49E-02 |
| Beryllium | Be-7 | 440,000,000 | 1.46E-01 |
| Bismuth | Bi-205 | 440,000,000 | 4.19E-02 |
| Bismuth | Bi-206 | 440,000,000 | 1.71E-02 |
| Bismuth | Bi-214 | 440,000,000 | 3.79E-05 |
| Berkelium | Bk-247 | 10,000 | 1.40E+03 |
| Berkelium | Bk-249 | 440,000,000 | 8.77E-01 |
| Berkelium | Bk-250 | 440,000,000 | 3.68E-04 |
| Carbon | C-14 | 7,207,207 | 5.73E+03 |
| Calcium | Ca-41 | 440,000,000 | 1.03E+05 |
| Calcium | Ca-45 | 440,000,000 | 4.46E-01 |
| Calcium | Ca-47 | 440,000,000 | 1.24E-02 |
| Cadmium | Cd-105 | 440,000,000 | 1.06E-04 |
| Cadmium | Cd-107 | 440,000,000 | 7.42E-04 |
| Cadmium | Cd-109 | 440,000,000 | 1.27E+00 |
| Cerium | Ce-129 | 440,000,000 | 6.66E-06 |
| Cerium | Ce-133 | 440,000,000 | 1.85E-04 |
| Cerium | Ce-137 | 440,000,000 | 1.03E-03 |

| ELEMENT | NUCLIDE | CLASS A CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Cerium | Ce-139 | 440,000,000 | 3.77E-01 |
| Cerium | Ce-141 | 440,000,000 | 8.90E-02 |
| Cerium | Ce-143 | 440,000,000 | 3.77E-03 |
| Cerium | Ce-144 | 440,000,000 | 7.81E-01 |
| Cerium | Ce-147 | 440,000,000 | 1.79E-06 |
| Californium | Cf-248 | 440,000,000 | 9.14E-01 |
| Californium | Cf-249 | 10,000 | 3.51E+02 |
| Californium | Cf-250 | 10,000 | 1.31E+01 |
| Californium | Cf-251 | 10,000 | 2.46E+00 |
| Californium | Cf-252 | 440,000,000 | 2.65E+00 |
| Chlorine | Cl-36 | 33,522,654,030 | 3.01E+05 |
| Curium | Cm-241 | 440,000,000 | 8.99E-02 |
| Curium | Cm-242 | 2,000,000 | 4.46E-01 |
| Curium | Cm-243 | 10,000 | 2.91E+01 |
| Curium | Cm-244 | 10,000 | 1.81E+01 |
| Curium | Cm-245 | 10,000 | 8.50E+03 |
| Curium | Cm-246 | 10,000 | 4.73E+03 |
| Curium | Cm-247 | 10,000 | 1.56E+07 |
| Curium | Cm-248 | 10,000 | 3.40E+05 |
| Curium | Cm-249 | 440,000,000 | 1.22E-04 |
| Cobalt | Co-56 | 440,000,000 | 2.12E-01 |
| Cobalt | Co-57 | 440,000,000 | 7.45E-01 |
| Cobalt | Co-58 | 440,000,000 | 1.94E-01 |
| Cobalt | Co-60 | 440,000,000 | 5.27E+00 |
| Cobalt | Co-63 | 440,000,000 | 8.69E-07 |
| Chromium | Cr-51 | 440,000,000 | 7.59E-02 |
| Cesium | Cs-134 | 440,000,000 | 2.07E+00 |
| Cesium | Cs-136 | 440,000,000 | 3.61E-02 |
| Cesium | Cs-137 | 630,000 | 3.01E+01 |
| Copper | Cu-67 | 440,000,000 | 1.69E-01 |
| Dysprosium | Dy-166 | 440,000,000 | 9.32E-03 |
| Einsteinium | Es-253 | 440,000,000 | 5.61E-02 |
| Einsteinium | Es-254 | 440,000,000 | 7.55E-01 |
| Europium | Eu-155 | 440,000,000 | 4.76E+00 |
| Europium | Eu-156 | 440,000,000 | 4.16E-02 |
| Iron | Fe-52 | 440,000,000 | 9.45E-04 |
| Iron | Fe-53 | 440,000,000 | 1.62E-05 |
| Iron | Fe-55 | 440,000,000 | 2.73E+00 |

| ELEMENT | NUCLIDE | CLASS A CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Iron | Fe-59 | 440,000,000 | 1.22E-01 |
| Fermium | Fm-252 | 440,000,000 | 2.90E-03 |
| Gallium | Ga-67 | 440,000,000 | 8.93E-03 |
| Gadolinium | Gd-151 | 440,000,000 | 3.40E-01 |
| Gadolinium | Gd-153 | 440,000,000 | 6.62E-01 |
| Germanium | Ge-68 | 440,000,000 | 7.42E-01 |
| Hydrogen | H-3 | 25,000,000 | 1.23E+01 |
| Hafnium | Hf-172 | 440,000,000 | 1.87E+00 |
| Hafnium | Hf-175 | 440,000,000 | 1.92E-01 |
| Hafnium | Hf-181 | 440,000,000 | 1.16E-01 |
| Mercury | Hg-203 | 440,000,000 | 1.28E-01 |
| Holmium | Ho-166 | 440,000,000 | 3.05E-03 |
| Iodine | I-123 | 440,000,000 | 1.52E-03 |
| Iodine | I-125 | 440,000,000 | 1.63E-01 |
| Iodine | I-126 | 440,000,000 | 3.59E-02 |
| Iodine | I-129 | 5,000 | 1.57E+07 |
| Iodine | I-131 | 440,000,000 | 2.20E-02 |
| Iodine | I-133 | 440,000,000 | 2.37E-03 |
| Iodine | I-135 | 440,000,000 | 7.50E-04 |
| Iodine | I-137 | 440,000,000 | 7.77E-07 |
| Indium | In-111 | 440,000,000 | 7.68E-03 |
| Indium | In-113m | 440,000,000 | 1.89E-04 |
| Indium | In-114 | 440,000,000 | 2.28E-06 |
| Indium | In-114m | 440,000,000 | 1.36E-01 |
| Iridium | Ir-192 | 440,000,000 | 2.02E-01 |
| Lanthanum | La-140 | 440,000,000 | 4.60E-03 |
| Manganese | Mn-52 | 440,000,000 | 1.53E-02 |
| Manganese | Mn-52m | 440,000,000 | 4.01E-05 |
| Manganese | Mn-54 | 440,000,000 | 8.56E-01 |
| Molybdenum | Mo-99 | 440,000,000 | 7.53E-03 |
| Sodium | Na-22 | 440,000,000 | 2.60E+00 |
| Niobium | Nb-94 | 13,000 | 2.03E+04 |
| Neodymium | Nd-147 | 440,000,000 | 3.01E-02 |
| Nickel | Ni-59 | 14,000,000 | 7.60E+04 |
| Nickel | Ni-63 | 2,200,000 | 1.00E+02 |
| Neptunium | Np-235 | 440,000,000 | 1.09E+00 |
| Neptunium | Np-237 | 10,000 | 2.14E+06 |
| Osmium | Os-191 | 440,000,000 | 4.22E-02 |

| ELEMENT | NUCLIDE | CLASS A CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Osmium | Os-191m | 440,000,000 | 1.50E-03 |
| Phosphorous | P-32 | 440,000,000 | 3.91E-02 |
| Phosphorous | P-33 | 440,000,000 | 6.93E-02 |
| Protactinium | Pa-233 | 440,000,000 | 7.39E-02 |
| Protactinium | Pa-234 | 440,000,000 | 7.65E-04 |
| Protactinium | Pa-234m | 440,000,000 | 2.23E-06 |
| Lead | Pb-203 | 440,000,000 | 5.92E-03 |
| Lead | Pb-214 | 440,000,000 | 5.10E-05 |
| Palladium | Pd-103 | 440,000,000 | 4.66E-02 |
| Promethium | Pm-143 | 440,000,000 | 7.26E-01 |
| Promethium | Pm-147 | 440,000,000 | 2.62E+00 |
| Polonium | Po-208 | 440,000,000 | 2.90E+00 |
| Polonium | Po-210 | 440,000,000 | 3.79E-01 |
| Polonium | Po-214 | 440,000,000 | 5.21E-12 |
| Plutonium | Pu-236 | 500 | 2.86E+00 |
| Plutonium | Pu-238 | 10,000 | 8.77E+01 |
| Plutonium | Pu-239 | 10,000 | 2.41E+04 |
| Plutonium | Pu-240 | 10,000 | 6.56E+03 |
| Plutonium | Pu-241 | 350,000 | 1.44E+01 |
| Plutonium | Pu-242 | 10,000 | 3.73E+05 |
| Plutonium | Pu-243 | 500 | 5.66E-04 |
| Plutonium | Pu-244 | 500 | 8.08E+07 |
| Radium | Ra-225 | 440,000,000 | 4.08E-02 |
| Radium | Ra-226 | 10,000 | 1.60E+03 |
| Rubidium | Rb-82 | 440,000,000 | 2.38E-06 |
| Rubidium | Rb-83 | 440,000,000 | 2.36E-01 |
| Rubidium | Rb-84 | 440,000,000 | 8.99E-02 |
| Rubidium | Rb-86 | 440,000,000 | 5.10E-02 |
| Rhenium | Re-183 | 440,000,000 | 1.92E-01 |
| Rhenium | Re-184 | 440,000,000 | 1.04E-01 |
| Rhenium | Re-184m | 440,000,000 | 4.63E-01 |
| Rhenium | Re-186 | 440,000,000 | 1.02E-02 |
| Rhenium | Re-187 | 38,000 | 4.35E+10 |
| Rhenium | Re-188 | 440,000,000 | 1.94E-03 |
| Rhodium | Rh-103m | 440,000,000 | 1.07E-04 |
| Ruthenium | Ru-103 | 440,000,000 | 1.08E-01 |
| Ruthenium | Ru-106 | 440,000,000 | 1.02E+00 |
| Sulfur | S-35 | 440,000,000 | 2.40E-01 |

| ELEMENT | NUCLIDE | CLASS A CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Antimony | Sb-122 | 440,000,000 | 7.40E-03 |
| Antimony | Sb-124 | 440,000,000 | 1.65E-01 |
| Antimony | Sb-125 | 440,000,000 | 2.76E+00 |
| Antimony | Sb-126 | 440,000,000 | 3.42E-02 |
| Antimony | Sb-126m | 440,000,000 | 3.61E-05 |
| Antimony | Sb-129 | 440,000,000 | 5.02E-04 |
| Scandium | Sc-41 | 440,000,000 | 1.89E-08 |
| Scandium | Sc-44 | 440,000,000 | 4.48E-04 |
| Scandium | Sc-46 | 440,000,000 | 2.30E-01 |
| Scandium | Sc-47 | 440,000,000 | 9.18E-03 |
| Selenium | Se-75 | 440,000,000 | 3.28E-01 |
| Selenium | Se-85 | 440,000,000 | 1.01E-06 |
| Samarium | Sm-145 | 440,000,000 | 9.32E-01 |
| Samarium | Sm-153 | 440,000,000 | 5.28E-03 |
| Tin | Sn-113 | 440,000,000 | 3.15E-01 |
| Tin | Sn-117m | 440,000,000 | 3.73E-02 |
| Tin | Sn-119m | 440,000,000 | 8.03E-01 |
| Tin | Sn-121 | 440,000,000 | 3.09E-03 |
| Strontium | Sr-81 | 440,000,000 | 4.24E-05 |
| Strontium | Sr-82 | 440,000,000 | 7.00E-02 |
| Strontium | Sr-85 | 440,000,000 | 1.78E-01 |
| Strontium | Sr-87m | 440,000,000 | 3.20E-04 |
| Strontium | Sr-89 | 440,000,000 | 1.38E-01 |
| Strontium | Sr-90 | 25,000 | 2.88E+01 |
| Tantalum | Ta-182 | 440,000,000 | 3.14E-01 |
| Terbium | Tb-160 | 440,000,000 | 1.98E-01 |
| Technetium | Tc-95 | 440,000,000 | 2.28E-03 |
| Technetium | Tc-95m | 440,000,000 | 1.67E-01 |
| Technetium | Tc-99 | 187,500 | 2.11E+05 |
| Technetium | Tc-99m | 440,000,000 | 6.86E-04 |
| Tellurium | Te-123m | 440,000,000 | 3.28E-01 |
| Tellurium | Te-125m | 440,000,000 | 1.57E-01 |
| Tellurium | Te-129 | 440,000,000 | 1.32E-04 |
| Tellurium | Te-129m | 440,000,000 | 9.21E-02 |
| Thorium | Th-231 | 440,000,000 | 2.91E-03 |
| Thorium | Th-234 | 440,000,000 | 6.60E-02 |
| Thallium | Tl-201 | 440,000,000 | 8.32E-03 |
| Thallium | Tl-202 | 440,000,000 | 3.35E-02 |

| ELEMENT | NUCLIDE | CLASS A CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Thallium | Tl-204 | 440,000,000 | 3.78E+00 |
| Thallium | Tl-210 | 440,000,000 | 2.47E-06 |
| Thulium | Tm-170 | 440,000,000 | 3.52E-01 |
| Thulium | Tm-171 | 440,000,000 | 1.92E+00 |
| Uranium | U-228 | 440,000,000 | 1.73E-05 |
| Uranium | U-230 | 440,000,000 | 5.70E-02 |
| Uranium | U-233 | 75,000 | 1.59E+05 |
| Uranium | U-235 | 15,500 | 7.04E+08 |
| Uranium | U-depleted | 370,000 | |
| Vanadium | V-48 | 440,000,000 | 4.38E-02 |
| Tungsten | W-181 | 440,000,000 | 3.32E-01 |
| Tungsten | W-185 | 440,000,000 | 2.06E-01 |
| Tungsten | W-187 | 440,000,000 | 2.71E-03 |
| Tungsten | W-188 | 440,000,000 | 1.90E-01 |
| Xenon | Xe-127 | 440,000,000 | 9.97E-02 |
| Xenon | Xe-131m | 440,000,000 | 3.27E-02 |
| Xenon | Xe-133 | 440,000,000 | 1.44E-02 |
| Xenon | Xe-133m | 440,000,000 | 6.00E-03 |
| Yttrium | Y-88 | 440,000,000 | 2.92E-01 |
| Yttrium | Y-91 | 440,000,000 | 1.60E-01 |
| Yttrium | Y-99 | 440,000,000 | 4.66E-08 |
| Ytterbium | Yb-169 | 440,000,000 | 8.78E-02 |
| Zinc | Zn-65 | 440,000,000 | 6.69E-01 |
| Zirconium | Zr-88 | 440,000,000 | 2.28E-01 |
| Zirconium | Zr-95 | 440,000,000 | 1.75E-01 |

## Table A-3

### List of Specific Activity Limits for Radionuclides Not Included in UAC R313-15-1009

| ELEMENT | NUCLIDE | SPECIFIC ACTIVITY CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Actinium | Ac-227 | 72,300,000,000,000 | 2.18E+01 |
| Silver | Ag-108m | 26,081,000,000,000 | 4.18E+02 |
| Aluminum | Al-26 | 18,600,000,000 | 7.40E+05 |
| Barium | Ba-133 | 256,160,000,000,000 | 1.05E+01 |
| Beryllium | Be-10 | 22,000,000,000 | 1.51E+06 |
| Bismuth | Bi-207 | 53,670,000,000,000 | 3.16E+01 |
| Bismuth | Bi-210m | 567,820,000 | 3.04E+06 |
| Cadmium | Cd-113 | 0.4303 | 9.30E+15 |
| Cadmium | Cd-113m | 224,520,000,000,000 | 1.41E+01 |
| Cesium | Cs-135 | 1,152,100,000 | 2.30E+06 |
| Europium | Eu-152 | 173,050,000,000,000 | 1.35E+01 |
| Europium | Eu-154 | 270,420,000,000,000 | 8.59E+00 |
| Iron | Fe-60 | 3,974,800,000 | 1.50E+06 |
| Gadolinium | Gd-148 | 32,228,000,000,000 | 7.46E+01 |
| Mercury | Hg-194 | 3,546,100,000,000 | 4.44E+02 |
| Holmium | Ho-166m | 1,800,000,000,000 | 1.20E+03 |
| Manganese | Mn-53 | 1,800,000,000 | 3.74E+06 |
| Niobium | Nb-91 | 5,780,000,000,000 | 6.80E+02 |
| Niobium | Nb-92 | 112,000,000 | 3.47E+07 |
| Niobium | Nb-93m | 263,460,000,000,000 | 1.61E+01 |
| Neodymium | Nd-144 | 4.27 | 2.29E+15 |
| Osmium | Os-194 | 307,330,000,000,000 | 6.00E+00 |
| Protactinium | Pa-231 | 47,000,000,000 | 3.28E+04 |
| Lead | Pb-202 | 3,400,000,000 | 5.25E+04 |
| Lead | Pb-210 | 76,000,000,000,000 | 2.23E+01 |
| Palladium | Pd-107 | 510,000,000 | 6.50E+06 |
| Promethium | Pm-145 | 140,000,000,000,000 | 1.77E+01 |
| Polonium | Po-209 | 16,781,000,000,000 | 1.02E+02 |
| Platinum | Pt-193 | 37,000,000,000,000 | 5.00E+01 |
| Radium | Ra-228 | 272,396,000,000,000 | 5.75E+00 |
| Selenium | Se-79 | 69,700,000,000 | 6.50E+04 |
| Silicon | Si-32 | 65,000,000,000,000 | 1.72E+02 |
| Samarium | Sm-151 | 26,320,000,000,000 | 9.00E+01 |

| ELEMENT | NUCLIDE | SPECIFIC ACTIVITY CONCENTRATION LIMIT (pCi/g) | HALF-LIFE (years) |
|---|---|---|---|
| Tin | Sn-121m | 53,754,000,000,000 | 5.50E+01 |
| Tin | Sn-126 | 28,391,000,000 | 1.00E+05 |
| Terbium | Tb-157 | 15,000,000,000,000 | 7.10E+01 |
| Terbium | Tb-158 | 15,000,000,000,000 | 1.80E+02 |
| Tellurium | Te-123 | 291 | 1.00E+13 |
| Thorium | Th-229 | 212,830,000,000 | 7.88E+03 |
| Thorium | Th-230 | 20,628,000,000 | 7.54E+04 |
| Thorium | Th-232 | 110,000 | 1.41E+10 |
| Titanium | Ti-44 | 156,350,000,000,000 | 6.30E+01 |
| Uranium | U-232 | 22,028,000,000,000 | 6.89E+01 |
| Uranium | U-234 | 6,210,000,000 | 2.46E+05 |
| Uranium | U-236 | 64,720,000 | 2.34E+07 |
| Uranium | U-238 | 336,260 | 4.47E+09 |
| Uranium | U-natural | 680,000 | |
| Vanadium | V-50 | 0.0511 | 1.40E+17 |
| Zirconium | Zr-93 | 2,514,100,000 | 1.53E+06 |

## Table A-4

### Disposed Class A Waste Inventory*

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Ac-224 | 6.10E-02 | 2.06E-08 | 1.14E-05 |
| Ac-225 | 2.61E+01 | 8.80E-06 | 4.89E-03 |
| Ac-227 | 1.08E+04 | 3.64E-03 | 2.02E+00 |
| Ac-228 | 1.64E+03 | 5.53E-04 | 3.07E-01 |
| Ag-105 | 8.91E-03 | 3.01E-09 | 1.67E-06 |
| Ag-108 | 8.16E-01 | 2.75E-07 | 1.53E-04 |
| Ag-108m | 2.46E+03 | 8.30E-04 | 4.61E-01 |
| Ag-109m | 1.35E-02 | 4.55E-09 | 2.53E-06 |
| Ag-110 | 5.23E+01 | 1.76E-05 | 9.80E-03 |
| Ag-110m | 6.76E+04 | 2.28E-02 | 1.27E+01 |
| Ag-111 | 7.65E-10 | 2.58E-16 | 1.43E-13 |
| Al-26 | 4.07E+01 | 1.37E-05 | 7.63E-03 |
| Am-241 | 2.55E+04 | 8.60E-03 | 4.78E+00 |
| Am-242 | 2.48E+00 | 8.36E-07 | 4.65E-04 |
| Am-242m | 1.83E-01 | 6.16E-08 | 3.42E-05 |
| Am-243 | 1.56E+02 | 5.25E-05 | 2.92E-02 |
| Am-244 | 6.71E-04 | 2.26E-10 | 1.26E-07 |
| Am-245 | 8.95E-04 | 3.02E-10 | 1.68E-07 |
| Am-246 | 2.24E-07 | 7.56E-14 | 4.20E-11 |
| Ar-37 | 5.30E-01 | 1.79E-07 | 9.94E-05 |
| Ar-39 | 4.00E-02 | 1.35E-08 | 7.50E-06 |
| Ar-41 | 1.69E-12 | 5.70E-19 | 3.17E-16 |
| Ar-42 | 2.11E-02 | 7.12E-09 | 3.95E-06 |
| As-73 | 1.24E+00 | 4.19E-07 | 2.33E-04 |
| As-74 | 2.98E-05 | 1.01E-11 | 5.58E-09 |
| As-76 | 1.00E+00 | 3.37E-07 | 1.87E-04 |
| At-211 | 6.89E-01 | 2.32E-07 | 1.29E-04 |
| At-217 | 4.77E+00 | 1.61E-06 | 8.94E-04 |
| Au-194 | 3.68E-03 | 1.24E-09 | 6.90E-07 |
| Au-195 | 5.95E+00 | 2.01E-06 | 1.11E-03 |
| Au-198 | 2.98E-01 | 1.00E-07 | 5.58E-05 |
| Au-199 | 4.77E-01 | 1.61E-07 | 8.94E-05 |
| Ba-131 | 4.28E+00 | 1.44E-06 | 8.02E-04 |
| Ba-133 | 1.05E+03 | 3.53E-04 | 1.96E-01 |
| Ba-133m | 8.25E+00 | 2.78E-06 | 1.55E-03 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Ba-137 | 4.80E-03 | 1.62E-09 | 8.99E-07 |
| Ba-137m | 2.67E+02 | 9.02E-05 | 5.01E-02 |
| Ba-140 | 4.96E+04 | 1.67E-02 | 9.30E+00 |
| Be-7 | 6.19E+03 | 2.09E-03 | 1.16E+00 |
| Be-10 | 1.02E-02 | 3.44E-09 | 1.91E-06 |
| Bi-205 | 2.74E+00 | 9.24E-07 | 5.13E-04 |
| Bi-206 | 1.08E-03 | 3.64E-10 | 2.02E-07 |
| Bi-207 | 1.99E+02 | 6.73E-05 | 3.74E-02 |
| Bi-208 | 3.30E+00 | 1.11E-06 | 6.18E-04 |
| Bi-210 | 5.17E+00 | 1.74E-06 | 9.68E-04 |
| Bi-211 | 2.54E-05 | 8.57E-12 | 4.76E-09 |
| Bi-212 | 3.13E+01 | 1.06E-05 | 5.86E-03 |
| Bi-213 | 4.77E+00 | 1.61E-06 | 8.94E-04 |
| Bi-214 | 2.25E+01 | 7.58E-06 | 4.21E-03 |
| Bk-247 | 1.50E-03 | 5.06E-10 | 2.81E-07 |
| Bk-249 | 7.19E-01 | 2.43E-07 | 1.35E-04 |
| C-14 | 3.86E+05 | 1.30E-01 | 7.23E+01 |
| Ca-41 | 1.49E-01 | 5.03E-08 | 2.79E-05 |
| Ca-45 | 3.07E+03 | 1.03E-03 | 5.75E-01 |
| Ca-47 | 2.11E-03 | 7.12E-10 | 3.95E-07 |
| Cd-109 | 2.19E+04 | 7.39E-03 | 4.11E+00 |
| Cd-113 | 8.12E-05 | 2.74E-11 | 1.52E-08 |
| Cd-113m | 1.80E+03 | 6.07E-04 | 3.37E-01 |
| Cd-115m | 1.29E+00 | 4.35E-07 | 2.42E-04 |
| Ce-137 | 4.39E+01 | 1.48E-05 | 8.23E-03 |
| Ce-139 | 2.46E+01 | 8.30E-06 | 4.61E-03 |
| Ce-141 | 1.01E+04 | 3.40E-03 | 1.89E+00 |
| Ce-143 | 9.19E-02 | 3.10E-08 | 1.72E-05 |
| Ce-144 | 8.09E+04 | 2.73E-02 | 1.52E+01 |
| Cf-249 | 6.86E+00 | 2.31E-06 | 1.29E-03 |
| Cf-250 | 1.84E-01 | 6.19E-08 | 3.44E-05 |
| Cf-251 | 8.55E-04 | 2.88E-10 | 1.60E-07 |
| Cf-252 | 2.27E+02 | 7.65E-05 | 4.25E-02 |
| Cl-36 | 1.37E+02 | 4.61E-05 | 2.56E-02 |
| Cm-241 | 9.78E-04 | 3.30E-10 | 1.83E-07 |
| Cm-242 | 1.12E+03 | 3.78E-04 | 2.10E-01 |
| Cm-243 | 8.35E+02 | 2.82E-04 | 1.56E-01 |
| Cm-244 | 8.99E+02 | 3.03E-04 | 1.68E-01 |
| Cm-245 | 2.63E+01 | 8.87E-06 | 4.93E-03 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Cm-246 | 3.94E+00 | 1.33E-06 | 7.38E-04 |
| Cm-247 | 2.88E-01 | 9.72E-08 | 5.40E-05 |
| Cm-248 | 3.82E-01 | 1.29E-07 | 7.17E-05 |
| Cm-250 | 7.51E-04 | 2.53E-10 | 1.41E-07 |
| Co-56 | 8.13E+02 | 2.74E-04 | 1.52E-01 |
| Co-57 | 1.57E+05 | 5.31E-02 | 2.95E+01 |
| Co-58 | 9.24E+05 | 3.12E-01 | 1.73E+02 |
| Co-58m | 3.31E+01 | 1.12E-05 | 6.20E-03 |
| Co-59 | 6.41E-03 | 2.16E-09 | 1.20E-06 |
| Co-60 | 1.36E+07 | 4.59E+00 | 2.55E+03 |
| Co-61 | 2.69E-05 | 9.07E-12 | 5.04E-09 |
| Cr-51 | 2.93E+05 | 9.88E-02 | 5.49E+01 |
| Cr-57 | 2.15E-01 | 7.25E-08 | 4.03E-05 |
| Cs-134 | 1.46E+05 | 4.93E-02 | 2.74E+01 |
| Cs-134m | 5.50E-01 | 1.86E-07 | 1.03E-04 |
| Cs-135 | 1.18E+02 | 3.98E-05 | 2.21E-02 |
| Cs-136 | 6.31E+00 | 2.13E-06 | 1.18E-03 |
| Cs-137 | 1.45E+06 | 4.89E-01 | 2.72E+02 |
| Cu-64 | 4.49E+01 | 1.52E-05 | 8.42E-03 |
| Cu-67 | 1.80E+00 | 6.07E-07 | 3.37E-04 |
| Dy-159 | 9.01E-03 | 3.04E-09 | 1.69E-06 |
| Es-254 | 5.04E-07 | 1.70E-13 | 9.44E-11 |
| Eu-146 | 1.30E-03 | 4.38E-10 | 2.44E-07 |
| Eu-147 | 3.24E-04 | 1.09E-10 | 6.07E-08 |
| Eu-148 | 2.70E-04 | 9.11E-11 | 5.06E-08 |
| Eu-149 | 3.45E-03 | 1.16E-09 | 6.46E-07 |
| Eu-150 | 3.84E-01 | 1.30E-07 | 7.20E-05 |
| Eu-152 | 2.50E+04 | 8.43E-03 | 4.68E+00 |
| Eu-152m | 9.39E-02 | 3.17E-08 | 1.76E-05 |
| Eu-154 | 3.92E+03 | 1.32E-03 | 7.35E-01 |
| Eu-155 | 1.51E+03 | 5.11E-04 | 2.84E-01 |
| Eu-156 | 3.67E+00 | 1.24E-06 | 6.88E-04 |
| F-18 | 4.53E-03 | 1.53E-09 | 8.49E-07 |
| Fe-55 | 2.88E+07 | 9.71E+00 | 5.40E+03 |
| Fe-59 | 1.32E+05 | 4.46E-02 | 2.48E+01 |
| Fr-221 | 4.77E+00 | 1.61E-06 | 8.94E-04 |
| Ga-67 | 4.75E+01 | 1.60E-05 | 8.90E-03 |
| Ga-68 | 1.78E+01 | 6.01E-06 | 3.34E-03 |
| Gd-146 | 1.18E-03 | 3.98E-10 | 2.21E-07 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Gd-148 | 1.15E-02 | 3.88E-09 | 2.15E-06 |
| Gd-151 | 4.01E-03 | 1.35E-09 | 7.51E-07 |
| Gd-152 | 1.00E+03 | 3.37E-04 | 1.87E-01 |
| Gd-153 | 1.22E+05 | 4.13E-02 | 2.29E+01 |
| Gd-159 | 1.00E-03 | 3.37E-10 | 1.87E-07 |
| Ge-68 | 1.04E+04 | 3.50E-03 | 1.95E+00 |
| H-3 | 4.01E+06 | 1.35E+00 | 7.52E+02 |
| Hf-172 | 4.34E-01 | 1.47E-07 | 8.14E-05 |
| Hf-175 | 3.84E+00 | 1.29E-06 | 7.19E-04 |
| Hf-181 | 1.79E+03 | 6.05E-04 | 3.36E-01 |
| Hg-194 | 1.69E+00 | 5.70E-07 | 3.17E-04 |
| Hg-197 | 1.89E-07 | 6.37E-14 | 3.54E-11 |
| Hg-203 | 5.39E+01 | 1.82E-05 | 1.01E-02 |
| Hg-207 | 1.00E-03 | 3.37E-10 | 1.87E-07 |
| Ho-166 | 8.57E-03 | 2.89E-09 | 1.61E-06 |
| Ho-166m | 7.81E+00 | 2.63E-06 | 1.46E-03 |
| I-123 | 6.01E+01 | 2.03E-05 | 1.13E-02 |
| I-124 | 3.39E-10 | 1.14E-16 | 6.35E-14 |
| I-125 | 1.12E+04 | 3.76E-03 | 2.09E+00 |
| I-126 | 2.37E-05 | 8.00E-12 | 4.45E-09 |
| I-129 | 2.10E+03 | 7.09E-04 | 3.94E-01 |
| I-131 | 6.31E+03 | 2.13E-03 | 1.18E+00 |
| I-132 | 2.00E-04 | 6.75E-11 | 3.75E-08 |
| I-133 | 3.02E+00 | 1.02E-06 | 5.66E-04 |
| In-111 | 2.57E+02 | 8.67E-05 | 4.82E-02 |
| In-113 | 1.00E-01 | 3.37E-08 | 1.87E-05 |
| In-113m | 1.74E+01 | 5.87E-06 | 3.26E-03 |
| In-114 | 1.31E+00 | 4.42E-07 | 2.45E-04 |
| In-114m | 1.96E+02 | 6.61E-05 | 3.67E-02 |
| In-115 | 1.00E-03 | 3.37E-10 | 1.87E-07 |
| In-133 | 4.50E-03 | 1.52E-09 | 8.43E-07 |
| Ir-189 | 4.40E-04 | 1.48E-10 | 8.24E-08 |
| Ir-192 | 1.66E+03 | 5.60E-04 | 3.11E-01 |
| K-40 | 1.34E+04 | 4.51E-03 | 2.50E+00 |
| K-42 | 4.21E-08 | 1.42E-14 | 7.89E-12 |
| Kr-85 | 1.33E+04 | 4.49E-03 | 2.49E+00 |
| Kr-85m | 4.00E-03 | 1.35E-09 | 7.50E-07 |
| La-140 | 1.07E+04 | 3.61E-03 | 2.01E+00 |
| Lu-172 | 4.41E-02 | 1.49E-08 | 8.26E-06 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Lu-173 | 1.33E+00 | 4.49E-07 | 2.50E-04 |
| Lu-174 | 5.04E-01 | 1.70E-07 | 9.44E-05 |
| Lu-177 | 2.32E+02 | 7.83E-05 | 4.35E-02 |
| Lu-177m | 5.59E+00 | 1.89E-06 | 1.05E-03 |
| Mn-52 | 1.96E+01 | 6.60E-06 | 3.67E-03 |
| Mn-53 | 1.16E-05 | 3.93E-12 | 2.18E-09 |
| Mn-54 | 2.74E+06 | 9.24E-01 | 5.13E+02 |
| Mn-56 | 3.71E-02 | 1.25E-08 | 6.95E-06 |
| Mn-57 | 1.44E-04 | 4.86E-11 | 2.70E-08 |
| Mo-93 | 6.30E-01 | 2.12E-07 | 1.18E-04 |
| Mo-99 | 9.75E+02 | 3.29E-04 | 1.83E-01 |
| Na-22 | 7.67E+03 | 2.59E-03 | 1.44E+00 |
| Na-24 | 3.01E+00 | 1.01E-06 | 5.63E-04 |
| Nb-90 | 2.42E-03 | 8.16E-10 | 4.53E-07 |
| Nb-91 | 6.30E-01 | 2.12E-07 | 1.18E-04 |
| Nb-92 | 6.30E-01 | 2.12E-07 | 1.18E-04 |
| Nb-93m | 8.36E+01 | 2.82E-05 | 1.57E-02 |
| Nb-94 | 7.73E+02 | 2.61E-04 | 1.45E-01 |
| Nb-95 | 1.26E+05 | 4.25E-02 | 2.36E+01 |
| Nb-95m | 2.60E+00 | 8.78E-07 | 4.88E-04 |
| Nb-97 | 1.12E+00 | 3.78E-07 | 2.10E-04 |
| Nd-147 | 7.30E-01 | 2.46E-07 | 1.37E-04 |
| Ni-57 | 4.15E-01 | 1.40E-07 | 7.78E-05 |
| Ni-59 | 2.15E+04 | 7.26E-03 | 4.03E+00 |
| Ni-63 | 2.37E+06 | 7.98E-01 | 4.44E+02 |
| Ni-65 | 2.03E-03 | 6.85E-10 | 3.80E-07 |
| Np-236 | 4.95E-03 | 1.67E-09 | 9.28E-07 |
| Np-237 | 2.57E+03 | 8.66E-04 | 4.81E-01 |
| Np-238 | 1.04E-06 | 3.51E-13 | 1.95E-10 |
| Np-239 | 4.06E+00 | 1.37E-06 | 7.60E-04 |
| Os-185 | 1.84E-01 | 6.21E-08 | 3.45E-05 |
| Os-191 | 4.56E+00 | 1.54E-06 | 8.54E-04 |
| Os-194 | 1.00E-04 | 3.37E-11 | 1.87E-08 |
| P-32 | 4.60E+03 | 1.55E-03 | 8.62E-01 |
| P-33 | 2.88E+03 | 9.70E-04 | 5.39E-01 |
| Pa-231 | 9.44E+03 | 3.18E-03 | 1.77E+00 |
| Pa-233 | 3.12E+00 | 1.05E-06 | 5.85E-04 |
| Pa-234 | 7.18E-01 | 2.42E-07 | 1.35E-04 |
| Pa-234m | 2.96E+02 | 9.97E-05 | 5.54E-02 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Pb-202 | 2.42E-03 | 8.16E-10 | 4.53E-07 |
| Pb-203 | 3.42E-01 | 1.16E-07 | 6.42E-05 |
| Pb-209 | 4.77E+00 | 1.61E-06 | 8.94E-04 |
| Pb-210 | 5.60E+05 | 1.89E-01 | 1.05E+02 |
| Pb-211 | 2.68E-07 | 9.04E-14 | 5.02E-11 |
| Pb-212 | 1.90E+03 | 6.40E-04 | 3.56E-01 |
| Pb-214 | 3.62E+01 | 1.22E-05 | 6.79E-03 |
| Pd-103 | 6.12E-01 | 2.06E-07 | 1.15E-04 |
| Pd-107 | 6.32E-01 | 2.13E-07 | 1.18E-04 |
| Pd-109 | 2.00E-05 | 6.75E-12 | 3.75E-09 |
| Pm-143 | 2.62E-03 | 8.84E-10 | 4.91E-07 |
| Pm-144 | 1.23E-01 | 4.16E-08 | 2.31E-05 |
| Pm-145 | 1.48E+01 | 4.99E-06 | 2.77E-03 |
| Pm-146 | 5.15E-01 | 1.74E-07 | 9.65E-05 |
| Pm-147 | 5.56E+03 | 1.88E-03 | 1.04E+00 |
| Po-208 | 1.00E-01 | 3.37E-08 | 1.87E-05 |
| Po-209 | 1.33E-02 | 4.50E-09 | 2.50E-06 |
| Po-210 | 5.61E+05 | 1.89E-01 | 1.05E+02 |
| Po-212 | 1.61E+01 | 5.42E-06 | 3.01E-03 |
| Po-213 | 4.58E+00 | 1.55E-06 | 8.59E-04 |
| Po-214 | 1.70E+00 | 5.73E-07 | 3.19E-04 |
| Po-216 | 2.50E+01 | 8.43E-06 | 4.68E-03 |
| Po-218 | 1.70E+00 | 5.73E-07 | 3.19E-04 |
| Pr-143 | 2.00E-04 | 6.75E-11 | 3.75E-08 |
| Pr-144 | 2.00E+01 | 6.73E-06 | 3.74E-03 |
| Pt-191 | 2.10E-08 | 7.08E-15 | 3.93E-12 |
| Pt-193 | 1.07E-01 | 3.61E-08 | 2.00E-05 |
| Pt-195m | 3.58E-01 | 1.21E-07 | 6.71E-05 |
| Pu-236 | 5.76E-02 | 1.94E-08 | 1.08E-05 |
| Pu-237 | 1.76E-03 | 5.94E-10 | 3.30E-07 |
| Pu-238 | 1.07E+05 | 3.62E-02 | 2.01E+01 |
| Pu-239 | 1.03E+05 | 3.47E-02 | 1.93E+01 |
| Pu-240 | 1.54E+04 | 5.20E-03 | 2.89E+00 |
| Pu-241 | 2.13E+05 | 7.19E-02 | 4.00E+01 |
| Pu-242 | 9.17E+01 | 3.09E-05 | 1.72E-02 |
| Pu-243 | 3.52E-02 | 1.19E-08 | 6.60E-06 |
| Pu-244 | 6.28E-01 | 2.12E-07 | 1.18E-04 |
| Ra-222 | 7.73E-05 | 2.61E-11 | 1.45E-08 |
| Ra-223 | 7.79E-02 | 2.63E-08 | 1.46E-05 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Ra-224 | 3.91E+01 | 1.32E-05 | 7.33E-03 |
| Ra-225 | 6.58E+00 | 2.22E-06 | 1.23E-03 |
| Ra-226 | 6.50E+05 | 2.19E-01 | 1.22E+02 |
| Ra-227 | 5.90E-03 | 1.99E-09 | 1.11E-06 |
| Ra-228 | 4.57E+03 | 1.54E-03 | 8.56E-01 |
| Rb-82 | 1.33E-01 | 4.49E-08 | 2.49E-05 |
| Rb-83 | 1.74E+04 | 5.85E-03 | 3.25E+00 |
| Rb-84 | 5.28E+03 | 1.78E-03 | 9.90E-01 |
| Rb-86 | 6.07E+02 | 2.05E-04 | 1.14E-01 |
| Rb-87 | 1.34E-02 | 4.52E-09 | 2.51E-06 |
| Re-183 | 1.43E-01 | 4.81E-08 | 2.67E-05 |
| Re-184 | 5.81E+01 | 1.96E-05 | 1.09E-02 |
| Re-184m | 4.96E-02 | 1.67E-08 | 9.29E-06 |
| Re-186 | 5.55E+00 | 1.87E-06 | 1.04E-03 |
| Re-187 | 4.03E-01 | 1.36E-07 | 7.55E-05 |
| Re-188 | 2.79E+04 | 9.41E-03 | 5.23E+00 |
| Rh-101 | 1.24E+01 | 4.17E-06 | 2.32E-03 |
| Rh-102 | 2.86E+01 | 9.65E-06 | 5.36E-03 |
| Rh-102m | 1.11E+01 | 3.74E-06 | 2.08E-03 |
| Rh-103m | 6.70E+00 | 2.26E-06 | 1.26E-03 |
| Rh-105 | 3.47E+00 | 1.17E-06 | 6.50E-04 |
| Rh-106 | 1.97E-01 | 6.64E-08 | 3.69E-05 |
| Rn-220 | 2.61E+01 | 8.81E-06 | 4.89E-03 |
| Rn-222 | 1.26E-01 | 4.25E-08 | 2.36E-05 |
| Ru-97 | 4.17E-07 | 1.41E-13 | 7.81E-11 |
| Ru-103 | 5.28E+02 | 1.78E-04 | 9.89E-02 |
| Ru-106 | 5.16E+03 | 1.74E-03 | 9.67E-01 |
| S-35 | 1.82E+04 | 6.15E-03 | 3.42E+00 |
| Sb-117 | 3.52E-07 | 1.19E-13 | 6.60E-11 |
| Sb-122 | 1.24E+02 | 4.20E-05 | 2.33E-02 |
| Sb-124 | 1.27E+04 | 4.28E-03 | 2.38E+00 |
| Sb-125 | 9.53E+04 | 3.21E-02 | 1.79E+01 |
| Sb-126 | 3.69E+00 | 1.24E-06 | 6.92E-04 |
| Sb-126m | 4.96E-07 | 1.67E-13 | 9.29E-11 |
| Sc-44 | 2.41E-03 | 8.13E-10 | 4.52E-07 |
| Sc-46 | 1.21E+03 | 4.07E-04 | 2.26E-01 |
| Sc-47 | 1.04E-02 | 3.51E-09 | 1.95E-06 |
| Sc-48 | 1.58E-01 | 5.32E-08 | 2.95E-05 |
| Se-75 | 1.75E+03 | 5.90E-04 | 3.28E-01 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Se-79 | 2.35E+00 | 7.93E-07 | 4.40E-04 |
| Si-31 | 1.00E-06 | 3.37E-13 | 1.87E-10 |
| Si-32 | 1.69E+00 | 5.70E-07 | 3.17E-04 |
| Sm-145 | 1.57E+01 | 5.30E-06 | 2.94E-03 |
| Sm-146 | 1.60E-01 | 5.40E-08 | 3.00E-05 |
| Sm-147 | 1.11E-02 | 3.74E-09 | 2.08E-06 |
| Sm-148 | 1.00E-04 | 3.37E-11 | 1.87E-08 |
| Sm-149 | 1.00E-04 | 3.37E-11 | 1.87E-08 |
| Sm-151 | 4.64E+01 | 1.56E-05 | 8.69E-03 |
| Sm-153 | 2.32E+02 | 7.82E-05 | 4.35E-02 |
| Sn-113 | 4.47E+03 | 1.51E-03 | 8.38E-01 |
| Sn-113m | 5.80E-02 | 1.96E-08 | 1.09E-05 |
| Sn-117 | 2.40E-04 | 8.09E-11 | 4.50E-08 |
| Sn-117m | 1.23E+01 | 4.15E-06 | 2.30E-03 |
| Sn-119m | 8.37E-01 | 2.82E-07 | 1.57E-04 |
| Sn-121 | 3.64E-01 | 1.23E-07 | 6.82E-05 |
| Sn-121m | 8.22E-05 | 2.77E-11 | 1.54E-08 |
| Sn-123 | 4.30E-01 | 1.45E-07 | 8.06E-05 |
| Sn-125 | 6.25E-02 | 2.11E-08 | 1.17E-05 |
| Sn-126 | 6.32E-02 | 2.13E-08 | 1.18E-05 |
| Sn-133 | 4.50E-03 | 1.52E-09 | 8.43E-07 |
| Sr-82 | 2.01E+02 | 6.79E-05 | 3.77E-02 |
| Sr-85 | 1.07E+03 | 3.61E-04 | 2.01E-01 |
| Sr-89 | 9.01E+03 | 3.04E-03 | 1.69E+00 |
| Sr-90 | 1.17E+05 | 3.94E-02 | 2.19E+01 |
| Sr-91 | 2.01E-01 | 6.78E-08 | 3.77E-05 |
| Sr-92 | 1.27E+00 | 4.28E-07 | 2.38E-04 |
| Ta-178 | 2.00E-03 | 6.75E-10 | 3.75E-07 |
| Ta-179 | 2.53E+00 | 8.53E-07 | 4.74E-04 |
| Ta-182 | 9.17E+02 | 3.09E-04 | 1.72E-01 |
| Tb-157 | 2.50E-03 | 8.43E-10 | 4.68E-07 |
| Tb-158 | 6.98E-02 | 2.35E-08 | 1.31E-05 |
| Tb-160 | 3.60E-03 | 1.21E-09 | 6.75E-07 |
| Tc-95 | 4.37E-01 | 1.47E-07 | 8.19E-05 |
| Tc-95m | 2.48E+00 | 8.37E-07 | 4.65E-04 |
| Tc-98 | 3.55E-02 | 1.20E-08 | 6.65E-06 |
| Tc-99 | 1.46E+06 | 4.92E-01 | 2.73E+02 |
| Tc-99m | 7.46E+02 | 2.52E-04 | 1.40E-01 |
| Te-121 | 5.06E-01 | 1.71E-07 | 9.48E-05 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| Te-121m | 6.05E-02 | 2.04E-08 | 1.13E-05 |
| Te-123 | 4.28E-01 | 1.44E-07 | 8.02E-05 |
| Te-123m | 2.07E+03 | 6.98E-04 | 3.88E-01 |
| Te-125m | 7.87E+01 | 2.65E-05 | 1.47E-02 |
| Te-127m | 1.08E-03 | 3.64E-10 | 2.02E-07 |
| Te-129m | 5.39E+00 | 1.82E-06 | 1.01E-03 |
| Te-132 | 6.15E+00 | 2.07E-06 | 1.15E-03 |
| Th-226 | 1.67E-03 | 5.63E-10 | 3.13E-07 |
| Th-227 | 1.21E+00 | 4.09E-07 | 2.27E-04 |
| Th-228 | 7.55E+03 | 2.55E-03 | 1.41E+00 |
| Th-229 | 1.28E+02 | 4.32E-05 | 2.40E-02 |
| Th-230 | 1.25E+06 | 4.22E-01 | 2.34E+02 |
| Th-231 | 4.05E+01 | 1.37E-05 | 7.59E-03 |
| Th-232 | 7.40E+04 | 2.49E-02 | 1.39E+01 |
| Th-234 | 1.50E+04 | 5.05E-03 | 2.80E+00 |
| Th-Nat | 1.13E+04 | 3.81E-03 | 2.12E+00 |
| Ti-44 | 1.10E+02 | 3.72E-05 | 2.07E-02 |
| Tl-201 | 2.17E+01 | 7.32E-06 | 4.07E-03 |
| Tl-202 | 1.56E+02 | 5.27E-05 | 2.93E-02 |
| Tl-204 | 9.03E+02 | 3.05E-04 | 1.69E-01 |
| Tl-207 | 2.26E-07 | 7.62E-14 | 4.23E-11 |
| Tl-208 | 5.82E+02 | 1.96E-04 | 1.09E-01 |
| Tl-209 | 1.93E-01 | 6.52E-08 | 3.62E-05 |
| Tm-170 | 3.46E+01 | 1.17E-05 | 6.48E-03 |
| Tm-171 | 5.10E-01 | 1.72E-07 | 9.56E-05 |
| U-230 | 3.00E-05 | 1.01E-11 | 5.62E-09 |
| U-232 | 3.14E+03 | 1.06E-03 | 5.89E-01 |
| U-233 | 4.16E+03 | 1.40E-03 | 7.79E-01 |
| U-234 | 7.66E+05 | 2.58E-01 | 1.44E+02 |
| U-235 | 1.75E+04 | 5.92E-03 | 3.29E+00 |
| U-235m | 8.68E-12 | 2.93E-18 | 1.63E-15 |
| U-236 | 1.61E+04 | 5.43E-03 | 3.02E+00 |
| U-237 | 5.28E-07 | 1.78E-13 | 9.89E-11 |
| U-238 | 1.43E+05 | 4.81E-02 | 2.67E+01 |
| U-239 | 8.55E-08 | 2.88E-14 | 1.60E-11 |
| U-Dep | 1.65E+07 | 5.57E+00 | 3.09E+03 |
| U-Nat | 1.49E+05 | 5.02E-02 | 2.79E+01 |
| V-48 | 7.89E-02 | 2.66E-08 | 1.48E-05 |
| V-49 | 1.80E+03 | 6.07E-04 | 3.37E-01 |

| Isotope | Disposed Activity (mCi) | Volume Concentration (mCi/m³) | Mass Concentration (pCi/g) |
|---|---|---|---|
| W-178 | 2.70E-03 | 9.11E-10 | 5.06E-07 |
| W-181 | 5.27E+00 | 1.78E-06 | 9.88E-04 |
| W-185 | 1.12E+04 | 3.77E-03 | 2.09E+00 |
| W-188 | 2.86E+04 | 9.65E-03 | 5.36E+00 |
| Xe-127 | 5.36E-03 | 1.81E-09 | 1.00E-06 |
| Xe-131m | 1.35E+02 | 4.56E-05 | 2.53E-02 |
| Xe-133 | 1.28E+01 | 4.31E-06 | 2.39E-03 |
| Xe-133m | 1.27E+00 | 4.28E-07 | 2.38E-04 |
| Y-86 | 1.00E-03 | 3.37E-10 | 1.87E-07 |
| Y-88 | 2.39E+02 | 8.06E-05 | 4.48E-02 |
| Y-90 | 9.77E+02 | 3.30E-04 | 1.83E-01 |
| Y-91 | 4.83E-01 | 1.63E-07 | 9.05E-05 |
| Yb-169 | 1.57E+02 | 5.31E-05 | 2.95E-02 |
| Yb-175 | 2.73E-13 | 9.21E-20 | 5.12E-17 |
| Zn-65 | 2.02E+06 | 6.81E-01 | 3.78E+02 |
| Zn-69 | 3.38E-02 | 1.14E-08 | 6.33E-06 |
| Zn-69m | 2.83E-09 | 9.54E-16 | 5.30E-13 |
| Zr-88 | 2.33E-01 | 7.86E-08 | 4.37E-05 |
| Zr-89 | 4.60E+00 | 1.55E-06 | 8.62E-04 |
| Zr-93 | 5.08E-02 | 1.71E-08 | 9.52E-06 |
| Zr-95 | 7.56E+04 | 2.55E-02 | 1.42E+01 |
| Zr-97 | 4.46E+00 | 1.50E-06 | 8.36E-04 |

* SOURCE: Energy*Solutions*, "Manifest Radionuclide Inventory Report", August 2012.

**Table A-5**

**Intruder-Driller Dose-To-Source Ratios**

| Nuclide | Dose / Source Ratio (mrem/yr per pCi/g) Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Ac-227+D | 3.01E-08 | 6.12E-09 | 6.59E-10 | 1.64E-17 | 1.08E-20 |
| Ag-108m+D | 4.99E-06 | 3.69E-06 | 2.42E-06 | 8.70E-08 | 2.17E-08 |
| Al-26 | 5.26E-05 | 5.10E-05 | 4.90E-05 | 3.55E-05 | 3.10E-05 |
| Am-241 | 8.40E-12 | 1.21E-11 | 1.67E-11 | 3.97E-11 | 4.47E-11 |
| Am-242+D | 2.08E-08 | 1.65E-08 | 1.20E-08 | 9.85E-10 | 3.56E-10 |
| Am-243+D | 5.72E-08 | 5.69E-08 | 5.65E-08 | 5.36E-08 | 5.24E-08 |
| Ar-39 | 1.02E-11 | 8.72E-12 | 6.99E-12 | 1.23E-12 | 5.93E-13 |
| Ba-133 | 1.11E-09 | 4.39E-11 | 4.79E-13 | 1.84E-28 | 6.57E-35 |
| Be-10 | 1.66E-11 | 1.66E-11 | 1.66E-11 | 1.66E-11 | 1.66E-11 |
| Bi-207 | 2.33E-06 | 9.07E-07 | 2.43E-07 | 7.74E-12 | 1.02E-13 |
| Bi-210m+D | 4.51E-07 | 4.38E-07 | 4.21E-07 | 3.05E-07 | 2.67E-07 |
| Bk-247 | 3.52E-08 | 3.46E-08 | 3.38E-08 | 2.81E-08 | 2.61E-08 |
| C-14 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ca-41 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Cd-113 | 9.75E-14 | 9.47E-14 | 9.09E-14 | 6.59E-14 | 5.76E-14 |
| Cd-113m | 4.42E-14 | 3.36E-15 | 9.10E-17 | 4.42E-29 | 3.13E-34 |
| Cf-249 | 8.51E-07 | 7.70E-07 | 6.71E-07 | 2.26E-07 | 1.44E-07 |
| Cf-250 | 1.91E-20 | 3.11E-20 | 4.84E-20 | 2.01E-19 | 2.73E-19 |
| Cf-251 | 3.35E-08 | 3.23E-08 | 3.06E-08 | 2.00E-08 | 1.68E-08 |
| Cf-252 | 1.55E-17 | 2.35E-17 | 3.47E-17 | 1.23E-16 | 1.59E-16 |
| Cl-36 | 2.46E-10 | 2.43E-10 | 2.38E-10 | 2.07E-10 | 1.95E-10 |
| Cm-243 | 4.95E-09 | 1.47E-09 | 2.68E-10 | 5.28E-13 | 5.16E-13 |
| Cm-244 | 8.16E-17 | 8.27E-17 | 8.23E-17 | 7.78E-17 | 7.60E-17 |
| Cm-245 | 5.44E-09 | 5.42E-09 | 5.39E-09 | 5.18E-09 | 5.10E-09 |
| Cm-246 | 8.53E-18 | 1.29E-17 | 1.92E-17 | 7.48E-17 | 1.01E-16 |
| Cm-247+D | 1.06E-06 | 1.06E-06 | 1.06E-06 | 1.07E-06 | 1.07E-06 |
| Cm-248 | 2.13E-12 | 3.20E-12 | 4.68E-12 | 1.63E-11 | 2.12E-11 |
| Cm-250+D | 4.15E-06 | 4.13E-06 | 4.10E-06 | 3.88E-06 | 3.79E-06 |
| Co-60 | 8.32E-11 | 1.16E-13 | 1.17E-17 | 0.00E+00 | 0.00E+00 |
| Cs-135 | 2.90E-15 | 2.90E-15 | 2.90E-15 | 2.90E-15 | 2.90E-15 |
| Cs-137+D | 3.54E-07 | 1.11E-07 | 2.21E-08 | 6.70E-14 | 3.30E-16 |
| Eu-150 | 1.06E-06 | 3.86E-07 | 9.35E-08 | 1.35E-12 | 1.27E-14 |
| Eu-152 | 7.30E-08 | 5.43E-09 | 1.42E-10 | 5.41E-23 | 3.46E-28 |
| Eu-154 | 5.75E-09 | 1.12E-10 | 4.51E-13 | 6.92E-32 | 9.38E-40 |
| Eu-155 | 4.60E-16 | 4.25E-19 | 2.40E-23 | 0.00E+00 | 0.00E+00 |

| | Dose / Source Ratio (mrem/yr per pCi/g) | | | | |
|---|---|---|---|---|---|
| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
| Fe-55 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Fe-60+D | 4.56E-05 | 4.56E-05 | 4.55E-05 | 4.54E-05 | 4.53E-05 |
| Gd-148 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| H-3 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Hg-194+D | 9.79E-06 | 8.57E-06 | 7.11E-06 | 1.64E-06 | 8.88E-07 |
| Ho-166m | 1.15E-05 | 1.12E-05 | 1.07E-05 | 7.80E-06 | 6.83E-06 |
| I-129 | 3.11E-25 | 3.07E-25 | 3.02E-25 | 2.62E-25 | 2.47E-25 |
| In-115 | 4.21E-12 | 4.21E-12 | 4.21E-12 | 4.21E-12 | 4.21E-12 |
| Mn-53 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mo-93 | 1.43E-34 | 1.41E-34 | 1.39E-34 | 1.25E-34 | 1.19E-34 |
| Na-22 | 5.38E-17 | 8.84E-23 | 7.04E-31 | 0.00E+00 | 0.00E+00 |
| Nb-93m | 1.23E-37 | 9.34E-39 | 2.53E-40 | 0.00E+00 | 0.00E+00 |
| Nb-94 | 1.21E-05 | 1.17E-05 | 1.12E-05 | 7.98E-06 | 6.92E-06 |
| Ni-59 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ni-63 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Np-236 | 2.82E-06 | 3.56E-06 | 4.14E-06 | 4.73E-06 | 4.73E-06 |
| Np-237+D | 2.77E-07 | 2.77E-07 | 2.77E-07 | 2.77E-07 | 2.77E-07 |
| Os-194+D | 4.59E-12 | 1.42E-14 | 4.37E-18 | 9.53E-46 | 0.00E+00 |
| Pa-231 | 7.64E-07 | 7.87E-07 | 7.92E-07 | 7.83E-07 | 7.79E-07 |
| Pb-202+D | 1.74E-06 | 1.74E-06 | 1.74E-06 | 1.73E-06 | 1.73E-06 |
| Pb-205 | 5.33E-43 | 5.33E-43 | 5.33E-43 | 5.33E-43 | 5.33E-43 |
| Pb-210+D | 1.94E-11 | 4.10E-12 | 4.66E-13 | 1.75E-20 | 1.38E-23 |
| Pd-107 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pm-145 | 3.98E-18 | 5.62E-19 | 3.63E-20 | 1.60E-29 | 1.97E-33 |
| Pm-147 | 1.39E-25 | 2.55E-31 | 2.37E-39 | 0.00E+00 | 0.00E+00 |
| Pt-193 | 1.06E-43 | 5.34E-44 | 2.00E-44 | 0.00E+00 | 0.00E+00 |
| Pu-236 | 8.59E-07 | 5.31E-07 | 2.71E-07 | 1.36E-09 | 1.48E-10 |
| Pu-238 | 1.10E-13 | 1.91E-13 | 4.42E-13 | 8.70E-12 | 1.53E-11 |
| Pu-239 | 2.46E-11 | 2.46E-11 | 2.45E-11 | 2.42E-11 | 2.40E-11 |
| Pu-240 | 3.00E-14 | 2.99E-14 | 2.96E-14 | 2.80E-14 | 2.73E-14 |
| Pu-241+D | 2.31E-13 | 3.52E-13 | 5.13E-13 | 1.30E-12 | 1.48E-12 |
| Pu-242 | 4.78E-14 | 4.92E-14 | 5.11E-14 | 6.60E-14 | 7.22E-14 |
| Pu-244+D | 2.76E-06 | 2.76E-06 | 2.76E-06 | 2.76E-06 | 2.76E-06 |
| Ra-226+D | 3.05E-05 | 2.99E-05 | 2.90E-05 | 2.28E-05 | 2.07E-05 |
| Ra-228+D | 5.06E-10 | 1.22E-12 | 2.64E-16 | 4.76E-45 | 0.00E+00 |
| Rb-87 | 9.24E-14 | 9.24E-14 | 9.24E-14 | 9.24E-14 | 9.24E-14 |
| Re-187 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Se-79 | 1.43E-16 | 1.39E-16 | 1.33E-16 | 9.61E-17 | 8.38E-17 |
| Si-32+D | 1.39E-09 | 1.29E-09 | 1.16E-09 | 4.95E-10 | 3.47E-10 |
| Sm-146 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| Nuclide | Dose / Source Ratio (mrem/yr per pCi/g) Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Sm-147 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Sm-151 | 8.61E-34 | 5.86E-34 | 3.42E-34 | 4.94E-36 | 8.40E-37 |
| Sn-121m+D | 1.49E-13 | 7.70E-14 | 3.06E-14 | 2.17E-17 | 1.04E-18 |
| Sn-126+D | 1.15E-05 | 1.12E-05 | 1.07E-05 | 7.75E-06 | 6.76E-06 |
| Sr-90+D | 5.45E-10 | 1.66E-10 | 3.13E-11 | 6.45E-17 | 2.70E-19 |
| Tb-157 | 1.13E-20 | 8.93E-21 | 6.46E-21 | 5.09E-22 | 1.76E-22 |
| Tb-158 | 4.92E-06 | 3.91E-06 | 2.83E-06 | 2.23E-07 | 7.69E-08 |
| Tc-98 | 9.66E-06 | 9.38E-06 | 9.00E-06 | 6.52E-06 | 5.70E-06 |
| Tc-99 | 9.91E-14 | 9.62E-14 | 9.23E-14 | 6.68E-14 | 5.83E-14 |
| Te-123 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Th-229+D | 1.36E-06 | 1.36E-06 | 1.35E-06 | 1.28E-06 | 1.25E-06 |
| Th-230 | 1.36E-06 | 2.01E-06 | 2.90E-06 | 9.02E-06 | 1.12E-05 |
| Th-232 | 6.57E-05 | 6.57E-05 | 6.57E-05 | 6.57E-05 | 6.57E-05 |
| Ti-44+D | 5.01E-06 | 2.41E-06 | 8.63E-07 | 2.73E-10 | 9.37E-12 |
| Tl-204 | 4.29E-20 | 4.34E-24 | 1.11E-29 | 0.00E+00 | 0.00E+00 |
| U-232 | 2.08E-05 | 1.29E-05 | 6.56E-06 | 3.29E-08 | 3.59E-09 |
| U-233 | 1.31E-08 | 1.95E-08 | 2.84E-08 | 9.65E-08 | 1.24E-07 |
| U-234 | 6.20E-10 | 1.38E-09 | 2.93E-09 | 3.30E-08 | 5.39E-08 |
| U-235+D | 6.12E-08 | 6.20E-08 | 6.32E-08 | 7.24E-08 | 7.61E-08 |
| U-236 | 5.91E-13 | 7.53E-13 | 9.80E-13 | 2.76E-12 | 3.51E-12 |
| U-238+D | 1.76E-07 | 1.76E-07 | 1.76E-07 | 1.76E-07 | 1.76E-07 |
| Zr-93 | 2.15E-35 | 2.16E-35 | 2.16E-35 | 2.16E-35 | 2.16E-35 |

## Table A-6

### Intruder-Worker Dose-To-Source Ratios

| Nuclide | Dose / Source Ratio (mrem/yr per pCi/g) | | | | |
|---|---|---|---|---|---|
| | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
| Ac-227+D | 1.00E-05 | 2.04E-06 | 2.20E-07 | 5.47E-15 | 3.60E-18 |
| Ag-108m+D | 1.66E-03 | 1.23E-03 | 8.07E-04 | 2.90E-05 | 7.23E-06 |
| Al-26 | 1.75E-02 | 1.70E-02 | 1.63E-02 | 1.18E-02 | 1.03E-02 |
| Am-241 | 2.80E-09 | 4.03E-09 | 5.57E-09 | 1.32E-08 | 1.49E-08 |
| Am-242+D | 6.93E-06 | 5.50E-06 | 4.00E-06 | 3.28E-07 | 1.19E-07 |
| Am-243+D | 1.91E-05 | 1.90E-05 | 1.88E-05 | 1.79E-05 | 1.75E-05 |
| Ar-39 | 3.40E-09 | 2.91E-09 | 2.33E-09 | 4.10E-10 | 1.98E-10 |
| Ba-133 | 3.70E-07 | 1.46E-08 | 1.60E-10 | 6.13E-26 | 2.19E-32 |
| Be-10 | 5.53E-09 | 5.53E-09 | 5.53E-09 | 5.53E-09 | 5.53E-09 |
| Bi-207 | 7.77E-04 | 3.02E-04 | 8.10E-05 | 2.58E-09 | 3.40E-11 |
| Bi-210m+D | 1.50E-04 | 1.46E-04 | 1.40E-04 | 1.02E-04 | 8.90E-05 |
| Bk-247 | 1.17E-05 | 1.15E-05 | 1.13E-05 | 9.37E-06 | 8.70E-06 |
| C-14 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ca-41 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Cd-113 | 3.25E-11 | 3.16E-11 | 3.03E-11 | 2.20E-11 | 1.92E-11 |
| Cd-113m | 1.47E-11 | 1.12E-12 | 3.03E-14 | 1.47E-26 | 1.04E-31 |
| Cf-249 | 2.84E-04 | 2.57E-04 | 2.24E-04 | 7.53E-05 | 4.80E-05 |
| Cf-250 | 6.37E-18 | 1.04E-17 | 1.61E-17 | 6.70E-17 | 9.10E-17 |
| Cf-251 | 1.12E-05 | 1.08E-05 | 1.02E-05 | 6.67E-06 | 5.60E-06 |
| Cf-252 | 5.17E-15 | 7.83E-15 | 1.16E-14 | 4.10E-14 | 5.30E-14 |
| Cl-36 | 8.20E-08 | 8.10E-08 | 7.93E-08 | 6.90E-08 | 6.50E-08 |
| Cm-243 | 1.65E-06 | 4.90E-07 | 8.93E-08 | 1.76E-10 | 1.72E-10 |
| Cm-244 | 2.72E-14 | 2.76E-14 | 2.74E-14 | 2.59E-14 | 2.53E-14 |
| Cm-245 | 1.81E-06 | 1.81E-06 | 1.80E-06 | 1.73E-06 | 1.70E-06 |
| Cm-246 | 2.84E-15 | 4.30E-15 | 6.40E-15 | 2.49E-14 | 3.37E-14 |
| Cm-247+D | 3.53E-04 | 3.53E-04 | 3.53E-04 | 3.57E-04 | 3.57E-04 |
| Cm-248 | 7.10E-10 | 1.07E-09 | 1.56E-09 | 5.43E-09 | 7.07E-09 |
| Cm-250+D | 1.38E-03 | 1.38E-03 | 1.37E-03 | 1.29E-03 | 1.26E-03 |
| Co-60 | 2.77E-08 | 3.87E-11 | 3.90E-15 | 0.00E+00 | 0.00E+00 |
| Cs-135 | 9.67E-13 | 9.67E-13 | 9.67E-13 | 9.67E-13 | 9.67E-13 |
| Cs-137+D | 1.18E-04 | 3.70E-05 | 7.37E-06 | 2.23E-11 | 1.10E-13 |
| Eu-150 | 3.53E-04 | 1.29E-04 | 3.12E-05 | 4.50E-10 | 4.23E-12 |
| Eu-152 | 2.43E-05 | 1.81E-06 | 4.73E-08 | 1.80E-20 | 1.15E-25 |
| Eu-154 | 1.92E-06 | 3.73E-08 | 1.50E-10 | 2.31E-29 | 3.13E-37 |
| Eu-155 | 1.53E-13 | 1.42E-16 | 8.00E-21 | 0.00E+00 | 0.00E+00 |

| Nuclide | Dose / Source Ratio (mrem/yr per pCi/g) Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Fe-55 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Fe-60+D | 1.52E-02 | 1.52E-02 | 1.52E-02 | 1.51E-02 | 1.51E-02 |
| Gd-148 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| H-3 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Hg-194+D | 3.26E-03 | 2.86E-03 | 2.37E-03 | 5.47E-04 | 2.96E-04 |
| Ho-166m | 3.83E-03 | 3.73E-03 | 3.57E-03 | 2.60E-03 | 2.28E-03 |
| I-129 | 1.04E-22 | 1.02E-22 | 1.01E-22 | 8.73E-23 | 8.23E-23 |
| In-115 | 1.40E-09 | 1.40E-09 | 1.40E-09 | 1.40E-09 | 1.40E-09 |
| Mn-53 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mo-93 | 4.77E-32 | 4.70E-32 | 4.63E-32 | 4.17E-32 | 3.97E-32 |
| Na-22 | 1.79E-14 | 2.95E-20 | 2.35E-28 | 0.00E+00 | 0.00E+00 |
| Nb-93m | 4.10E-35 | 3.11E-36 | 8.43E-38 | 0.00E+00 | 0.00E+00 |
| Nb-94 | 4.03E-03 | 3.90E-03 | 3.73E-03 | 2.66E-03 | 2.31E-03 |
| Ni-59 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ni-63 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Np-236 | 9.40E-04 | 1.19E-03 | 1.38E-03 | 1.58E-03 | 1.58E-03 |
| Np-237+D | 9.23E-05 | 9.23E-05 | 9.23E-05 | 9.23E-05 | 9.23E-05 |
| Os-194+D | 1.53E-09 | 4.73E-12 | 1.46E-15 | 3.18E-43 | 0.00E+00 |
| Pa-231 | 2.55E-04 | 2.62E-04 | 2.64E-04 | 2.61E-04 | 2.60E-04 |
| Pb-202+D | 5.80E-04 | 5.80E-04 | 5.80E-04 | 5.77E-04 | 5.77E-04 |
| Pb-205 | 1.78E-40 | 1.78E-40 | 1.78E-40 | 1.78E-40 | 1.78E-40 |
| Pb-210+D | 6.47E-09 | 1.37E-09 | 1.55E-10 | 5.83E-18 | 4.60E-21 |
| Pd-107 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pm-145 | 1.33E-15 | 1.87E-16 | 1.21E-17 | 5.33E-27 | 6.57E-31 |
| Pm-147 | 4.63E-23 | 8.50E-29 | 7.90E-37 | 0.00E+00 | 0.00E+00 |
| Pt-193 | 3.53E-41 | 1.78E-41 | 6.67E-42 | 0.00E+00 | 0.00E+00 |
| Pu-236 | 2.86E-04 | 1.77E-04 | 9.03E-05 | 4.53E-07 | 4.93E-08 |
| Pu-238 | 3.67E-11 | 6.37E-11 | 1.47E-10 | 2.90E-09 | 5.10E-09 |
| Pu-239 | 8.20E-09 | 8.20E-09 | 8.17E-09 | 8.07E-09 | 8.00E-09 |
| Pu-240 | 1.00E-11 | 9.97E-12 | 9.87E-12 | 9.33E-12 | 9.10E-12 |
| Pu-241+D | 7.70E-11 | 1.17E-10 | 1.71E-10 | 4.33E-10 | 4.93E-10 |
| Pu-242 | 1.59E-11 | 1.64E-11 | 1.70E-11 | 2.20E-11 | 2.41E-11 |
| Pu-244+D | 9.20E-04 | 9.20E-04 | 9.20E-04 | 9.20E-04 | 9.20E-04 |
| Ra-226+D | 1.02E-02 | 9.97E-03 | 9.67E-03 | 7.60E-03 | 6.90E-03 |
| Ra-228+D | 1.69E-07 | 4.07E-10 | 8.80E-14 | 1.59E-42 | 0.00E+00 |
| Rb-87 | 3.08E-11 | 3.08E-11 | 3.08E-11 | 3.08E-11 | 3.08E-11 |
| Re-187 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Se-79 | 4.77E-14 | 4.63E-14 | 4.43E-14 | 3.20E-14 | 2.79E-14 |
| Si-32+D | 4.63E-07 | 4.30E-07 | 3.87E-07 | 1.65E-07 | 1.16E-07 |
| Sm-146 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| | Dose / Source Ratio (mrem/yr per pCi/g) | | | | |
|---|---|---|---|---|---|
| **Nuclide** | **Year 100** | **Year 150** | **Year 220** | **Year 710** | **Year 1,000** |
| Sm-147 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Sm-151 | 2.87E-31 | 1.95E-31 | 1.14E-31 | 1.65E-33 | 2.80E-34 |
| Sn-121m+D | 4.97E-11 | 2.57E-11 | 1.02E-11 | 7.23E-15 | 3.47E-16 |
| Sn-126+D | 3.83E-03 | 3.73E-03 | 3.57E-03 | 2.58E-03 | 2.25E-03 |
| Sr-90+D | 1.82E-07 | 5.53E-08 | 1.04E-08 | 2.15E-14 | 9.00E-17 |
| Tb-157 | 3.77E-18 | 2.98E-18 | 2.15E-18 | 1.70E-19 | 5.87E-20 |
| Tb-158 | 1.64E-03 | 1.30E-03 | 9.43E-04 | 7.43E-05 | 2.56E-05 |
| Tc-98 | 3.22E-03 | 3.13E-03 | 3.00E-03 | 2.17E-03 | 1.90E-03 |
| Tc-99 | 3.30E-11 | 3.21E-11 | 3.08E-11 | 2.23E-11 | 1.94E-11 |
| Te-123 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Th-229+D | 4.53E-04 | 4.53E-04 | 4.50E-04 | 4.27E-04 | 4.17E-04 |
| Th-230 | 4.53E-04 | 6.70E-04 | 9.67E-04 | 3.01E-03 | 3.73E-03 |
| Th-232 | 2.19E-02 | 2.19E-02 | 2.19E-02 | 2.19E-02 | 2.19E-02 |
| Ti-44+D | 1.67E-03 | 8.03E-04 | 2.88E-04 | 9.10E-08 | 3.12E-09 |
| Tl-204 | 1.43E-17 | 1.45E-21 | 3.70E-27 | 0.00E+00 | 0.00E+00 |
| U-232 | 6.93E-03 | 4.30E-03 | 2.19E-03 | 1.10E-05 | 1.20E-06 |
| U-233 | 4.37E-06 | 6.50E-06 | 9.47E-06 | 3.22E-05 | 4.13E-05 |
| U-234 | 2.07E-07 | 4.60E-07 | 9.77E-07 | 1.10E-05 | 1.80E-05 |
| U-235+D | 2.04E-05 | 2.07E-05 | 2.11E-05 | 2.41E-05 | 2.54E-05 |
| U-236 | 1.97E-10 | 2.51E-10 | 3.27E-10 | 9.20E-10 | 1.17E-09 |
| U-238+D | 5.87E-05 | 5.87E-05 | 5.87E-05 | 5.87E-05 | 5.87E-05 |
| Zr-93 | 7.17E-33 | 7.20E-33 | 7.20E-33 | 7.20E-33 | 7.20E-33 |

**Table A-7**

**Intruder-Driller Doses (mrem/yr) For The**

**Current Class A Waste Inventory**

| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Ac-227+D | 6.09E-08 | 1.24E-08 | 1.33E-09 | 3.32E-17 | 2.19E-20 |
| Ag-108m+D | 2.30E-06 | 1.70E-06 | 1.12E-06 | 4.01E-08 | 1.00E-08 |
| Al-26 | 4.01E-07 | 3.89E-07 | 3.74E-07 | 2.71E-07 | 2.36E-07 |
| Am-241 | 4.01E-11 | 5.78E-11 | 7.98E-11 | 1.90E-10 | 2.14E-10 |
| Am-242+D | 9.67E-12 | 7.67E-12 | 5.58E-12 | 4.58E-13 | 1.65E-13 |
| Am-243+D | 1.67E-09 | 1.66E-09 | 1.65E-09 | 1.56E-09 | 1.53E-09 |
| Ar-39 | 7.64E-17 | 6.54E-17 | 5.24E-17 | 9.22E-18 | 4.44E-18 |
| Ba-133 | 2.18E-10 | 8.61E-12 | 9.40E-14 | 3.61E-29 | 1.29E-35 |
| Be-10 | 3.17E-17 | 3.17E-17 | 3.17E-17 | 3.17E-17 | 3.17E-17 |
| Bi-207 | 8.71E-08 | 3.39E-08 | 9.08E-09 | 2.89E-13 | 3.81E-15 |
| Bi-210m+D | 4.36E-10 | 4.24E-10 | 4.07E-10 | 2.95E-10 | 2.58E-10 |
| Bk-247 | 9.89E-15 | 9.72E-15 | 9.50E-15 | 7.90E-15 | 7.34E-15 |
| C-14 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ca-41 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Cd-113 | 1.48E-21 | 1.44E-21 | 1.38E-21 | 1.00E-21 | 8.76E-22 |
| Cd-113m | 1.49E-14 | 1.13E-15 | 3.07E-17 | 1.49E-29 | 1.06E-34 |
| Cf-249 | 1.09E-09 | 9.90E-10 | 8.63E-10 | 2.91E-10 | 1.85E-10 |
| Cf-250 | 6.57E-25 | 1.07E-24 | 1.66E-24 | 6.91E-24 | 9.39E-24 |
| Cf-251 | 5.37E-15 | 5.17E-15 | 4.90E-15 | 3.20E-15 | 2.69E-15 |
| Cf-252 | 6.59E-19 | 9.99E-19 | 1.47E-18 | 5.23E-18 | 6.76E-18 |
| Cl-36 | 6.30E-12 | 6.23E-12 | 6.10E-12 | 5.30E-12 | 5.00E-12 |
| Cm-243 | 7.74E-10 | 2.30E-10 | 4.19E-11 | 8.26E-14 | 8.07E-14 |
| Cm-244 | 1.37E-17 | 1.39E-17 | 1.39E-17 | 1.31E-17 | 1.28E-17 |
| Cm-245 | 2.68E-11 | 2.67E-11 | 2.66E-11 | 2.55E-11 | 2.51E-11 |
| Cm-246 | 6.30E-21 | 9.52E-21 | 1.42E-20 | 5.52E-20 | 7.46E-20 |
| Cm-247+D | 5.72E-11 | 5.72E-11 | 5.72E-11 | 5.78E-11 | 5.78E-11 |
| Cm-248 | 1.53E-16 | 2.29E-16 | 3.35E-16 | 1.17E-15 | 1.52E-15 |
| Cm-250+D | 5.84E-13 | 5.81E-13 | 5.77E-13 | 5.46E-13 | 5.33E-13 |
| Co-60 | 2.12E-07 | 2.96E-10 | 2.99E-14 | 0.00E+00 | 0.00E+00 |
| Cs-135 | 6.42E-17 | 6.42E-17 | 6.42E-17 | 6.42E-17 | 6.42E-17 |
| Cs-137+D | 9.62E-05 | 3.02E-05 | 6.00E-06 | 1.82E-11 | 8.97E-14 |
| Eu-150 | 7.63E-11 | 2.78E-11 | 6.73E-12 | 9.71E-17 | 9.14E-19 |
| Eu-152 | 3.42E-07 | 2.54E-08 | 6.65E-10 | 2.53E-22 | 1.62E-27 |
| Eu-154 | 4.22E-09 | 8.23E-11 | 3.31E-13 | 5.08E-32 | 6.89E-40 |

| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Eu-155 | 1.31E-16 | 1.21E-19 | 6.81E-24 | 0.00E+00 | 0.00E+00 |
| Fe-55 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Fe-60+D | 1.13E-03 | 1.13E-03 | 1.13E-03 | 1.12E-03 | 1.12E-03 |
| Gd-148 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| H-3 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Hg-194+D | 3.10E-09 | 2.71E-09 | 2.25E-09 | 5.19E-10 | 2.81E-10 |
| Ho-166m | 1.68E-08 | 1.64E-08 | 1.57E-08 | 1.14E-08 | 9.99E-09 |
| I-129 | 1.22E-25 | 1.21E-25 | 1.19E-25 | 1.03E-25 | 9.72E-26 |
| In-115 | 7.89E-19 | 7.89E-19 | 7.89E-19 | 7.89E-19 | 7.89E-19 |
| Mn-53 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mo-93 | 1.69E-38 | 1.66E-38 | 1.64E-38 | 1.48E-38 | 1.40E-38 |
| Na-22 | 7.74E-17 | 1.27E-22 | 1.01E-30 | 0.00E+00 | 0.00E+00 |
| Nb-93m | 1.93E-39 | 1.46E-40 | 3.96E-42 | 0.00E+00 | 0.00E+00 |
| Nb-94 | 1.75E-06 | 1.69E-06 | 1.62E-06 | 1.16E-06 | 1.00E-06 |
| Ni-59 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ni-63 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Np-236 | 2.62E-12 | 3.30E-12 | 3.84E-12 | 4.39E-12 | 4.39E-12 |
| Np-237+D | 1.33E-07 | 1.33E-07 | 1.33E-07 | 1.33E-07 | 1.33E-07 |
| Os-194+D | 8.60E-20 | 2.66E-22 | 8.19E-26 | 1.79E-53 | 0.00E+00 |
| Pa-231 | 1.35E-06 | 1.39E-06 | 1.40E-06 | 1.38E-06 | 1.38E-06 |
| Pb-202+D | 7.89E-13 | 7.89E-13 | 7.89E-13 | 7.84E-13 | 7.84E-13 |
| Pb-205 | 3.42E-47 | 3.42E-47 | 3.42E-47 | 3.42E-47 | 3.42E-47 |
| Pb-210+D | 2.04E-09 | 4.30E-10 | 4.89E-11 | 1.84E-18 | 1.45E-21 |
| Pd-107 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pm-145 | 1.10E-20 | 1.56E-21 | 1.01E-22 | 4.44E-32 | 5.46E-36 |
| Pm-147 | 1.45E-25 | 2.66E-31 | 2.47E-39 | 0.00E+00 | 0.00E+00 |
| Pt-193 | 2.13E-48 | 1.07E-48 | 4.01E-49 | 0.00E+00 | 0.00E+00 |
| Pu-236 | 9.27E-12 | 5.73E-12 | 2.92E-12 | 1.47E-14 | 1.60E-15 |
| Pu-238 | 2.21E-12 | 3.84E-12 | 8.88E-12 | 1.75E-10 | 3.07E-10 |
| Pu-239 | 4.75E-10 | 4.75E-10 | 4.73E-10 | 4.67E-10 | 4.63E-10 |
| Pu-240 | 8.67E-14 | 8.64E-14 | 8.55E-14 | 8.09E-14 | 7.89E-14 |
| Pu-241+D | 9.23E-12 | 1.41E-11 | 2.05E-11 | 5.20E-11 | 5.92E-11 |
| Pu-242 | 8.21E-16 | 8.45E-16 | 8.78E-16 | 1.13E-15 | 1.24E-15 |
| Pu-244+D | 3.25E-10 | 3.25E-10 | 3.25E-10 | 3.25E-10 | 3.25E-10 |
| Ra-226+D | 3.72E-03 | 3.64E-03 | 3.53E-03 | 2.78E-03 | 2.52E-03 |
| Ra-228+D | 4.33E-10 | 1.04E-12 | 2.26E-16 | 4.07E-45 | 0.00E+00 |
| Rb-87 | 2.32E-19 | 2.32E-19 | 2.32E-19 | 2.32E-19 | 2.32E-19 |
| Re-187 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Se-79 | 6.30E-20 | 6.12E-20 | 5.86E-20 | 4.23E-20 | 3.69E-20 |
| Si-32+D | 4.40E-13 | 4.09E-13 | 3.67E-13 | 1.57E-13 | 1.10E-13 |
| Sm-146 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Sm-147 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Sm-151 | 7.49E-36 | 5.09E-36 | 2.97E-36 | 4.29E-38 | 7.30E-39 |
| Sn-121m+D | 2.29E-21 | 1.19E-21 | 4.71E-22 | 3.34E-25 | 1.60E-26 |
| Sn-126+D | 1.36E-10 | 1.33E-10 | 1.27E-10 | 9.18E-11 | 8.01E-11 |
| Sr-90+D | 1.19E-08 | 3.63E-09 | 6.85E-10 | 1.41E-15 | 5.91E-18 |
| Tb-157 | 5.29E-27 | 4.18E-27 | 3.03E-27 | 2.38E-28 | 8.24E-29 |
| Tb-158 | 6.43E-11 | 5.11E-11 | 3.70E-11 | 2.92E-12 | 1.01E-12 |
| Tc-98 | 6.43E-11 | 6.24E-11 | 5.99E-11 | 4.34E-11 | 3.79E-11 |
| Tc-99 | 2.71E-11 | 2.63E-11 | 2.52E-11 | 1.83E-11 | 1.59E-11 |
| Te-123 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Th-229+D | 3.27E-08 | 3.27E-08 | 3.24E-08 | 3.08E-08 | 3.00E-08 |
| Th-230 | 3.19E-04 | 4.71E-04 | 6.79E-04 | 2.11E-03 | 2.62E-03 |
| Th-232 | 9.11E-04 | 9.11E-04 | 9.11E-04 | 9.11E-04 | 9.11E-04 |
| Ti-44+D | 1.04E-07 | 4.99E-08 | 1.79E-08 | 5.65E-12 | 1.94E-13 |
| Tl-204 | 7.26E-21 | 7.34E-25 | 1.88E-30 | 0.00E+00 | 0.00E+00 |
| U-232 | 1.22E-05 | 7.60E-06 | 3.86E-06 | 1.94E-08 | 2.11E-09 |
| U-233 | 1.02E-08 | 1.52E-08 | 2.21E-08 | 7.52E-08 | 9.67E-08 |
| U-234 | 8.90E-08 | 1.98E-07 | 4.21E-07 | 4.74E-06 | 7.74E-06 |
| U-235+D | 2.01E-07 | 2.04E-07 | 2.08E-07 | 2.38E-07 | 2.50E-07 |
| U-236 | 1.78E-12 | 2.27E-12 | 2.96E-12 | 8.33E-12 | 1.06E-11 |
| U-238+D | 4.70E-06 | 4.70E-06 | 4.70E-06 | 4.70E-06 | 4.70E-06 |
| Zr-93 | 2.05E-40 | 2.06E-40 | 2.06E-40 | 2.06E-40 | 2.06E-40 |
| **TOTAL** | 6.20E-03 | 6.20E-03 | 6.27E-03 | 6.94E-03 | 7.19E-03 |

# Table A-8

## Intruder-Worker Doses (mrem/yr) For The

## Current Class A Waste Inventory

| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Ac-227+D | 2.03E-05 | 4.13E-06 | 4.43E-07 | 1.11E-14 | 7.30E-18 |
| Ag-108m+D | 7.67E-04 | 5.67E-04 | 3.73E-04 | 1.34E-05 | 3.33E-06 |
| Al-26 | 1.34E-04 | 1.30E-04 | 1.25E-04 | 9.03E-05 | 7.87E-05 |
| Am-241 | 1.34E-08 | 1.93E-08 | 2.66E-08 | 6.33E-08 | 7.13E-08 |
| Am-242+D | 3.22E-09 | 2.56E-09 | 1.86E-09 | 1.53E-10 | 5.50E-11 |
| Am-243+D | 5.57E-07 | 5.53E-07 | 5.50E-07 | 5.20E-07 | 5.10E-07 |
| Ar-39 | 2.55E-14 | 2.18E-14 | 1.75E-14 | 3.07E-15 | 1.48E-15 |
| Ba-133 | 7.27E-08 | 2.87E-09 | 3.13E-11 | 1.20E-26 | 4.30E-33 |
| Be-10 | 1.06E-14 | 1.06E-14 | 1.06E-14 | 1.06E-14 | 1.06E-14 |
| Bi-207 | 2.90E-05 | 1.13E-05 | 3.03E-06 | 9.63E-11 | 1.27E-12 |
| Bi-210m+D | 1.45E-07 | 1.41E-07 | 1.36E-07 | 9.83E-08 | 8.60E-08 |
| Bk-247 | 3.30E-12 | 3.24E-12 | 3.17E-12 | 2.63E-12 | 2.45E-12 |
| C-14 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ca-41 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Cd-113 | 4.93E-19 | 4.80E-19 | 4.60E-19 | 3.33E-19 | 2.92E-19 |
| Cd-113m | 4.97E-12 | 3.77E-13 | 1.02E-14 | 4.97E-27 | 3.53E-32 |
| Cf-249 | 3.63E-07 | 3.30E-07 | 2.88E-07 | 9.70E-08 | 6.17E-08 |
| Cf-250 | 2.19E-22 | 3.57E-22 | 5.53E-22 | 2.30E-21 | 3.13E-21 |
| Cf-251 | 1.79E-12 | 1.72E-12 | 1.63E-12 | 1.07E-12 | 8.97E-13 |
| Cf-252 | 2.20E-16 | 3.33E-16 | 4.90E-16 | 1.74E-15 | 2.25E-15 |
| Cl-36 | 2.10E-09 | 2.08E-09 | 2.03E-09 | 1.77E-09 | 1.67E-09 |
| Cm-243 | 2.58E-07 | 7.67E-08 | 1.40E-08 | 2.75E-11 | 2.69E-11 |
| Cm-244 | 4.57E-15 | 4.63E-15 | 4.63E-15 | 4.37E-15 | 4.27E-15 |
| Cm-245 | 8.93E-09 | 8.90E-09 | 8.87E-09 | 8.50E-09 | 8.37E-09 |
| Cm-246 | 2.10E-18 | 3.17E-18 | 4.73E-18 | 1.84E-17 | 2.49E-17 |
| Cm-247+D | 1.91E-08 | 1.91E-08 | 1.91E-08 | 1.93E-08 | 1.93E-08 |
| Cm-248 | 5.10E-14 | 7.63E-14 | 1.12E-13 | 3.90E-13 | 5.07E-13 |
| Cm-250+D | 1.95E-10 | 1.94E-10 | 1.92E-10 | 1.82E-10 | 1.78E-10 |
| Co-60 | 7.07E-05 | 9.87E-08 | 9.97E-12 | 0.00E+00 | 0.00E+00 |
| Cs-135 | 2.14E-14 | 2.14E-14 | 2.14E-14 | 2.14E-14 | 2.14E-14 |
| Cs-137+D | 3.21E-02 | 1.01E-02 | 2.00E-03 | 6.07E-09 | 2.99E-11 |
| Eu-150 | 2.54E-08 | 9.27E-09 | 2.24E-09 | 3.24E-14 | 3.05E-16 |
| Eu-152 | 1.14E-04 | 8.47E-06 | 2.22E-07 | 8.43E-20 | 5.40E-25 |
| Eu-154 | 1.41E-06 | 2.74E-08 | 1.10E-10 | 1.69E-29 | 2.30E-37 |
| Eu-155 | 4.37E-14 | 4.03E-17 | 2.27E-21 | 0.00E+00 | 0.00E+00 |

| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Fe-55 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Fe-60+D | 3.77E-01 | 3.77E-01 | 3.77E-01 | 3.73E-01 | 3.73E-01 |
| Gd-148 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| H-3 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Hg-194+D | 1.03E-06 | 9.03E-07 | 7.50E-07 | 1.73E-07 | 9.37E-08 |
| Ho-166m | 5.60E-06 | 5.47E-06 | 5.23E-06 | 3.80E-06 | 3.33E-06 |
| I-129 | 4.07E-23 | 4.03E-23 | 3.97E-23 | 3.43E-23 | 3.24E-23 |
| In-115 | 2.63E-16 | 2.63E-16 | 2.63E-16 | 2.63E-16 | 2.63E-16 |
| Mn-53 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mo-93 | 5.63E-36 | 5.53E-36 | 5.47E-36 | 4.93E-36 | 4.67E-36 |
| Na-22 | 2.58E-14 | 4.23E-20 | 3.37E-28 | 0.00E+00 | 0.00E+00 |
| Nb-93m | 6.43E-37 | 4.87E-38 | 1.32E-39 | 0.00E+00 | 0.00E+00 |
| Nb-94 | 5.83E-04 | 5.63E-04 | 5.40E-04 | 3.87E-04 | 3.33E-04 |
| Ni-59 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ni-63 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Np-236 | 8.73E-10 | 1.10E-09 | 1.28E-09 | 1.46E-09 | 1.46E-09 |
| Np-237+D | 4.43E-05 | 4.43E-05 | 4.43E-05 | 4.43E-05 | 4.43E-05 |
| Os-194+D | 2.87E-17 | 8.87E-20 | 2.73E-23 | 5.97E-51 | 0.00E+00 |
| Pa-231 | 4.50E-04 | 4.63E-04 | 4.67E-04 | 4.60E-04 | 4.60E-04 |
| Pb-202+D | 2.63E-10 | 2.63E-10 | 2.63E-10 | 2.61E-10 | 2.61E-10 |
| Pb-205 | 1.14E-44 | 1.14E-44 | 1.14E-44 | 1.14E-44 | 1.14E-44 |
| Pb-210+D | 6.80E-07 | 1.43E-07 | 1.63E-08 | 6.13E-16 | 4.83E-19 |
| Pd-107 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Pm-145 | 3.67E-18 | 5.20E-19 | 3.37E-20 | 1.48E-29 | 1.82E-33 |
| Pm-147 | 4.83E-23 | 8.87E-29 | 8.23E-37 | 0.00E+00 | 0.00E+00 |
| Pt-193 | 7.10E-46 | 3.57E-46 | 1.34E-46 | 0.00E+00 | 0.00E+00 |
| Pu-236 | 3.09E-09 | 1.91E-09 | 9.73E-10 | 4.90E-12 | 5.33E-13 |
| Pu-238 | 7.37E-10 | 1.28E-09 | 2.96E-09 | 5.83E-08 | 1.02E-07 |
| Pu-239 | 1.58E-07 | 1.58E-07 | 1.58E-07 | 1.56E-07 | 1.54E-07 |
| Pu-240 | 2.89E-11 | 2.88E-11 | 2.85E-11 | 2.70E-11 | 2.63E-11 |
| Pu-241+D | 3.08E-09 | 4.70E-09 | 6.83E-09 | 1.73E-08 | 1.97E-08 |
| Pu-242 | 2.74E-13 | 2.82E-13 | 2.93E-13 | 3.77E-13 | 4.13E-13 |
| Pu-244+D | 1.08E-07 | 1.08E-07 | 1.08E-07 | 1.08E-07 | 1.08E-07 |
| Ra-226+D | 1.24E+00 | 1.21E+00 | 1.18E+00 | 9.27E-01 | 8.40E-01 |
| Ra-228+D | 1.44E-07 | 3.47E-10 | 7.53E-14 | 1.36E-42 | 0.00E+00 |
| Rb-87 | 7.73E-17 | 7.73E-17 | 7.73E-17 | 7.73E-17 | 7.73E-17 |
| Re-187 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Se-79 | 2.10E-17 | 2.04E-17 | 1.95E-17 | 1.41E-17 | 1.23E-17 |
| Si-32+D | 1.47E-10 | 1.36E-10 | 1.22E-10 | 5.23E-11 | 3.67E-11 |
| Sm-146 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Sm-147 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

| Nuclide | Year 100 | Year 150 | Year 220 | Year 710 | Year 1,000 |
|---|---|---|---|---|---|
| Sm-151 | 2.50E-33 | 1.70E-33 | 9.90E-34 | 1.43E-35 | 2.43E-36 |
| Sn-121m+D | 7.63E-19 | 3.97E-19 | 1.57E-19 | 1.11E-22 | 5.33E-24 |
| Sn-126+D | 4.53E-08 | 4.43E-08 | 4.23E-08 | 3.06E-08 | 2.67E-08 |
| Sr-90+D | 3.97E-06 | 1.21E-06 | 2.28E-07 | 4.70E-13 | 1.97E-15 |
| Tb-157 | 1.76E-24 | 1.39E-24 | 1.01E-24 | 7.93E-26 | 2.75E-26 |
| Tb-158 | 2.14E-08 | 1.70E-08 | 1.23E-08 | 9.73E-10 | 3.37E-10 |
| Tc-98 | 2.14E-08 | 2.08E-08 | 2.00E-08 | 1.45E-08 | 1.26E-08 |
| Tc-99 | 9.03E-09 | 8.77E-09 | 8.40E-09 | 6.10E-09 | 5.30E-09 |
| Te-123 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Th-229+D | 1.09E-05 | 1.09E-05 | 1.08E-05 | 1.03E-05 | 1.00E-05 |
| Th-230 | 1.06E-01 | 1.57E-01 | 2.26E-01 | 7.03E-01 | 8.73E-01 |
| Th-232 | 3.04E-01 | 3.04E-01 | 3.04E-01 | 3.04E-01 | 3.04E-01 |
| Ti-44+D | 3.47E-05 | 1.66E-05 | 5.97E-06 | 1.88E-09 | 6.47E-11 |
| Tl-204 | 2.42E-18 | 2.45E-22 | 6.27E-28 | 0.00E+00 | 0.00E+00 |
| U-232 | 4.07E-03 | 2.53E-03 | 1.29E-03 | 6.47E-06 | 7.03E-07 |
| U-233 | 3.40E-06 | 5.07E-06 | 7.37E-06 | 2.51E-05 | 3.22E-05 |
| U-234 | 2.97E-05 | 6.60E-05 | 1.40E-04 | 1.58E-03 | 2.58E-03 |
| U-235+D | 6.70E-05 | 6.80E-05 | 6.93E-05 | 7.93E-05 | 8.33E-05 |
| U-236 | 5.93E-10 | 7.57E-10 | 9.87E-10 | 2.78E-09 | 3.53E-09 |
| U-238+D | 1.57E-03 | 1.57E-03 | 1.57E-03 | 1.57E-03 | 1.57E-03 |
| Zr-93 | 6.83E-38 | 6.87E-38 | 6.87E-38 | 6.87E-38 | 6.87E-38 |
| **TOTAL** | **2.07E+00** | **2.07E+00** | **2.09E+00** | **2.31E+00** | **2.40E+00** |

## Table A-9

### Intruder-Driller Doses For The Embankment

### Full of Blended Resins

| Isotope | Peak Dose (100 years) (mrem/yr) |
|---|---|
| C-14 | 0.00E+00 |
| Co-58 | 0.00E+00 |
| Co-60 | 2.27E-04 |
| Cs-137+D | 1.11E-01 |
| Fe-55 | 0.00E+00 |
| H-3 | 0.00E+00 |
| I-129 | 1.42E-22 |
| Kr-85 | 0.00E+00 |
| Mn-54 | 0.00E+00 |
| Ni-63 | 0.00E+00 |
| Sr-90+D | 3.55E-06 |
| Zn-65 | 0.00E+00 |
| **TOTAL** | **1.11E-01** |

## Table A-10

### Intruder-Worker Doses For The Embankment

### Full of Blended Resins

| Isotope | Peak Dose (100 years) (mrem/yr) |
|---|---|
| C-14 | 0.00E+00 |
| Co-58 | 0.00E+00 |
| Co-60 | 7.57E-02 |
| Cs-137+D | 3.70E+01 |
| Fe-55 | 0.00E+00 |
| H-3 | 0.00E+00 |
| I-129 | 4.73E-20 |
| Kr-85 | 0.00E+00 |
| Mn-54 | 0.00E+00 |
| Ni-63 | 0.00E+00 |
| Sr-90+D | 1.18E-03 |
| Zn-65 | 0.00E+00 |
| **TOTAL** | **3.70E+01** |

## Table A-11

### Mortality Rates From The Consumption Of Clive's Natural Groundwater

| | Clive's Average Natural Groundwater Concentration[a] | Radiological Mortality Slope Factor (per µCi)[b] | Risk[d] |
|---|---|---|---|
| **Radiologics (pCi/L)** | | | |
| H-3 | 2.89E+02 | 3.49E-08 | 3.08E-07 |
| C-14 | 8.46E+00 | 1.07E-06 | 2.76E-07 |
| K-40 | 4.18E+02 | 1.59E-05 | 2.03E-04 |
| I-129 | 1.94E+00 | 1.51E-05 | 8.90E-07 |
| Np-237 | 4.02E-01 | 4.07E-05 | 4.99E-07 |
| Ra226 | 5.05E-01 | 2.65E-04 | 4.09E-06 |
| Ra-228 | 9.75E-01 | 7.40E-04 | 2.20E-05 |
| Sr-90 | 1.09E+00 | 4.96E-05 | 1.65E-06 |
| Tc-99 | 5.52E+00 | 1.58E-06 | 2.67E-07 |
| Th-230 | 2.15E-01 | 6.18E-05 | 4.06E-07 |
| Th-232 | 1.14E-01 | 6.92E-05 | 2.41E-07 |
| U-234 | 2.10E+00 | 4.59E-05 | 2.94E-06 |
| U-235 | 1.75E-01 | 4.48E-05 | 2.39E-07 |
| U-238 | 1.11E+00 | 4.18E-05 | 1.42E-06 |
| | | **Drinking Water Unit Risk (per µg/L)[c]** | |
| **Anions (mg/L)** | | | |
| Bromide | 1.56E+01 | 2.00E-05 | 3.12E-01 |
| Chloride | 3.14E+04 | 5.00E-04 | 1.57E+04 |
| Nitrate | 1.63E+00 | 8.00E-03 | 1.31E+01 |
| Nitrite | 1.38E+00 | 5.00E-04 | 6.91E-01 |
| Sulfate | 6.52E+03 | 1.44E-01[e] | 9.39E+05 |
| **Metals (mg/L)** | | | |
| Antimony | 5.00E-03 | 2.00E-06 | 1.00E-05 |
| Arsenic (ICP) | 8.80E-02 | 2.50E-07 | 2.20E-05 |
| Arsenic (GFAA) | 4.30E-02 | 2.50E-07 | 1.08E-05 |
| Barium | 1.90E-02 | 1.00E-03 | 1.90E-02 |
| Beryllium | 3.00E-03 | 1.00E-05 | 3.00E-05 |
| Cadmium | 4.40E-03 | 2.50E-06 | 1.10E-05 |
| Chromium | 1.80E-02 | 1.50E-05 | 2.70E-04 |
| Cyanide | 6.00E-03 | 3.00E-06 | 1.80E-05 |
| Mercury | 3.00E-04 | 1.50E-06 | 4.50E-07 |
| Molybdenum | 6.64E-01 | 2.50E-05 | 1.66E-02 |
| Selenium (GFAA) | 3.80E-02 | 2.50E-05 | 9.50E-04 |
| Silver | 8.00E-03 | 2.50E-05 | 2.00E-04 |
| TDS | 6.08E+04 | 1.64E-02[e] | 1.00E+06 |

| | Clive's Average Natural Groundwater Concentration[a] | Drinking Water Unit Risk (per µg/L)[c] | Risk[d] |
|---|---|---|---|
| Zinc | 6.60E-02 | 1.50E-03 | 9.90E-02 |
| **Volatiles (mg/L)** | | | |
| Acetone | 1.51E+01 | 4.50E-03 | 6.81E+01 |
| 2-Butanone (MEK) | 1.43E+01 | 2.10E-05 | 3.01E-01 |
| Carbon disulfide | 3.74E+00 | 5.00E-04 | 1.87E+00 |
| Chloroform | 2.44E+00 | 5.00E-05 | 1.22E-01 |
| 1,2-Dichloroethane | 2.44E+00 | 2.60E-06 | 6.33E-03 |
| Methylene chloride | 2.39E+00 | 2.10E-05 | 5.02E-02 |
| 1,1,2-Trichloroethane | 1.36E+01 | 1.60E-06 | 2.18E-02 |
| Vinyl Chloride | 1.28E+01 | 2.10E-05 | 2.70E-01 |
| **Semi-Volatiles (mg/L)** | | | |
| Benz(a)anthracene | 3.94E+01 | 2.10E-04 | 8.27E+00 |
| Benzo(a)pyrene | 3.94E+01 | 2.10E-04 | 8.27E+00 |
| Benzo(b)fluoranthene | 4.11E+01 | 2.10E-04 | 8.64E+00 |
| Benzo(k)fluoranthene | 3.94E+01 | 2.10E-04 | 8.28E+00 |
| Chrysene | 3.94E+01 | 2.10E-04 | 8.27E+00 |
| Dibenz(a,h)anthracene | 3.94E+01 | 2.10E-04 | 8.27E+00 |
| Diethyl phthalate | 6.61E+00 | 4.00E-01 | 2.64E+03 |
| 2-Methylnaphthalene | 5.46E+00 | 1.00E-04 | 5.46E-01 |
| Naphthalene | 4.79E+00 | 1.00E-04 | 4.79E-01 |
| **Pesticides (mg/L)** | | | |
| Chlordane | 5.47E+00 | 1.00E-05 | 5.47E-02 |
| | | **TOTAL CARCINOGENIC MORTALITY RISK** | **1.96E+06** |

[a] Long-term average concentrations from up-gradient well GW-19A, as reported in Energy*Solutions*, (2012). "Comprehensive Groundwater Quality Evaluation Report – Waste Disposal Facility, Clive Utah" Report to the Utah Division of Radiation Control, December 10, 2012.

[b] Eckerman, et.al. (1999) "Federal Guidance Report No. 13· Cancer Risk Coefficients for Environmental Exposure to Radionuclides " (EPA 402-R-99-001). Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, September 1999

[c] EPA (2013) "Integrated Risk Information System (IRIS)" (http://www epa.gov/iris/). Accessed 26 September 2013, U.S Environmental Protection Agency, 2013.

[d] Deaths per 1,000,000 individuals.

[e] Patterson, H.H , et.a. (2005) "Effect of Total Dissolved Solids and Sulfates in Drinking Water for Growing Steers" Departments of Animal and Range Sciences and Veterinary Science, 2005.

**Table A-12**

**Net Infiltration Through the Alternate Evapotranspirative Cover Designs**

| Evaporative Zone Thickness (cm) | Net Infiltration Flux through Cover Design A (cm/yr) | Net Infiltration Flux through Cover Design B (cm/yr) |
|---|---|---|
| 15.2 | 2.51E-04 | 1.92E-04 |
| 30.5 | 1.97E-04 | 1.89E-04 |
| 45.7 | 1.95E-04 | 1.89E-04 |

ENERGYSOLUTIONS

# APPENDIX B

## Responses to

## Round 1 Request for Information

## INTERROGATORY RESPONSE TOPICAL INDICES

**Responses to Round 1 Request for Information**

## 1.0 INTRODUCTION

In response to its updated Site-Specific Performance Assessment (submitted to the Division 8 October 2013), Energy*Solutions* received Round 1 Requests for Information (dated 7 June 2013). Instead of mirroring the structure of the Performance Assessment Report, the Division chose instead to arrange its comments topically, while referring to the original sections of this Report. Responses to the Division Interrogatories are provided herein following the same topical order.

## 2.0 CODES, REGULATION AND LAW

**2.1 INTERROGATORY STATEMENT(S):** Under R313-15-401: Periods of Performance, the following statement is made on Page 1-3: "1. Licensees shall determine the peak annual total effective dose equivalent to the general public within 1,000 years after decommissioning." [UAC R313-15-401(4)]. UAC R313-15-401(4) appears to be misquoted. Please quote it correctly in its entirety.

**ENERGY*SOLUTIONS'* RESPONSE:** The citation has been expanded to include the requirement in its entirety.

**2.2 INTERROGATORY STATEMENT(S):** In Section 1.4.1.3 on Page 1-3, groundwater classifications and limits on groundwater contamination are discussed. Reference is made to (i) "the Ground Water Quality Discharge Permit, derived from Ground Water Quality Standards listed in UAC R317-6-2, (ii) "Class IV, (iii) "saline ground water" and (iv) "protection limits as 'non-degradation standards.'" The DRC does not fully understand the references to these terms made in Section 1.4.1.3 and requests that the Licensee clarify the meanings of all terms used in this section and also make explicit any arguments or requests that the Licensee is attempting to make.

**ENERGY*SOLUTIONS'* RESPONSE:** As is correctly reflected in Section 1.4.1.3, Energy*Solutions* is required to comply with ground water protection levels (GWPLs), derived from Ground Water Quality Standards (GWQS, UAC R317-6-2) as found in ground water quality discharge Permit No. UGW450005, wherein radionuclides are assigned a performance standard of 500 years.

As part of the basis for their interrogatory, the Division cites the 10,000-year performance criteria promulgated in UAC R313-25-8(5)(a). However, the requirements provided in UAC R313-25-8(5) are specifically related to, "*. . . any facility that proposes to land dispose of significant quantities of concentrated depleted uranium (more than one metric ton in total accumulation) after June 1, 2010 . . .*" As such, compliance with this regulatory requirement is demonstrated in a separate Performance Assessment already submitted to the Division by Energy*Solutions* (developed in support of proposed disposal of significant volumes of depleted uranium) (McCandless, 2011).

The Division also notes in the basis for this interrogatory that there is "*a possible change of classification of groundwater to Class IV is currently under review by state regulators.*" Energy*Solutions* continually strives to demonstrate compliance with all applicable regulatory requirements. As such, Energy*Solutions* is aware that not only are groundwater classifications and associated requirements under review by applicable State agencies, but so are the U.S. Nuclear Regulatory Commission's Licensing Requirements for Land Disposal of Radioactive Waste (10 CFR 61) – which serve as the basis for the Division's UAC R313-25. However, until such time as any hypothetical revisions are finalized into rule, requirements for demonstration of compliance are highly subjective and inappropriate. Therefore, no further Report revisions are necessary.

2.3 **INTERROGATORY STATEMENT(S):** On Page 1-3, it says that "*the limitation of this comparison is of concentration (not dose) for a period of 500 years following embankment closure, and of projected peak groundwater well concentrations for each individual radionuclide for a time period of 10,000 years following embankment closure. [UAC R317-6]*" Please correct the reference, or provide a justification for it.

**ENERGY*SOLUTIONS'* RESPONSE:** In the Basis for the Interrogatory of Report Section 1.4.1.3, the Division acknowledges that Energy*Solutions* is required to comply with ground water protection levels (GWPLs), in which radionuclides are assigned a performance standard of 500 years in the Ground Water Quality Standards (GWQS, UAC R317-6-2). The text of Section 1.4.1 has been revised to improve clarity of this regulatory requirement.

As part of the basis for their interrogatory, the Division cites the 10,000-year performance criteria promulgated in UAC R313-25-8(5)(a). However, the requirements provided in UAC R313-25-8(5) are specifically related to, "*. . . any facility that proposes to land dispose of significant quantities of concentrated depleted uranium (more than one metric ton in total accumulation) after June 1, 2010 . . .*" As such, compliance with this regulatory requirement is demonstrated in a separate Performance Assessment already submitted to the Division by Energy*Solutions* (developed in support of proposed disposal of significant volumes of depleted uranium) (McCandless, 2011).

2.4 **INTERROGATORY STATEMENT(S):** The Licensee writes in the PA that "the approach to dose assessment suggested by UAC R313-25-19 is now dated" and argues (incorrectly, as shown later in this document) that guidance from the NRC should override this rule.

Please rewrite section 1.4.2.1 to indicate conformity with UAC R313-25-19, entitled, Protection of the General Public, and the Federal regulation 10 CFR 61.41, entitled, Protection of the general population from releases of radioactivity, both of which read as follows:

*"Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."*

**ENERGY*SOLUTIONS'* RESPONSE:** Justification for the conservatisms and applicability of NRC's recommended 25 mrem/yr total effective dose equivalent has been added to Section 1.4.2.1.

**2.5 INTERROGATORY STATEMENT(S):** On page 1-5, the Licensee states:

"... and contacting the waste (which is in excess of the UAC R313-25's Class A requirements)."

Please correct the PA to remove the implication that the waste will exceed Class A limits.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 1.4.2.2 has been revised as directed.

## 3.0 WASTE AND SOURCE TERM

**3.1 INTERROGATORY STATEMENT(S):** On Page 1.1, the Licensee states:

"*On 14 February 2011, Energy*Solutions *requested concurrence from the Utah Division of Radiation Control (the Division) that previous licensing activities allowed for the receipt and disposal of blended ion-exchange resin waste on a large-scale at the Clive facility (Shrum, 2011). The Division reviewed Energy*Solutions' *analysis supporting this request and determined that Energy*Solutions *could receive blended waste up to 40,000 cubic feet per year. However, in order to receive blended waste at volumes greater than 40,000 cubic feet per year, Energy*Solutions *would be required to conduct a new performance assessment analyses that include "prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways" (Lundberg, 2011).*"

In order to evaluate the submitted Performance Assessment (PA) and analyses contained therein concerning prediction of nuclide concentration and peak dose, the DRC requires modifications to the contaminant fate and transport modeling process. Some issues that remain to be resolved are discussed in the DRC (2011) document entitled Technical Assessment: Energy*Solutions* Proposed Disposal of Low-Level Radioactive Waste Generated by SempraSafe Treatment Process. This document summarizes a number of important issues and sets forth corresponding objectives that should be met in the PA. These have not yet been fully addressed by the Licensee. As indicated elsewhere within this review, numerous changes are required within the existing PA model. Once these changes are made, there will likely be a need to address multiple isotopes, not just the single isotope addressed in the current model. With greater infiltration, a model may show faster contaminant transport, with consequent breakthrough for a number of isotopes within the 10,000-year modeling period.

DRC (2011) describes several of the pertinent modeling problems. The licensee needs to address these. These problems include the following:

> "*The horizontal domain of the July 19, 2000 ES PA model also simulated 24 isotopes, but many are different from those found in the NRC DEIS. Comparison shows that 17 nuclides from the NRC DEIS were omitted from the horizontal domain of the ES PA model, as indicated in italics in Table 1, below. Most of the 17 omitted nuclides are not mobile in groundwater, and therefore are of little consequence to Clive embankment PA predictions. However, the same may not be said for 2 others not previously analyzed: carbon-14 (C-14), and neptunium-237 (Np-237). Two others, uranium-235 (U-235) and uranium-238 (U-238), may also need to be considered, in that they are somewhat mobile in oxidizing groundwater environments.*"

> "*The vertical domain of the July 19, 2000 ES PA model did consider all of the 24 isotopes NRC deemed important in its 1981 DEIS. However, additional work should be undertaken to re-examine the Clive horizontal domain predictions for at least 4 isotopes known to be mobile or somewhat mobile in groundwater (C-14, Np-237 and U-235 and U-238).*"

> "*The effect of the new peak dose requirement in UAC R313-25-8(1)(b) on the Utah PA Standard that DRC previously applied to the Class A and Class A North Cells, is currently unknown, but can be examined during new PA analysis. New PA analysis is warranted in that after approval of the July, 2000 ES PA model, the NRC published new scientific guidance for PA modeling that has yet to be applied to the Clive facility. New PA modeling with this guidance will provide an opportunity to examine the effects of waste with elevated isotope source term concentrations with respect to disposal facility and site performance.*"

> "*More current human dosimetry research (and DCFs) ... should be considered in determining GWQS for the Clive facility ...*"

> "*Did the July 19, 2000 ES PA model predict peak nuclide groundwater concentrations (PCi/I) at the poe wells? If so, will the proposed SempraSafe waste have concentrations that are more than 10% of said ES PA source term? Answer: peak concentrations were available for many nuclides in the vertical domain of the ES PA. However the POC well is found in the horizontal domain, and is currently considered the potential point of*

*exposure to the public. DRC review of the ES PA horizontal model predictions shows peak concentration (and hence peak dose) for only 1 of the 90 nuclides simulated, rhenium-l 87 (Re-187) ... UAC R313-25-8(1)(c): (1) The licensee or applicant shall conduct a site-specific performance assessment and receive Executive Secretary approval prior to accepting any radioactive waste if: ... ( c) the waste will result in greater than 10 percent of the total site source term over the operational life of the facility, or"*

*"Six examples of mobile isotopes in this situation are found in Table 3, below (Al-26, Ca-41 , CI-36, K-40, Re-187, and Th-158). This finding reinforces the need to consider PA model inputs and results to establish maximum isotope activity inventory limits for each disposal cell (and for the site), in order to determine compliance with UAC R313-25-8(1)(c)."*

*"However, Table 4 also shows 11 other isotopes identified in the recent EPRI report were omitted from analysis in the horizontal domain of the July, 2000 ES PA model. Of these 11, six have half-lives that range from 30 to 76,000 years, and should be considered for analysis in a new PA model, including: C-14, Ni-59, Ni-63, Nb-94, Cs-137, and Pu-238. Here again, the opportunity to improve the ES PA model is important in order to assess the long term performance of these and other nuclides at the Clive disposal site."*

*"DRC staff compared this ES information and found about 25 longer-lived isotopes have been disposed at Clive, and were not analyzed in the approved PA report. These same 24 unanalyzed isotopes were also not considered in the 1981 NRC DEIS. For details, see Table 5, below. While it is currently unclear if all or any of these 24 unanalyzed isotopes will actually be disposed as part of the SempraSafe waste, the Executive Secretary has decided to err on the side of conservatism until ES is able to successfully demonstrate otherwise. In summary, these 24 un-analyzed isotopes deserve consideration in a new PA model in order to determine if any pose a concern for long-term facility performance."*

**ENERGY*SOLUTIONS'* RESPONSE:** The following responses are provided for the various issues raised by the Division in this Interrogatory.

1) The Division remarks that the horizontal domain of the July 19, 2000 ES PA model simulated an isotope list different from that found in the NRC DEIS. As is discussed in Section 2.3 of this Report, Energy*Solutions*' updated Site-Specific Performance Assessment evaluates 260 isotopes, including those the Division deemed absent from the 2000 ES PA's horizontal domain.

2) The Division remarks that the vertical domain of the July 19, 2000 ES PA model simulations of C-14, Np-237, U-235, and U-238 should be re-examined. As is discussed in Section 2.3 of this Report, Energy*Solutions*' updated Site-Specific Performance Assessment re-evaluates the 4 isotopes included in this Interrogatory.

3) The Division requested demonstration that the updated Site-Specific Performance Assessment has been developed in compliance with the U.S. NRC scientific guidance in NUREG-1573. The text has been expanded to clarify compliance of this Assessment with the cited NRC guidance.

4) Reference to application of a more current dosimetry research (and DCFs) in determining GWQS for the Clive facility . . ." is included in Section 1.4.2.1 (as is also referenced in the Division's Interrogatory for that section). Section 1.4.2.1 and Appendix A have been expanded to clarify use of more current dosimetry research and DCFs.

5) As requested, Section 1.1 has been expanded to demonstrate Energy*Solutions*' compliance with UAC R313-25-8(1)(c).

6) As is concluded in Section 3 and Appendix A of revision 0, the Class A maximum isotope activity inventory limits are applicable for disposal of Al-26, Ca-41, Cl-36, K-40, Re-187, and Tb-158.

7) As requested, Table A-1 and Section 2.3 have been expanded to demonstrate incorporation into the updated Site-Specific Performance Assessment of what the Division termed as, "un-analyzed isotopes."

**3.2 INTERROGATORY STATEMENT(S):** On Page 1.1, the Licensee states:

> "*However, in order to receive blended waste at volumes greater than 40,000 cubic feet per year, Energy*Solutions *would be required to conduct a new performance assessment analyses that include "prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways" (Lundberg, 2011).*"

In order to assess the appropriateness of emplacement of blended cation-exchange resin waste in the Clive embankment, the DRC requires additional information regarding this waste source. Please provide as complete as possible a summary of estimated values for all potentially significant physical and chemical properties of the blended waste, and address, in detail, the variability and uncertainty associated with these properties, as is required under current NRC guidance.

Physical properties would include such factors as density, moisture content, organic carbon content, percent clay, particle size distribution, porosity and hydraulic conductivity. Other physical properties, where available, should be described as well. The anticipated forms and condition of the waste should be described in the PA. Containers and backfill also need to be described in detail. Stability should be addressed in terms of expected lifetime of the forms and how instability at some point is accounted for in modeling work.

The chemical and geochemical environments of the waste and materials around the waste need to be described, with particular reference to any factors potentially affecting transport. Discuss all factors potentially affecting rates of migration in all affected environmental media (e.g., contaminated zone, vadose zone, and saturated zone). Values of pertinent variables need to be estimated, where feasible, based on scientific or engineering assessments. Chemical properties and conditions that need to be estimated include diffusion rates, tortuosity, corrosion rates, soilwater partition information (e.g., ~s, or batch-test isotherm data) and leaching rate constants, pH, Eh (or other redox parameter(s), ionic strength, buffer capacity, chemical composition (including presence of non-radioactive metals or organics), speciation and complexation.

In estimating values for variables affecting the source term, both sensitivity analysis and uncertainty analysis should be conducted. Unless the most conservative parameter values are used in a deterministic model, from which a single set of outcomes will be obtained, probabilistic modeling is required. A Monte Carlo approach with a large number of model realizations may be appropriate. Tables and graphs illustrating geometric mean values, geometric standard deviations, and 75% confidence values for all significant outcomes should be provided. Where possible, field data should corroborate or justify the range and probability of model parameter values chosen.

**ENERGY*SOLUTIONS'* RESPONSE:** The actual benefits in retardation of contaminant transport associated with the specific forms of wastes are conservatively excluded in the Updated Site-Specific Performance Assessment. The physical and chemical properties of blended ion-exchange resins have been previously provided to the Division (Shrum, 2011a and Shrum, 2011b). Impact in the variability and uncertainty in these properties is addressed in Appendices A of revision 0 and G of revision 1.

**3.3 INTERROGATORY STATEMENT(S):** On Page 1.1, the Licensee quotes part of a DRC statement speaking of a "need to revisit/update the waste source term ... (Lundberg, 2011)".

Please provide the following:

1. A listing of all variables commonly used to describe the source of contamination, i.e., the waste. This list may include, for example, those variables listed in the interrogatory above.
2. Please identify which source or waste-related variables are not used in the existing PA model, and justify why it is not necessary to explicitly account for them.
3. For all variables used in the model to describe the waste or the source term, please justify the values chosen for modeling.
4. For those variables used in the model to describe the waste or the source, please indicate the possible range of values that might exist for that variable, given the uncertainties associated specifically with the site and the waste.
5. Conduct a sensitivity analysis to determine which waste or source variables to which the model is most sensitive.

6. Conduct an uncertainty analysis for the model applied to all sensitive waste or source variables.

**ENERGY*SOLUTIONS'* RESPONSE:** Conservatively bounding input parameters used in the updated Site-Specific Performance Assessment are presented in Tables 1 through 4 of Appendix B from revision 0 of this updated Site-Specific Performance Assessment.

3.4 **INTERROGATORY STATEMENT(S):** In Section 1.3, entitled Blended Ion-Exchange Resins, the term "Reformed residue" is used to describe the end product of the THOR$^{SM}$ process, which is the same type of material that is disposed of in the Clive facility. Please use a different term other than "residue" in the PA and elsewhere in describing the waste. The term "residue", like the term "residual", is deemed by the DRC to be inappropriate for use in the State of Utah to describe thermally processed waste. Please replace the term "reformed residue" with a more appropriate term, e.g., processed ion-exchange resin waste.

**ENERGY*SOLUTIONS'* RESPONSE:** As directed, the terms "reformed residue", "residual", and "residue" have been replaced with the phrase "processed ion-exchange resin waste" in the Report.

3.5 **INTERROGATORY STATEMENT(S):** On Page 1-2, the licensee states, "*The end result of the process is a homogeneous and environmentally-stable waste.*" Please define the term "environmentally stable," and demonstrate, using actual data, that the result of the THOR$^{SM}$ process is environmentally stable.

**ENERGY*SOLUTIONS'* RESPONSE:** References to the justification of the environmental stability of processed ion-exchange resin waste previously provided to the Division has been added to Section 1.3.

3.6 **INTERROGATORY STATEMENT(S):** On Page 1-3 of the PA, it says that NRC staff members have stated, "*NRC's new position is that large-scale LLRW blending may be conducted when it can be demonstrated to be safe.* (NRC, 2010)." Please fix the reference.

**ENERGY*SOLUTIONS'* RESPONSE:** As directed, the reference has been revised.

3.7 **INTERROGATORY STATEMENT(S):** No reference is provided in the PA in regard to the "*sum of the fractions rule.*" Please describe the sum of the fractions rule in the PA and explain how it applies to waste disposed of at Clive.

**ENERGY*SOLUTIONS'* RESPONSE:** The sum of fractions rule is described in UAC R313-15-1009(1)(g).

**3.8 INTERROGATORY STATEMENT(S):** Please provide an analysis of the potential for generation of hydrogen from buried metals under the proposed evapotranspirative cover with subsequent fire or explosion.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 3.8 of Appendix F, the issue of hydrogen generation associated with subsurface radioactive waste has been a topic of investigation in the waste management literature. While limited hydrogen generation associated with disposed LLW is possible, significant accumulation of hydrogen gas is generally regarded as a minor concern for disposal of Class A low-level radioactive waste under shallow unsaturated zone conditions similar to Clive. More specifically, the reformed resin waste is disposed using the Clive Containerized Waste (CWF) design (see pages 1-5 to 1-6 of Appendix B of Revision 0 of the updated Site-Specific Performance Assessment). The resin containers are placed in a honeycomb pattern of concrete silos, void spaces are backfilled with sand and covered with sand, silt and clays. There is sufficient porosity in the backfill and cover material for efficient diffusion of hydrogen gas. The likelihood of significant accumulations of hydrogen gas is extremely low.

## 4.0 EROSION

**4.1 INTERROGATORY STATEMENT(S):** It is stated on Page 2-6 that "*Long-term stabilization of the Embankment is accomplished through erosion control and flood protection.*"

The statement above that stabilization of the embankment is accomplished over the long-term using erosion control does not appear to be supported by existing data, as noted in the following photos. These photos show that existing erosion control for clay soils on site is in some places only partially effective, and that erosion control needs to be undertaken from year to year. Stabilization now does not necessarily indicate stabilization over time within the modeled timeframe (i .e., 10,000 years). Please either justify the statement above, or revise it to be consistent with existing data.

**ENERGY*SOLUTIONS'* RESPONSE:** The analyses described in Appendix C demonstrate that the proposed evapotranspirative cover designs and associated installation procedures comply with UAC R313-25-8(4)(a) and (b); UAC R313-25-18; UAC R313-25-19; UAC R313-25-20; UAC R313-25-8(4)(d); and UAC R313-25-22 by establishing a stable and functioning system comprised of native vegetation and soil biota that minimizes any near-term episodic erosional exposure of contaminated materials. A functioning native ecosystem also provides long-term soil stabilization via soil development, plant roots in upper soil layers, and biological soil crusts.

Erosion and gullying of the evapotranspirative cover system, and the soil-stabilizing and evapotranspirative functioning of native vegetation, will be monitored during a restoration period of approximately 3–5 years, and throughout the 100-year Institutional Control period. Development of a mature vegetation community generally requires 3–5 years (ITRC 2003). A similar revegetation time frame was instituted for the establishment and development of a steady-state plant community at Monticello (Waugh et al. 2008). Monitoring during the 3-5 year revegetation period and 100-year institutional control period will allow timely response to episodic damage to or gradual loss of soil stability or natural soil stabilization processes. Any and all maintenance required while the ET cover system is approaching steady state will be well within the initial 100-year Institutional Control period and of minor nature, such as regrading and reseeding erosional rills.

4.2 **INTERROGATORY STATEMENT(S):** While the licensee claims on Page 2-6 that "*Long-term stabilization of the Embankment is accomplished through erosion control and flood protection*", the licensee must demonstrate through acceptable experiments and/or mathematical or numerical modeling that the proposed soil/gravel admixture with only 15% gravel in the surface layer will be adequate to prevent formation of rills and gullies in the surface layer of the cover system throughout the mandated 10,000- year modeling time period. Alternatively, the Licensee can redesign the cover system to ensure appropriate levels of erosion protection. The procedure described by Anderson and Stonnont (2005) may be an appropriate starting place for this.

**ENERGY*SOLUTIONS'* RESPONSE:** The analyses described in Appendix D demonstrates that the design of the proposed evapotranspirative cover system achieves sheet, rill and gully erosion control. Erosion is a critical element to the design process and the basis for that design is given in this response. Methodologies employed therein address the Division's concerns about the adequacy of the erosion protection. The potential for future erosion is projected using several different methods. The chosen methods for determining the adequacy of the erosion control for the proposed Evapotranspirative Cover are commonly used and have been accepted and recommended by the US Environmental Protection Agency and the US Nuclear Regulatory Commission.

In their interrogatory, the Division identified various locations around the Clive facility that have experienced rill erosion. As is discussed further as a result of subsequent field investigation by SWCA in Appendix C, all of the sites shown in the examples are areas that have been disturbed, are non-vegetated and without any apparent effort to restore the slope to natural conditions. Natural conditions for the slopes can be defined as slope cover conditions (vegetation, biological soil crust, plant litter, etc) that exist in the Clive area on stable native slopes. Additionally, SWCA found numerous comparable stable native slopes throughout the area. The Evapotranspirative Cover that is contemplated by Energy*Solutions* includes such erosion control measures such as the establishment of native vegetation, gravel admixture, establishment of native soil crusts and plant litter, and appropriate compaction. Following its construction, Energy*Solutions* will have the 100-year institutional control period to ensure that the prerequisite long-term, steady-state conditions are established and that excessive rilling and gullying will not occur. There is a significant difference between the slope of the proposed Evapotranspirative Cover design and the DRC-photographed highly disturbed slope with bare-soil.

4.3 **INTERROGATORY STATEMENT(S):** It is stated on Page 2-6 that "*Long-term stabilization of the Embankment is accomplished through erosion control and flood protection.*"

The surface layer, which is the focus of erosion control, contains a gravel admixture of 15% gravel within Unit 4 material. However, the size and shape of the gravel are not specified. Please specify them.

**ENERGY*SOLUTIONS'* RESPONSE:** Geotechnical requirements for the alternate evapotranspirative cover designs are addressed in the proposed revisions to the Appendix C - CQA/QC Manual, Appendix B – Drawing Package, and Appendix K – HAL ET Slope and Ditch Tech Memo (submitted in conjunction with the Radioactive Material License UT2300249 - License Renewal Application (Energy*Solutions*, 2013).

4.4 **INTERROGATORY STATEMENT(S):** On Page 2-6, it says, "*However, as part of this updated Performance Assessment, the Division requested EnergySolutions evaluate alternative cover designs that more efficiently maximize the amount of time that precipitation is available for evapotranspiration within the alternative cover designs.*"

The DRC once again asks the Licensee to research pertinent data and examine potential designs for the cover-system, paying special attention to developing a system that not only strongly resists erosion, but also provides for better water storage, prevents or minimizes biointrusion, allows for minimal distortion, enables long-term stability, and enhances evaporation and transpiration to very high levels (or alternatively provides robust drains to remove infiltrated water). Such a low-erosion system needs to be planned for and described in a revised PA.

**ENERGY*SOLUTIONS'* RESPONSE:** As is described in Appendix D and SWCA (2012), SWCA (2011), and HAL (2011) previously submitted to the Division, in preparation of this updated site-specific Performance Assessment, Energy*Solutions* has evaluated pertinent data and examined potential designs for the cover-system that strongly resists erosion, provide improved water storage, minimizes biointrusion, allows for minimal distortion, enables long-term stability, and enhances evaporation and transpiration to very high levels.

4.5 **INTERROGATORY STATEMENT(S):** On Pages 2-6 and 2-7, a "traditional rock armor" cover system is described. Such a system has a number of advantages. Some disadvantages are mentioned in the PA. Please design a system that offers, to the extent feasible, the advantages of a "traditional rock armor" system without its disadvantages. This will involve designing a cover system that, while offering erosional resistance, e.g., as using cobble layers in a "traditional rock armor" cover system may do, also focuses on permitting evaporation and transpiration to readily occur, as can generally occur using clayey or silty loams. This may involve design and use of innovative cover-system materials.

**ENERGY*SOLUTIONS'* RESPONSE:** In review of applicable regulatory requirements of UAC R313-25, Energy*Solutions* does not locate specific cover design requirements that mandate a design with "*the advantages of a 'traditional rock armor' system without it disadvantages.*" Even so, the performance of Energy*Solutions'* proposed alternative evapotranspirative cover is projected to be in compliance with applicable regulatory requirements of UAC R313-25.

4.6 **INTERROGATORY STATEMENT(S):** Page 2-8 states that the surface layer "is composed of native vegetated Unit 4 material with 15% gravel mixture. This layer is 6 inches thick. The functions of this layer are to control runoff, minimize erosion, and maximize water loss from evapotranspiration. This layer of silty clay used in both evapotranspirative designs provides storage for water accumulating from precipitation events, enhances losses due to evaporation, and provides a rooting zone for plants that will further decrease the water available for downward movement.

Please conduct a complete engineering analysis of erosion. It should be based on the measured mineralogical as well as grain-size characteristics of site-specific clays, and, preferably, on experimental data. If modeling is selected for use in support of the analysis, then please specify exactly what type of model is used, and provide all assumptions used in modeling. Please design the cover system so as to be able to withstand all anticipated flows, including those of a foreseeable storm or series of storms of maximum intensity. Please incorporate within the model various scenarios including that of up to 10.87 cm (4.28 inches) of precipitation falling at the Clive Disposal Facility in one month, as occurred in May of 2011.

If the layer of silty clay with only 15% gravel is considered to be highly erosion resistant, then please justify that opinion through experimental data or through comparisons with studies of erosion of clays consisting dominantly of calcium carbonate, as are found on site, combined with approximately 15% gravel.

If it is decided that the surface layer of silty clay with 15% gravel as proposed in the October 2012 PA would not be sufficiently erosion resistant, then please redesign the surface layer. The combined use of rock cobbles and clay may provide superior erosional resistance. Please evaluate, via experiment and/or modeling, the potential use of an infilled cobble system (see Abt et al., 1986), or something comparable in terms of performance for a surface layer, and develop a design based on that evaluation.

Regardless of the quantitative outcome of modeling or experimentation dealing with erosion, please address radionuclide exposure associated with erosion of soil or waste particles coupled with water-borne or air-borne transport.

**ENERGY*SOLUTIONS'* RESPONSE:** Appendix D summarizes the erosion analysis for the evapotranspirative cover design.

**4.7** **INTERROGATORY STATEMENT(S):** The design surface-layer portion of the cover system as described on Page 2-8 consists of on-site silty clay mixed with only 15% gravel. Based on comparisons with percentages of gravel planned for or used in other alternative cover systems, the DRC finds that planned design of only 15% of gravel in the surface layer at the site appears to be too low to adequately resist erosion. Experts generally recommend percentages in the range of 30-50%. Please design a surface-layer using an appropriately higher percentage of gravel, or provide justification through experiment or modeling that use of only 15% gravel with provide erosion protection for 10,000 years.

**ENERGY*SOLUTIONS*' RESPONSE:** HAL (2011) and Appendix D justify the adequacy in erosion resistance of the evapotranspirative cover designs evaluated.

**4.8** **INTERROGATORY STATEMENT(S):** Pages 3-1 and 3-2 say, "*that after final placement of the waste and closure of the Embankment with a rock armored cover, the facility design prevents any further migration of radioactivity through the air pathway. Analysis of the longevity of the alternate evapotranspirative cover designs, which provide equivalent isolation of waste from the atmosphere, also demonstrates that no such air-related doses are projected following closure and institutional control.*"

The DRC finds this statement to be inapplicable to the proposed cover system design and also finds that a possibility exists for transport of radioactivity through an air pathway should sufficient erosion in cover system soils occur, with consequent exposure of the waste to wind. Please address the issues associated with erosion potentially leading to a break of the cover system and devise and plan for the engineered means to prevent this. Show through modeling, if possible, that erosional breaching of the proposed cover will not occur with the relatively rare carbonate silty clay found at the Clive site, mixed with 15% gravel. Alternatively, redesign the cover to provide for greater long-term protection against erosion. If gullies do form down into the waste, then there would be high potential for transport of radioactive particles along with soil. There would accordingly be potential for windblown transport of radionuclides with consequent downwind exposure of people or animals through the air pathway. Show through modeling the risk from ingestion or inhalation of eroded soil that might occur to a receptor, such as an inadvertent intruder who builds a residence on site at some point in the future.

**ENERGY*SOLUTIONS*' RESPONSE:** HAL (2011) and Appendix D justify the adequacy in erosion resistance of the evapotranspirative cover designs evaluated.

**4.9** **INTERROGATORY STATEMENT(S):** On Page 3-2, the PA claims, "*After closure of the embankment, all waste is covered by a cover system designed to protect against erosion and losses of integrity due to waste settlement.*" Please revise the above statement as the DRC finds that, based on available evidence, adequate protection against erosion of proposed cover-system soils has not yet been demonstrated in the PA.

**ENERGY*SOLUTIONS'* RESPONSE:** The analyses justified in Appendix C demonstrates that no revision is needed to the statement in question from the Performance Assessment, because an abundance of evidence indicates that there will be multiple levels of protection against erosion of proposed cover system soils.

Energy*Solutions* recognizes that erosion is a possible threat to the long-term stability of the evapotranspirative cover. Both evapotranspirative cover designs are comprised of native silt and clay soil layers that, if left unaltered and exposed, would be highly susceptible to erosion. As discussed in the response for Division Interrogatory 4.1, functioning native ecosystems comprised of the borrow soils at the Clive site do not show evidence of significant erosion as the Division suggests. SWCA (2012) finds no evidence of erosion induced by precipitation events or flooding on undisturbed soils at the Clive site, and soil-surface patterns indicated that long-term aeolian processes are the primary erosional force. In the short-term, the surface of a soil-based evapotranspirative cover system will be highly susceptible to wind and water erosion and must be stabilized. Installation of the proposed evapotranspirative cover design will include reclamation measures to quickly stabilize soils and initiate the development of a functioning native vegetation community. Over the long-term, the top and sides of the cover system will be stabilized by biological soil crust organisms and native vegetation.

**4.10 INTERROGATORY STATEMENT(S):** Page 53 says that the model uses the rainfall and runoff factor of 0.01, whereas the default value in RESRAD-OFFSITE is 160. The rainfall and runoff factor is said to be "*set to 0.01 to produce a negligible erosion rate.*"

Existing evidence of serious erosion potential on site refutes the concept that the model should have rainfall and runoff factors "set to 0.01 to produce a negligible erosion rate." Please develop and support by documented evidence an appropriate design for a cover system for the Class A West embankment that protects against erosion while still enhancing evaporation and transpiration. Please also make relevant and appropriate changes in the model and the PA text. Alternatively, provide justification for the existing plans.

**ENERGY*SOLUTIONS'* RESPONSE:** RESRAD-OFFSITE is not used or intended to be used to evaluate the potential for erosion. As is presented in Response 4.10 of Appendix F, the PA makes adjustments to the RESRAD-OFFSITE allowed inputs to mimic the HYDRUS model results. The purpose of this part of the modeling is purely to mimic the HYDRUS modeling. For example, the runoff factor is adjusted to match the RESRAD-OFFSITE infiltration rates to the HYDRUS results and does not represent actual model conditions or expected runoff fractions.

## 5.0 BIOINTRUSION BY MAMMALS

5.1 **INTERROGATORY STATEMENT(S):** On Page 2-5, it says that, during a biological survey, there were "83 deer mice and one kangaroo rat trapped" at the Clive disposal facility site. Please remedy the cover design to prevent or minimize biointrusion by kangaroo rats and deer mice.

**ENERGY*SOLUTIONS*' RESPONSE:** The analyses described in Appendix C demonstrates that the proposed design contains multiple structural and compositional features that have been demonstrated to limit or prevent biointrusion: 1) 18-30 inches (46-75 cm) of surface soils where most biointrusion would occur; 2) a biointrusion barrier consisting of 18 in (46 cm) of cobble filled with gravel and fines; 3) capillary breaks at the top of the frost protection zone (12-24 in (30-60 cm]) and filter zone (30-42 in [60-107 cm]); and 4) three compacted clay layers.

As suggested by the Division, the preferred cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively prevent biointrusion by small mammals. The primary biointrusion barrier proposed by Energy*Solutions* is the frost-protection zone, which consists of18 in (46 cm) of gravel and cobble mixture in-filled with small gravel, sand, and other fines (cobble and gravel to 16 inches [40.6 cm] diameter), which will also produce a capillary effect that will hold moisture is upper soil layers.

Based on the specifications given in the literature and designs currently in use in similar environments for evapotranspirative cover systems, these layers provide multiple biointrusion barriers. The preferred evapotranspirative cover design contains a biointrusion barrier that comprises the frost protection zone. The frost protection layer outlined in Energy*Solutions'* Performance Assessment consists of fines with particles to 16 in (41 cm) diameter, or bank run material. This mixture of large cobble (10-16 in [25-41 cm]), medium (1-10 in [2.5-25 cm]), and fine (<10 in [<2.5 cm]) materials will function to prevent biointrusion by 1) densely-packed cobble that is large enough that it cannot be moved by small animals; 2) pore sizes that cannot be circumvented by small animals; and 3) gravel and fines-filled interspaces that are further deterrent to small burrowing animals . The bank run material provides a barrier of cobbles much larger than the prey species (mice, kangaroo rats, and ground squirrels) with pore sizes between the cobbles that are too small these species to penetrate or inhabit or that are filled with gravel and fines that have been demonstrated to be unattractive to burrowing animals. This small mammal biointrusion barrier limits badger foraging to the uppermost 30 in (77 cm) of the ET cover. The evidence supporting this ET cover design includes effective biointrusion barriers at operational ET covers and demonstration sites, small mammal biology, and data from field studies at the Clive site.

5.2 **INTERROGATORY STATEMENT(S):** Also on Page 2-5, it says that, during the biological survey, burrows of badgers were observed at the Clive disposal facility site. This is in addition to the siting of multiple badgers on site (SWCA, 2012). Please remedy the cover design to prevent or minimize biointrusion by badgers.

**ENERGY*SOLUTIONS'* RESPONSE:** The analyses described in Appendix D demonstrates that Energy*Solutions* has incorporated design elements in the proposed evapotranspirative cover system that have been demonstrated elsewhere to be sufficient to prevent significant release of contaminants by burrowing animals. Although badgers are capable of burrowing to depths over 6.5 ft (2 m), this behavior is restricted to pursuit of prey. Therefore, preventing biointrusion by prey species is a key design element for the proposed evapotranspirative cover system. In order to prevent badger foraging at depth, the cover design incorporates multiple elements that restrict small mammal burrowing below the evaporative soil layers (see the response to Interrogatory 5.1 for additional discussion of small mammal biointrusion barriers in the evapotranspirative cover design).

The preferred evapotranspirative cover design contains a biointrusion barrier as part of the frost protection zone. This large cobble small mammal biointrusion barrier limits badger foraging to the uppermost 12-24 in (30-60 cm) of the evapotranspirative cover. The evidence supporting the evapotranspirative cover design includes effective biointrusion barriers at operational evapotranspirative covers and demonstration sites, reviews of badger and prey species biology, and data from field studies at the Clive site. Supporting evidence of biointrusion barrier designs from operational and demonstration evapotranspirative cover system is summarized under Division Interrogatory Response 5.1.

5.3 **INTERROGATORY STATEMENT(S):** In addition to badgers, kangaroo rates and deer mice, it is said on Page 2-5 that ground squirrels were observed during field studies at the Clive facility site. Please provide an appropriate design to defend against biointrusion by ground squirrels.

**ENERGY*SOLUTIONS'* RESPONSE:** Responses to Division Interrogatories 5.1 and 5.2, in addition to the analyses described in Appendix C, demonstrate that the same biointrusion barrier effectiveness rationale presented in the Division Interrogatory 5.1 response also applies to ground squirrels. The cobble sizes and interspaces also apply to exclusion of the larger body sizes of ground squirrels compared to deer mice and kangaroo rats.

5.4 **INTERROGATORY STATEMENT(S):** While badgers, ground squirrels, kangaroo rats, and deer mice are mentioned in the PA as burrowing mammals that live on or near the site, coyotes are not mentioned in the PA. Please provide an appropriate design to defend against biointrusion by coyotes.

**ENERGY*SOLUTIONS'* RESPONSE:** Responses to Division Interrogatory 5.2, in addition to the analyses described in Appendix D, demonstrate that the same rationale for biointrusion barrier effectiveness that is presented in the Division Interrogatory 5.2 response also applies to coyotes. The preferred evapotranspirative cover design contains a biointrusion barrier as part of the frost-protection zone. This large, cobble, small mammal biointrusion barrier limits coyote foraging to the uppermost 12-24 in (30 - 60 cm) of the evapotranspirative cover. The evidence supporting the evapotranspirative cover design includes effective biointrusion barriers at operational evapotranspirative covers and demonstration sites, as well as reviews of burrowing mammal biology. Supporting evidence of biointrusion barrier designs from operational and demonstration evapotranspirative cover system is summarized under Division Interrogatory Response 5.1.

5.5 **INTERROGATORY STATEMENT(S):** Not mentioned in the PA in this section describing burrowing animals on site are kit foxes. Kit foxes should be mentioned here. Please do so.

**ENERGY*SOLUTIONS'* RESPONSE:** Responses to Division Interrogatory 5.2, in addition to the analyses described in Appendix D, demonstrate that the same rationale for biointrusion barrier effectiveness that is presented in the Division Interrogatory 5.2 response also applies to kit foxes. The preferred evapotranspirative cover design contains a biointrusion barrier as part of the frost protection zone. This large cobble small mammal biointrusion barrier limits kit fox foraging to the uppermost 12-24 in (30.5-61 cm) of the evapotranspirative cover. The evidence supporting the evapotranspirative cover design includes effective biointrusion barriers at operational evapotranspirative covers and demonstration sites and reviews of burrowing mammal biology. Supporting evidence of biointrusion barrier designs from the operational and demonstration evapotranspirative cover system is summarized under Division Interrogatory Response 5.1.

5.6 **INTERROGATORY STATEMENT(S):** Page 2-5 contains the following paragraph:

> "*Although a vegetation community of sufficient diversity and density is desired to maximize transpiration from the soil, vegetation density was positively correlated with small mammal and burrowing activity. As such, bioturbation should be expected to increase with increasing vegetation. Furthermore, the presence of badgers and a large family of burrowing owls indicates that the biota can potentially move large volumes of soil. Because of this, the bank-run borrow material layer has been included in both of the evapotranspirative cover designs as a bio-intrusion and bioturbation barrier (also serving to minimize the penetration by ants through the cover layers).*"

The DRC finds that the bank-run borrow material layer included in the proposed design is not likely to minimize biointrusion. The DRC accordingly requires a more effective and detailed plan than proposed.

**ENERGY*SOLUTIONS'* RESPONSE:** Responses to Division Interrogatories 5.1 and 5.2, in addition to the analyses described in Appendix D, demonstrate that the preferred cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively minimize or eliminate biointrusion by small mammals. The primary biointrusion barrier is the frost protection zone that will comprise 18 in (46 cm) of gravel and cobble mixture in-filled with small gravel, sand, and other fines, which will also produce a capillary effect that will hold moisture is upper soil layers. The rationale and scientific basis for the biointrusion barrier proposed is detailed in the Division Interrogatory 5.1 response. Detailed description of expected vegetation-animal burrowing interactions under different vegetation densities is described in detail in the Division Interrogatory 5.2 response.

5.7 **INTERROGATORY STATEMENT(S):** Page 2-6 says, "Soil conditions on and near the Clive site are typical of soils formed in arid environments." Please rewrite the text to show that soils on site are not typical of but are, in fact, relatively rare for arid environments.

**ENERGY*SOLUTIONS*' RESPONSE:** The text in Section 2.1.11 has been revised, as directed.

5.8 **INTERROGATORY STATEMENT(S):** Page 3-4 says, "*The site-specific Performance Assessment developed in support of the disposal of depleted uranium evaluated the impact of ant burrowing on the transport of contaminant and found no significant associated impact to the performance of the Embankment.*" That study and its conclusions are not found to be relevant to this PA. Please revise this PA to provide analysis of potential significant impact on embankment performance and effects on human health and the environment due to harvester ants burrowing through cover-system soils.

**ENERGY*SOLUTIONS*' RESPONSE:** As is reflected in the analyses described in Appendix C, designs similar to the evapotranspirative cover designs have been demonstrated to be effective in excluding ants. In addition to the proposed biointrusion barrier, the overlying soil layers are sufficiently deep to allow for ant activity and soil displacement without compromising underlying layers. While Energy*Solutions* does not expect the biointrusion prevention mechanisms included in the cover design to eliminate all biointrusion into lower soil layers or the frost protection zone over the long term, these measures will minimize any biointrusion to an insignificant level. Furthermore, projection of the total proportion of soil potentially excavated by harvesting ants demonstrates a minute total soil excavation potential associated with average ant nest densities on the proposed evapotranspirative cover.

5.9 **INTERROGATORY STATEMENT(S):** After mention of ants, it says on Page 3-4, "*other burrowing animals at the site include jackrabbits, mice, and foxes.*" Please make this listing of burrowing animals at the site more complete by adding to the list kangaroo rats, ground squirrels, badgers and coyotes.

**ENERGY*SOLUTIONS*' RESPONSE:** As directed, Section 3.1.6 has been revised to include kangaroo rats, ground squirrels, badgers and coyotes, and any additional fossorial mammals with potential to occur on or near the Clive site.

5.10 **INTERROGATORY STATEMENT(S):** Page 3-4 refers to "other burrowing animals at the site" and lists among them "jackrabbits". Jackrabbits do not burrow, per se. Please correct the quoted statement.

**ENERGY*SOLUTIONS*' RESPONSE:** The text in Section 3.1.6 has been revised, as directed.

5.11 **INTERROGATORY STATEMENT(S):** On Page 3-4, it states, "*The first deterrent to burrowing animals is the rock armor rip-rap erosion barrier and evapotranspirative bioturbation* *barrier.*" Why is a barrier made of rip rap material mentioned in connection with deterrence of burrowing when preferred cover system designs discussed in the PA do not use rip rap? Also, what is meant by "evapotranspirative bioturbation barrier" which supposedly is a component of the first deterrent to burrowing animals? Also, please revise the language here to clarify statements made and to be consistent with peer-reviewed literature references. Please correct technical errors. Alternatively, please justify the statement quoted as is.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 3.1.6 has been clarified.

5.12 **INTERROGATORY STATEMENT(S):** On Page 3-4, the following is stated, with reference to the "rock armor rip-rap erosion barrier" (which does not exist in the proposed preferred design 1 and design 2 designs), and "evapotranspirative bioturbation barrier" (which, as proposed in the design, would be nearly useless against burrowing by many species of mammals): "While these may be only partially effective in deterring animals, the primary protective barrier is the clay radon barrier. The burrowing species at the site are not known to dig to such a depth that their burrows could penetrate through the entire cover and into the waste." Please revise the text description and incorporate into it the modeling effects of damages to the proposed cover system from burrowing into the proposed cover system soils and the underlying waste, and design the cover system to prevent or minimize biointrusion. In models, use conservative assumptions based on professional literature findings when considering potential effects of burrowing.

**ENERGY*SOLUTIONS'* RESPONSE:** As is described in Appendix C, performance impacts of possible cover damage from burrowing is negligible.

5.13 **INTERROGATORY STATEMENT(S):** It says on Page 3-4 "*After final placement of the cover, the design features of the facility, primarily the thick soil cover that isolates the waste from burrowing animals, will control releases and doses. Because of this, the likelihood of any animals burrowing through the entire cover and exhuming waste materials is sufficiently low that it was not included in the safety assessment calculations.*" The Licensee needs to recognize the potential problem here. The statement that "the likelihood of any animals burrowing through the entire cover and exhuming waste materials is" sufficiently low that the Licensee need not regard it in safety assessment calculations appears to be egregiously in error. The Licensee needs to develop in both its design and its modeling efforts effective measures to understand and prevent or minimize mammalian biointrusion into the radon barrier and waste. Any modeling that assumes no changes in cover-system soil hydraulic conductivity, such as that resulting from biointrusion and other processes, is unacceptable to the DRC. The Licensee must consider biointrusion through the cover and into the waste in its safety assessment calculations.

**ENERGY*SOLUTIONS'* RESPONSE:** Responses to Division Interrogatories 5.1 and 5.2, in addition to the analyses described in Appendix C, demonstrate that the preferred evapotranspirative cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively minimize or eliminate biointrusion by small mammals. The primary biointrusion barrier is the frost protection zone that will comprise 18 in

(46 cm) of gravel and cobble mixture in-filled with small gravel, sand, and other fines, which will also produce a capillary effect that will hold moisture is upper soil layers. The rationale and scientific basis for the biointrusion barrier proposed is detailed in the Division Interrogatory 5.1 response. Detailed description of expected vegetation-animal burrowing interactions under different vegetation densities is described in detail in the Division Interrogatory 5.2 response

5.14 **INTERROGATORY STATEMENT(S):** On page 3-7, it says, with respect to the current operational period, "Burrowing animals are prevented from contacting the waste materials." Please explain how this is currently being accomplished.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 3.3 has been revised to remove the statement.

## 6.0 PLANT COVER, MODEL PLANT PARAMETERS AND BIOINTRUSION BY PLANT ROOTS

6.1 **INTERROGATORY STATEMENT(S):** It is said on Page 2-5 "*The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses.*" The DRC requests the Licensee to specify whether they will attempt to plant flora on the engineered embankment as part of the proposed ET cover. If so, then the Licensee must describe the suitability of plants used, and the suitability of the soil properties and soil thickness for growing them. Also, if plants intended for planting (if that is to be done) have successfully been introduced during reclamation into other environments similar to the one at Clive, please describe and document this as well.

**ENERGY*SOLUTIONS'* RESPONSE:** As is reflected in the analysis in Appendix C, the vegetation communities that occur on and near Clive, and the shrub, forb, and grass species that comprise them were documented during 2010 and 2012 field studies (SWCA 2010, 2012). Inter-Mountain Basins Mixed Salt Desert Scrub is the dominant vegetation cover type on analogs to the Clive site. The target vegetation community on the evapotranspirative cover consists of approximately 15% cover of small stature native shrub species (Atriplex confertifolia, Atriplex canescens, Bassia americana, Picrothamnus desertorum, and Suaeda torreyana), with additional cover provided by sparse native forbs and grasses (see Attachment A of Appendix D for more detailed discussion of the proposed vegetation composition for the ET cover). Locally adapted plant materials will be used to the extent possible. Greasewood will not be included in the target community due to its deep rooting habit, the affinity of badgers for larger stature shrub species, and the demonstrated affinity of small mammals for higher shrub densities (see the Division Interrogatory 6.3 response for detailed discussion of greasewood potential on the ET cover).

The target vegetation community for the evapotranspirative cover is based on documented species cover and densities as well as plant materials adapted to local climate and soil conditions. Native plant species diversity at the site is low. The native plant species that occur at Clive are well-adapted to the saline, high pH, low-fertility soil conditions, and low average annual precipitation of less than 10 inches (25 cm). Plant species on and near Clive occur in silty clay soils that possess a naturally occurring compacted clay layer at approximately 24 in (60 cm) depth. As such, the native shrub species are not found to root deeply, and appear able to take advantage of moisture perched above the compacted clay by extending root growth laterally instead of into the clay.

The shrub species that dominate the vegetation at the site are small in stature compared to their conspecifics in deeper, more fertile soils, and areas with greater average annual precipitation. The site's unique soil conditions and aridity are considered in the vegetation plan because it is unlikely that shrubs will achieve the sizes or rooting depths demonstrated in environments elsewhere. At Clive, large individuals of the species had roots an average of 8-16 in (20–40 cm) and a maximum of 28 in (70 cm) long. This shallow growth habit is likely due to the compacted clay layer at approximately 24 in (60-cm) depth.

6.2 **INTERROGATORY STATEMENT(S):** It is said on Page 2-5 "The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses." Please provide an appropriate biointrusion defense design for the cover system effective against deep plant rooting, or account in modeling for increases over time in infiltration rates.

**ENERGY*SOLUTIONS'* RESPONSE:** As is described in the analysis of Appendix C, the preferred evapotranspirative cover design composed of a thin covering of gravel mulch, 15 cm of soil/gravel mixture, 18 in (46 cm) of soil, 18 in (46 cm) of cobble-fines, 6-18 in (15–46 cm) of coarse sand and gravel, and 24 in (61 cm) of compacted clay above a 12 in (30-cm) temporary clay cover. Based on the specifications given in the literature and designs currently in use for evapotranspirative cover systems, these layers provide multiple biointrusion barriers (see the Division Interrogatory 5.1 and 5.2 responses).

The preferred evapotranspirative cover design contains a biointrusion barrier as part of the frost protection zone. The frost protection layer outlined in EnergySolutions' Performance Assessment consists of fines with cobbles to 16 in (41 cm) diameter. The primary biointrusion barrier is the frost protection zone, which comprises 10 to 16–inch (25 - 41 cm) cobble in-filled with gravels and fines. This material also will produce a capillary effect. The biointrusion barrier overlies a 6-18 inch (15–46 cm) -deep filter zone that will also act as a capillary break. Any root penetration into the filter zone will likely consist of lateral root growth that will follow any available water and not penetrate the radon barriers. As such, root growth will be concentrated in the uppermost 77 cm of the evapotranspirative cover, with some root penetration into the frost zone.

The presence of a capillary break at 36-60 in (91 -152 cm) depth was cited as an effective deterrent to plant biointrusion by the Division. The cover design contains multiple layers that will act as capillary breaks, including the dense cobble layer in the frost protection zone (30-42 in [60-107 cm]) and the filter zone (36-60 in [91-152 cm]). Provided that these capillary breaks are effective at holding moisture in upper soil layers, which is to be expected with actively growing vegetation and low average annual precipitation, the break should limit any root growth into the filter zone and radon barriers. The coarse sand and gravel mixture in the filter zone is expected to remain dry except for high precipitation or snowmelt events when infiltration is greatest.

The actively growing vegetation on the cover surface is an important design component. Transpiration from plants and movement of water from lower to upper soil layers by plant roots enhance the functioning of the evapotranspirative cover system. Some areas of dense plant roots in the soil layers are desirable because they enhance movement of any water stored in deeper soils, or in the interspaces of the frost protection zone.

6.3 **INTERROGATORY STATEMENT(S):** It is said on Page 2-5 "*The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses*." The Licensee needs to account for the potential for greasewood, a native, salt-tolerant shrub presently growing on site, to grow roots to depths much deeper than the proposed thickness of the entire cover system. This has obvious implications for biointrusion into the radon barriers and waste and also speaks to an onsite need for effective plant-root biointrusion barriers. Please address these.

The PA, on Page 2-6, also says, "*A few large, woody roots were encountered in deeper soils. Rooting depths were shallower than expected, with the maximum rooting depth of dominant woody plant species ranging from 16 to 28 inches.*" The Licensee needs to acknowledge that potential exists at site locations other than those excavated for black greasewood to root more deeply than 0.4 to 0.7 meters (16 to 28 inches), perhaps even down to depths of 3 to 9 meters (10 to 30 feet), and adjust modeling concepts and parameters accordingly.

**ENERGY*SOLUTIONS'* RESPONSE:** As is illustrated in the assessment in Appendix C, observations at the Clive site and ecological analogues demonstrate that the low fertility, alkalinity, and aridity of local soils limit plant growth and prevent the development of large, deep rooted plants. Use of local soil materials in the evaporative cover will elicit the same response from native plant materials. In addition, water storage in upper soil layers, and capillary breaks at the frost protection zone and filter zone have been demonstrated to effectively deter or limit penetration by deep rooting plants into protective layers.

Over the long term (> 5 years), it is to be expected that greasewood will become established on the evapotranspirative cover. However, greasewood roots follow available water, which will be limited to upper storage layers, and any infiltration to the depth of barrier layers will be directed laterally across the filter zone. Because the water table levels below the evapotranspirative cover are at depths beyond the maximum levels accessible by greasewood (> 33 ft [10 m]) and the functioning evapotranspirative cover will prevent water infiltration below the depth of the filter zone (0.9-1.5 m), root penetration to the water table is not possible.

It is highly unlikely that greasewood can root to these depths at Clive. Deep rooting by greasewood and other shrub species is limited or absent at Clive because there is little or no capillary rise between the deep water table and upper soil layers. Extremely deep rooting by greasewood only occurs when precipitation infiltrates to groundwater, because greasewood roots cannot penetrate the very dry soil that occurs below the zone of infiltration. The greasewood has a root-to-shoot ratio of 1.0 to 1.5, which translates to a root biomass that is approximately 66% of aboveground plant volume. It is unlikely that any greasewood plants on or near the Clive site are of sufficient stature to root deeply (> 3m). Greasewood root density decreases exponentially with soil depth, whereby the majority of root biomass will be concentrated in upper soil layers regardless of plant stature. Nutrients tend to be concentrated in upper soil horizons and decrease with depth in desert soils, with declining efficiency of growth investment to nutrient return in soils with low nitrogen content.

The exclusion of deep roots from below the filter zone is discussed in the Division's Interrogatory 6.2 response. As stated above, the presence of a capillary break at 36-60 in (91 to 152 cm) is cited as an effective deterrent to plant biointrusion by the Division. The cover design contains multiple layers that act as capillary breaks, including the dense cobble layer in the frost protection zone and the filter zone. Provided that these capillary breaks are effective at holding moisture in upper soil layers, which is to be expected with actively growing vegetation and low average annual precipitation, the break will limit any root growth into the filter zone and radon barriers. The coarse sand and gravel mixture in the filter zone is expected to remain dry except for high-precipitation or snowmelt events when infiltration is greatest.

**6.4 INTERROGATORY STATEMENT(S):** On Page 2-5, it says, "*The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses.*" Please revise proposed plans accordingly to include only native plants, or justify inclusion of non-native species. If non-native species are included, then the licensee must provide the percent coverage of "desirable" non-native plants and their names to allow the DRC to assess vegetative cover design performance.

**ENERGY*SOLUTIONS*' RESPONSE:** As is illustrated in the assessment in Appendix C, the target vegetation community on the evapotranspirative cover consists of approximately 15% cover of small stature native shrub species (see Attachment A pf revision 0 and Appendix C of revision 1), with additional cover provided by sparse native forbs and grasses. Locally adapted plant materials will be used to the extent possible. There are differences in plant species composition and cover at different locations on and near the Clive site that were considered for the target vegetation community and long-term biointrusion potential. Native vegetation on the soils that occur at the site is limited to shadscale saltbush, fourwing saltbush, gray molly, greasewood, and perennial grasses such as squirreltail (Elymus elymoides), Indian ricegrass (Achnatherum hymenoides), and Sandberg bluegrass (Poa secunda).

Locally-adapted plant materials will be required to create a functioning vegetation community on the evapotranspirative cover. As stated in the Division's Interrogatory 6.1 response, the target vegetation community on the evapotranspirative cover consists of approximately 15% cover of small stature native shrub species (Atriplex confertifolia, Atriplex canescens, Bassia americana, Picrothamnus desertorum, and Suaeda torreyana), with additional cover provided by sparse native forbs and grasses. Although several of these shrub species have been documented to root very deeply along waterways or under wetter climatic conditions elsewhere, the soil and climate conditions on and near the Clive site clearly limit the sizes and densities of native shrubs. This pattern is demonstrated by the very low shrub densities that consistently occur on and near Clive. Native shrub species targeted for use on the evapotranspirative cover occur at 0.1% to 3.9% average cover, and one to 16 stems per square meter. Greasewood, where it occurs, has much higher average cover of 11.5% to 19.0%. Greasewood will not be included in the target community due to its deep rooting habit, the affinity of badgers for larger stature shrub species, and the demonstrated affinity of small mammals for higher shrub densities. See the Division Interrogatory 5.2 response for additional discussion of greasewood potential on the ET cover.

The target vegetation community for the cover is based on documented species cover and densities as well as plant materials adapted to local climate and soil conditions. Native plant species diversity at the site is low, with a total of less than 20 plant species documented in the study sites. The native plant species that occur at Clive are well-adapted to the saline, high pH, and low-fertility soil conditions and low average annual precipitation of less than 10 in (25 cm). Plant species on and near Clive occur in silty clay soils that possess a naturally occurring compacted clay layer at approximately 24 in (60 cm) depth. As such, the native shrub species are not found to root deeply and appear to be able to take advantage of moisture perched above the compacted clay by extending root growth laterally instead of into the clay.

The only non-native plant materials that will be included in the vegetation plan are non-invasive, fast-growing grasses used for initial soil stabilization (Quick Guard sterile Triticale; see Table A-1 in Attachment A of Appendix C). These grasses will be seeded in the fall or early winter to provide cover to stabilize soils and enhance soil development and biological soil crust cover. The sterile rye (Quick Guard sterile Triticale) will not persist beyond the first 1-2 years of vegetation cover development. Only approved reclamation materials from reputable seed suppliers will be used.

There are several invasive plant species that occur in the area: cheatgrass (Bromus tectorum), halogeton (Halogeton glomeratus), and kochia (Bassia species). These species will be targeted by weed-control efforts, particularly during the first 1 to 2 years of vegetation development to allow native species to dominate the cover system (see Weed Management Section in Attachment A of Appendix D).

**6.5** **INTERROGATORY STATEMENT(S):** On Page 3-3, the PA claims, "*The plant uptake pathway is not a viable exposure pathway at the embankment because of natural site characteristics and design features of the embankment. Exposure by the plant uptake pathway could occur by (1) the production of food crops in contaminated soil at the site, and (2) root intrusion into the waste by native plants that are subsequently consumed by humans or animals.*"

Please either justify the statement that "the plant uptake pathway is not a viable exposure pathway at the embankment" or else revise this section of the PA to take into account information about potential plant uptake of radionuclides from greasewood or other phreatophytes on site, as presented previously and below. If the latter course is selected, then please provide an assessment of possible plant uptake at the site from all potentially deep-rooting plants existing at the site.

**ENERGY*SOLUTIONS*' RESPONSE:** The inapplicability of a plant root uptake pathway in the updated site-specific Performance Assessment is addressed in Appendix C.

**6.6** **INTERROGATORY STATEMENT(S):** Page 3-3 includes this statement: "The candidate thick covers include capillary break, biointrusion, and bioturbation barriers that make the waste less accessible to plant roots after closure of the facility." Please explain how the proposed cover-system design 1 and design 2 include effective biointrusion barriers.

**ENERGY*SOLUTIONS*' RESPONSE:** As is reflected in Appendix C, the design and rationale for the preferred evapotranspirative cover design biointrusion barrier is described under the Division Interrogatory 5.2 response.

**6.7** **INTERROGATORY STATEMENT(S):** The statement is made on Page 3-3 that "the overall scarcity of deep-rooted plant species in the site vicinity and the configuration of the earthen cover will offer an inhospitable environment for extension of these types of roots into the waste." This statement is not correct, since greasewood is relatively prevalent at Clive and it constitutes up to 14% of the plant community there. Please modify the PA text to reflect the facts that greasewood is not scarce on site, and that it can potentially root far more deeply than the top of the waste. Alternatively, justify the text as is. The configuration of the proposed cover seems to have little to do with whether greasewood roots can penetrate the waste, although the DRC is willing to consider an explanation.

**ENERGY*SOLUTIONS*' RESPONSE:** See the discussion of the preferred evapotranspirative cover design biointrusion barrier under the Division Interrogatory 5.2 response, and the discussion of greasewood potential on the preferred evapotranspirative cover design under the Division Interrogatory 5.2 and 6.3 responses.

**6.8** **INTERROGATORY STATEMENT(S):** Page 19 of Neptune and Company, Inc. (2012) says, "Parameters for describing root water uptake were available from vegetation surveys at the site."

Please specify exactly which parameters were used and which values were obtained for these parameters, along with specific reference information.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 6.8 of Appendix F, the root water parameters including references are described in Section 5.3.2 of Appendix B of revision 0 of this updated Site-Specific Performance Assessment and the values used in the model are provided there.

**6.9** **INTERROGATORY STATEMENT(S):** Page 29 of Neptune and Company, Inc. (2012) speaks of "site characteristics influencing movement of water from precipitation through the vadose zone to the water table at the Clive site" and mentions one as "native vegetation." Please clarify whether proposed plans are to plant or transplant either native or non-native shrubs and grasses, or do proposed plans only envision establishment of native plants through natural succession? If a proposal is made to plant, please indicate the percent coverage intended.

**ENERGY*SOLUTIONS'* RESPONSE:** As stated in the Division Interrogatory 6.1 response, the target vegetation community on the evapotranspirative cover consists of approximately 15% cover of small stature native shrub species (Atriplex confertifolia, Atriplex canescens, Bassia americana, Picrothamnus desertorum, and Suaeda torreyana), with additional cover provided by sparse native forbs and grasses (see Attachment A of Appendix D for more detailed discussion of the proposed vegetation composition for the evapotranspirative cover). Locally sourced seed and/or seedlings will be used to the extent feasible.

As is presented in Response 6.9 of Appendix F, the cited text is in Section 5.1 of Appendix B of revision 0 of the update Site-Specific Performance Assessment. The quoted section of the report is a general discussion of the conceptual model of the hydrology of the site, not a specific description of the cover revegetation plans.

**6.10** **INTERROGATORY STATEMENT(S):** Page 29 of Neptune and Company, Inc. (2012) speaks of "site characteristics influencing movement of water from precipitation through the vadose zone to the water table at the Clive site" and mentions one as "native vegetation." Please clarify whether proposed plans are to plant or transplant either native or non-native shrubs and grasses, or do proposed plans only envision establishment of native plants through natural succession?

Assuming that the cover system will undergo natural succession with growth of native plants, the DRC requires plans and surety for the following:

1- Development of design criteria and submission of them to the DRC for approval in a revised PA detailing plans for (1) minimum percent vegetative cover, (2) plant species diversity, and (3) maximum allowable spatial density of any potentially deep-rooting plants, such as black greasewood or fourwing saltbush;
2- Development and costing out mitigative measures that would need to be taken in the event that plant cover growth does not meet each of the design criteria in the above

paragraph during various intervals of the 100-year institutional control period as described below;

3- Natural succession needs to be monitored during an initial five-year interval, another five-year interval immediately following the first interval, a 10-year interval following that, and four subsequent twenty-year intervals collectively constituting the 100-year institutional control period;

4- At the end of each interval, a report will be needed on progress of plant and plant community growth and succession to ensure that they meet the criteria described in the design specification;

5- If not, then the planned mitigative measures must be taken to establish individual plants and plant communities so as to meet the criteria described above over the remainder of the institutional control period.

**ENERGY*SOLUTIONS'* RESPONSE:** Plant development and succession is addressed in Appendix C.

**6.11 INTERROGATORY STATEMENT(S):** Table 3 of the Neptune and Company, Inc. (2012) report shows mean values for black greasewood, Sandberg bluegrass, shadscale saltbush, and gray molly on SWCA vegetation survey plots on site to be 8.5%, 0.7%, 3.7%, and 1.5%, respectively.

Please fix, note and comment on, or justify all discrepancies associated with this and like statements in the PA. Part of the information about species is missing from the statement above, as discussed below. Please add it.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 6.11 of Appendix F, the Neptune and Company model (Appendix B of revision 0 of this updated Site-Specific Performance Assessment ) is based on data collected across five 1-hectare study sites along an elevational gradient from the Clive site to the lower benches of the Cedar Mountains. The objective of the Neptune study, conducted in 2010, is to provide supporting information for long-term vegetation trajectories over geologic time periods. However, the SWCA 2012 plant species cover estimates were based on data collected in seven 1/10th-hectare ecological analogs to the conditions on the Clive site. The average species cover and densities are not the same as the vegetation data collected during the Neptune (2010) study reported in 2012, because of the SWCA (2012) focus on salt desert scrub vegetation on the Clive site and ecological analogues to the conditions on the Clive site.

**6.12 INTERROGATORY STATEMENT(S):** On Page 36 of Neptune and Company, Inc. (2012), there is mention of two excavations by SWCA Environmental Consultants (2011) from which data for Figure 11 rooting depths for shadscale and greasewood were obtained. Roots are claimed to only extend down to about 0.8 meters (2.6 feet) of depth. Elsewhere (SWCA, 2011), it is said that roots extend only to about 0.4 to 0.7 meters (1.3 to 2.3 feet) of depth, depending on location of excavation.

The DRC requests the Licensee provide a synopsis of research findings for greasewood rooting depths at other sites and compare the data to that found in these two excavations. Please provide an explanation for the anomalous on-site data, reconcile discrepancies, and assess the likelihood that the data from the limited number of excavations represents all land locally owned or leased by licensee, i.e., the entire site and surrounding area. Provide support or justification for all assumptions and claims.

The DRC specifically requests the Licensee discuss rooting depths for greasewood at the site in the context of (1) the shallow rooting of greasewood noted at a few locations at Clive does not necessary mean that rooting will be shallow at all locations at Clive, (2) greasewood is an obligate phreatophyte, with roots that almost always go down to within a short distance of the water table, and rooting depths for greasewood are noted at other sites to be as deep as 10 meters (33 feet) or more, (3) roots for greasewood at the site tend to terminate at or about at a thin, highly compressed layer noted to be present at an average depth of approximately 60 centimeters (2.0 feet) in several excavations, (4) thin, highly compressed layer will no longer exist locally once soil is mined for cover systems, (5) according to a recent NRC document (Benson et al., 2011), low-permeability cover-system soil over time is likely to experience greatly increased hydraulic conductivity due to multiple potential causes, which may include plant root intrusion, and (6) in the absence of a perched aquifer or other biological barrier, greasewood roots growing down to typical depths reported in the literature could potentially extend down through the radon barrier, through the waste, and into the capillary fringe, or water table, which may be present at a substantial depth.

The DRC requests that the Licensee consider in modeling work that biointrusion by greasewood (1) may damage the cover system soils and increase their effective hydraulic conductivity values, (2) this could dramatically increase drainage of infiltrated water, (3) this could potentially increase radon emanations through the cover, and (4) biointrusion of greasewood roots into waste may also allow for the conveyance of contaminated water up through roots and then through stems and leaves of greasewood, resulting in transport of radionuclides to the surface.

The leaves may be eaten by foraging animals, such as cattle or sheep. Some of the animals may then be eaten by humans. This source of risk needs to be addressed fully in risk assessment and in the context of inadvertent intruder analysis.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 6.12 of Appendix F, the greasewood has the potential to root at depths well below the depths of soil layers, the frost protection zone, and the filter zone in the proposed evapotranspirative cover system. Deep rooting by greasewood is not observed on-site due to the presence of a naturally occurring compacted clay layer at approximately 24 in (60 cm) depth on the Clive site. As cited by the Division, precipitation likely perches above the compacted clay and causes plant roots to grow laterally along the top of the layer. The root excavations in 2010 comprised two pits adjacent to large greasewood plants. Although this is a limited sample of rooting depths, the aboveground mass of greasewood on and near the site was represented in the two excavations performed. The aboveground mass of greasewood plants on and near Clive is consistent with low water availability. Because greasewood taproots typically penetrate to the capillary fringe overlying the water table, roots are expected to follow water availability and not penetrate compacted layers.

See the discussion of the preferred evapotranspirative cover design biointrusion barrier under the Division Interrogatory 5.2 response, and the discussion of greasewood potential on the preferred evapotranspirative cover design under the Division Interrogatory 5.2 and 6.3 responses.

6.13 **INTERROGATORY STATEMENT(S):** It states on Page 36 of Neptune and Company, Inc. (2012) that "root density was modeled as decreasing linearly with depth" and that maximum depth was 80 centimeters (0.80 meters, or 2.6 feet)).

Please explain, justify or fix the function characterizing root density as a function of depth.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 6.13 of Appendix F, the root density data acquired by SWCA (2011) show a distribution with generally higher root density near the surface decreasing with depth. As noted by DRC, this was represented in the HYDRUS model as a linear function with root density decreasing with depth. Changing the root density function has very little effect on model results. Water loss from the cover system is dominated by soil evaporation.

6.14 **INTERROGATORY STATEMENT(S):** Figure 11 of Neptune and Company, Inc. (2012) is entitled "Root Density with Depth." The abscissa axis is labeled "Root Density [roots/cm]."

Please explain, justify or fix root density data. Please explain the significance of the values in Figure 11 [roots/cm] from a physical and biological standpoint. Please explain how the root density values are used in the Hydrus-ID model. Does the input for root density in the Hydrus-ID model match the definition of root density given by SWCA (2011)? Are the units the same? Is the meaning of root density the same? Please document all of this.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 6.14 of Appendix F, the SWCA approach provides a simple way to get relative root densities in a linear cross section at specific depth intervals. The general trend for native species shows the highest root density at the surface and the lowest at the maximum rooting depth. The representation of root density in the HYDRUS models is a simplification of the data. While there was some non-linear variation in the mean values of the data with depth, the general trend in root density was approximated as linear with the highest density at the surface decreasing with depth to zero at the average maximum rooting depth. Sensitivity analyses would be required to determine the influence of this simplification on estimated net infiltration. However, considering that water loss from the cover system is dominated by soil evaporation, any impact of this simplification can be seen to be minor.

**6.15 INTERROGATORY STATEMENT(S):** On Page 37 of Neptune and Company, Inc. (2012), it says, "osmotic stress is assumed to be negligible for these simulations so $h_\varphi$ is zero."

Please justify this assumption, or correct the model, as needed.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 6.15 of Appendix F, the water fluxes in the cover system are overwhelmingly controlled by soil evaporation. Minor reductions of transpiration have little effect on the overall water balance. Given the similarity in ranges of salinity in the surface soils at the Clive Site and for optimum halophyte growth, the influence of the osmotic head reduction in the root-water uptake water stress response function is considered negligible and was, consequently, not included in the model.

## 7.0 TRANSPIRATION

**7.1 INTERROGATORY STATEMENT(S):** In regard to the Page 2-8 statement about the surface layer being "composed of native vegetated Unit 4 material with 15% gravel mixture", the DRC has concerns about plant growth and plant coverage on this layer and the ability of plants to provide as much transpiration as expected in the model. Based on information found in other interrogatories and concerns about the ability for plants to flourish and provide sufficient plant coverage on engineered embankments, as well as the potential for native shrub roots to biointrude past radon barriers and into the waste, the DRC requests that the licensee revisit sections dealing with transpiration and provide support or evidence for its assumed transpiration parameter values.

**ENERGY*SOLUTIONS'* RESPONSE:** As is illustrated in Appendix C, the alternative landfill cover system at the Monticello, Utah, uranium mill tailings disposal site serves as a conservative demonstration site for the Clive evapotranspirative cover system. The Monticello site is the closest ecologically-analogous operational evapotranspirative cover system to Clive, and has similar seasonal precipitation and rainfall patterns and vegetation conditions. However, the Monticello site differs from the Clive site. Monticello receives approximately 50% greater average annual precipitation than Clive (15.4 in). The Monticello cover is comprised of clay-loam to sandy-loam soils that are less alkaline and more fertile than the saline, alkaline silty-clay soils at Clive (Waugh et al. 2008). The native vegetation at Monticello is dominated by big sagebrush shrublands and grasslands that are more diverse and of larger stature – with greater target plant densities and cover for the evapotranspirative cover – than those proposed at at Clive.

The Monticello cover was seeded and planted in fall of 2000 with native vegetation. Monitoring through 2007 indicates that evapotranspiration levels closely tracked precipitation. The same pattern is expected to occur at Clive, regardless of vegetation stature, as the size and densities of shrub and grass species at Clive reflects local soil conditions and water availability. There was no infiltration to the evapotranspirative cover during the first 4 years, and the only infiltration detected was in response to precipitation greater than 250% of normal in 2004-2005. Overall, infiltration at Monticello is 100-1000 times less than conventional cover systems.

As is expected at Clive, plant cover from years 1 to 3 was dominated by invasive annual weeds. The Monticello site was reseeded with native bottlebrush squirreltail (Elymus elymoides) and shrub species in Year 4 to compete with cheatgrass. Initial invasion of newly placed soils by cheatgrass, halogeton, and other annual weeds is anticipated in the Revegetation and management plan (see Attachment A to Appendix C).

The total plant cover on the vegetated cover will be 15% shrubs with additional, more seasonal cover by forbs and grasses. This level of cover is expected to be achieved within 3–5 years of revegetation efforts. The mature cover will be dominated by biological soil crust cover, which will serve to stabilize soils and capture precipitation and hold it close to the soil surface. Low annual precipitation in the area limits water infiltration and storage, which is reflected in local plant communities. The vegetation cover and densities that exist on and near the Clive site reflect the volume of water that is available to be evaporated from the soil surface or transpired by actively growing plants. The vegetation diversity and density proposed for the evapotranspirative cover is to the limit that local soils and climate can support and are thereby adequate to move available water from upper soil layers to the atmosphere.

Because of very low average annual precipitation and the chemistry and fertility levels found in native and borrow soils at the Clive site, the cover is unlikely to support vegetation cover above 15%. Climatic and edaphic limitations on plant sizes and densities were evident in the 2012 field study of ecological analogs to the Clive site. The potential diversity and density of small mammals and their predators are also limited by conditions on and near Clive, and that will occur on the vegetated cover system. Detailed discussed of vegetation and biointrusion potential on the evapotranspirative cover is provide in the Division Interrogatory 5.1 and 5.2 responses.

As discussed in the Division Interrogatory 6.2 and 6.3 responses above, the proposed cover design includes a biointrusion barrier and capillary break, both of which have been demonstrated to be effective at limiting root penetration beyond upper soil layers and in directing any deep root growth to follow the filter zone and not penetrate radon barriers.

7.2 **INTERROGATORY STATEMENT(S):** Page 33 of Neptune and Company, Inc. (2012) says "Where the $a_{bl}$ coefficient accounts for radiation intercepted by vegetation and is given the default value of 0.5 (Varado et al. 2006). Estimates of LAI are not available for the site so $E_p$ and $T_p$ were calculated using the method of SimUnek et al. (2009). This method uses an estimate of vegetated soil cover fraction (SCF) to calculate $E_p$ and $T_p$ as

$$T_p = PET*SCF$$

$$E_p = PET * (I\text{-}SCF)$$

The soil cover fraction was estimated from vegetation surveys conducted in the vicinity of the site."

The Licensee must find another approach to account for $T_p$ and $E_p$. Otherwise, the model will produce non-viable output, not being in harmony with the objectives and requirements found in the rules and regulations listed below.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 7.2 of Appendix F, the use of percent cover obtained from vegetation surveys at the Clive site was used in an initial approach for partitioning potential evapotranspiration (PET) into transpiration and soil evaporation in the absence of other data. However, the results of calculations suggest that adjustments of plant parameters in the HYDRUS model will have little influence on the modeled net infiltration.

7.3 **INTERROGATORY STATEMENT(S):** Page 48 of Neptune and Company, Inc. (2012) discusses use of a soil cover fraction (SCF) of 0.18, which corresponds to a leaf area index (LAI) of 0.4. The claim is made that this value is low relative to literature values.

Please modify the model to use a more appropriate lower value for the SCF and the LAI, and also change the PA text to give an SCF value correlating to an LAI value that is comparable to relevant field-based values for LAI in the Great Basin area, obtained from the literature.

**ENERGY*SOLUTIONS'* RESPONSE:** Leaf surface area is discussed in further detail in Response 7.2 of Appendix F.

7.4 **INTERROGATORY STATEMENT(S):** Page 48 states that "the influence of plant transpiration on the long-term annual net infiltration into the waste was examined by modeling net infiltration for design 1 with a 6 inch thick Evaporative Zone with no root water uptake. The long-term annual net infiltration rate into the waste for the cover system without vegetation is shown in Table 8. A comparison with the results for design 1 with a 6 inch Evaporative Zone thickness shown in Table 5 indicates only a 3.5 percent increase in long-term net infiltration when the cover is not vegetated. The I-D HYDRUS models and the associated input and output files are provided in the attached electronic files."

Research findings indicate that the absence of vegetation generally tends to result in greatly increased rates of infiltration. This is in contrast to results claimed for modeling. Please provide justification for the model results discussed above in light of these apparently conflicting published research findings, or review the model and re-run it with more appropriate parameter values (as discussed elsewhere in these comments) to obtain results consistent with published research findings.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 7.4 of Appendix F, Clive's water balance models show minimal impact of vegetation on net infiltration. These characteristics include nearly six times greater mean annual potential evaporation than mean annual precipitation, cover layers with material properties that tend to hold the water in storage in the near surface where it is available for evaporation, and sparse vegetation. Under these conditions where potential evaporation greatly exceeds precipitation a decrease in actual transpiration by not including root water uptake in the model can be compensated by an increase in actual evaporation.

## 8.0 EVAPORATION

8.1 **INTERROGATORY STATEMENT(S):** On page 2-2, the Licensee discusses "the 17-year average annual evaporation rate at the Clive site", provides a value for it, and mentions that it is based on exclusion of two years of reported instrument malfunction. In the same paragraph, the Licensee states that "Pan evaporation measurements are taken from April through October ..."

However, on Page 10 of the attached Modeling Report, reference is made to pan evaporation measurements having been made at the NOAA station at BYU. The text says, "Mean monthly values of pan evaporation measured at the BYU NOAA station in Provo, Utah over the period 1980 to 2005 are shown in Figure 2. Mean annual pan evaporation over this time period is 49.94 inches. This station is located 83 miles to the southeast of the Clive facility. Data from this station are used because pan evaporation data are not available for the Dugway station."

Please provide clarification regarding the apparent conflict between PA Section 2.1.6, which implies that pan evaporation measurements were taken at the Clive site, and latter references on Page 10 of the attached Modeling Report, which refers to use of pan evaporation measurements made at the NOAA Station at BYU.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 8.1 of Appendix F, the discussion of average annual pan evaporation rates from measurements made at the Clive site and the discussion of average annual pan evaporation rates made by NOAA are descriptions of two datasets included to provide insight into the climate at the site. These discussions are not in conflict. They describe two different data sets.

8.2 **INTERROGATORY STATEMENT(S):** On Page 2-8, Cover Design 2, or Evapotranspiration Cover Design A, is described. A statement is made that indicates that the proposed cover system will assist in releasing water through evaporation from the soil surface. However, there are outstanding issues associated with anticipated erosion of the proposed surface soil if no cobbles are used. On the other hand, if only cobbles were to be used, then it would be expected that evaporation rates would greatly decline. Please take into account the following information and describe how cover-system soils will be selected and used so that evaporation rates will be maintained at high values while erosion is limited to acceptably low values.

**ENERGY*SOLUTIONS'* RESPONSE:** The ability of the alternate evapotranspirative cover designs to withstand erosion is addressed in Appendix E.

8.3 **INTERROGATORY STATEMENT(S):** Page 11 of Neptune and Company, Inc. (2012) says, "Assuming pan evaporation is approximately equal to potential evapotranspiration (PET) the ratio of annual average precipitation to PET is 0.17."

Please recalculate the annual average pan evaporation in a way more consistent with current professional practice. Please use one of several equations developed and available in published sources to account for transfer of energy through the sides and bottom of the pan to re-calculate the estimated ratio between average annual precipitation and PET. Then, recalculate the ratio of annual average precipitation to PET. Alternatively, justify the calculation made in the quote above.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 8.3 of Appendix F, the P/PET ratio is often used as a climate indicator for sites where evaporation and transpiration may be important factors affecting the net infiltration. P/PET ratios are used in the PA discussion to maintain compatibility for comparison with data from other sites. These ratios are used only to provide information for the conceptual site model, they are not used as input to the HYDRUS or RESRAD models.

8.4 **INTERROGATORY STATEMENT(S):** Please fix the apparent misstatement copied below and clarify the message to make it consistent with other discussion in Appendix A. On Page 13 of Neptune and Company, Inc. (2012), it says, "*References in this report to ... evaporative zone depth refer only to the function and characteristics of a layer in the ET cover system designs.*"

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 8.4 of Appendix F, the clarification is noted. The text should read "*If the vertical percolation layer is located within the EZD of a HELP model, evaporation is modeled as an extraction and can only occur until the specified wilting point moisture content has been reached.*"

8.5 **INTERROGATORY STATEMENT(S):** Please provide clarification of apparent inconsistencies between various Licensee consultant reports relative to evaporation and use of rip rap. On one hand, the Whetstone Associates (2011a) document argues at length in its Pages 6 and 7 that significant evaporation would occur from the rip rap surface layer. On the other hand, it says on Page 13 of Neptune and Company, Inc. (2012) that "*the rip rap surface layer inhibits evaporation, so more water is available for infiltration.*"

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 8.5 of Appendix F, the two statements are not contradictory. The presence of a rip rap cover inhibits evaporation over what it would be from a vegetated soil cover. However that does not mean that evaporation is insignificant in the case of the rip rap surface. This conceptual model is supported by the acceptable infiltration-limiting performance of the traditional rip rap cover system as compared with the improved infiltration-limiting performance of an ET cover system.

8.6 **INTERROGATORY STATEMENT(S):** As stated earlier in Chapter 7.0, Transpiration, Page 33 of the Neptune and Company, Inc. (2012) report gives an equation for potential evaporation as

$$E_p = PET * (1\text{-}SCF)$$

This equation is not appropriate for the Clive, Utah site. The Licensee must find another approach to account for $E_p$. Otherwise, the model will produce non-viable output.

**ENERGY*SOLUTIONS*' RESPONSE:** See the response presented for Interrogatories 7.2 and 7.3 of Appendix F.

8.7 **INTERROGATORY STATEMENT(S):** Page 37 of Neptune and Company, Inc. (2012) indicates that "osmotic stress is assumed to be negligible ..."

However, relatively high salinity causes osmotic stress leading to diminished evaporation. Please account for this when calculating infiltration in the model.

**ENERGY*SOLUTIONS*' RESPONSE:** As is presented in Response 8.7 of Appendix F, this interrogatory statement addresses the influence of elevated salinity on soil water evaporation. Salhotra et al. (1985) and many other studies document a decrease in evaporation due to salinity in open water. Other studies of the effects of salinity on evaporation from soil are more appropriate for this discussion.

## 9.0 FREEZING OF THE RADON BARRIER

9.1 **INTERROGATORY STATEMENT(S):** On Page 2-2, under Temperature, it says that "data from the Clive facility from 1992 through 2011 indicate that monthly temperatures range from about -2°C (29°F) in December to 26°C (78°F) in July (MSI, 2012)." An analysis of temperature data for the Clive site indicates that there is potential for freezing of the radon barrier, with adverse consequences. Please revise the proposed CAW cover-system thickness to prevent potential freezing of radon barrier clay at depth.

**ENERGY*SOLUTIONS*' RESPONSE:** The analyses described in Appendix F demonstrates that the frost depths calculated as part of the analysis give results that are in line with the depths of cover and frost protection proposed in the Energy*Solutions* Evapotranspirative Cover system design. The proposed radon barrier begins at depths ranging from 30-inches to 42-inches, which provides frost protection for the calculated 100-year frost penetration depth of 22.4 inches to 27.8 inches for the top slope and side slope, respectively.

9.2 **INTERROGATORY STATEMENT(S):** On Page 2-8, it says, concerning the Evaporative Zone Layer, "The thickness of this layer is varied in the Performance Assessment from 6 inches to 18 inches, to evaluate the influence of additional thickness on the water flow into the waste layer."

The DRC finds a thickness of 6 inches to be inadequate. Please ensure that the thickness of soil underlying the surface layer in the zone now referred to as the Evaporative Zone Layer is adequate to protect against frost damage to the radon barrier soils and any overlying capillary barriers or biointrusion barriers.

**ENERGY*SOLUTIONS'* RESPONSE:** The adequacy of the alternate evapotranspirative cover designs to protect clay barrier layers from frost damage is addressed in Appendix E.

## 10.0 CAPILLARY BARRIER

10.1 **INTERROGATORY STATEMENT(S):** Page 2-8 identifies a Frost Protection Layer in the proposed ET cover system ostensibly designed to prevent underlying layers from freezing. However, layers other than the Frost Protection Layer (e.g., one or more biointrusion barriers, and a capillary barrier) may be helpful or necessary in minimizing unwanted effects of biointrusion and in dealing with increases in hydraulic conductivity resulting in greater infiltration, drainage and percolation. Once the Hydrus 2/3-D model has been revised to more fully account for changes in hydraulic conductivity of low-permeability layers, mammalian burrowing, frost-heave, distortion, etc., please use the model to evaluate and compare scenarios of drainage of water through the cover system under the following scenarios: (i) with and without one or more biointrusion barriers (which, if present, may somewhat diminish increases in hydraulic conductivity from burrowing, and which may be needed to protect the upper surface of a capillary barrier), and (ii) with and without a capillary barrier (which, if present, may increase rates of evapotranspiration and decrease deeper drainage and percolation).

**ENERGY*SOLUTIONS'* RESPONSE:** The modeling of infiltration into, within, and through the alternate evapotranspirative cover designs is addressed in Appendices A of revision 0 and F of revision 1.

10.2 **INTERROGATORY STATEMENT(S):** COVER DESIGN 3: Evapotranspirative Cover Design B is described on Page 2-9 of the PA. This proposed design includes a filter zone. However, the filter zone is not described in the PA as acting as a capillary barrier. If it does not act as such, then how would overall infiltration, drainage and percolation at the site be modified by changing the grain-size distribution in the lower part of the Frost Protection Layer to form a fine-grained cap, thereby allowing the underlying filter zone (if the grain-size distribution is appropriately modified) to act as a capillary barrier?

**ENERGY*SOLUTIONS'* RESPONSE:** The frost protection function and characteristics of the filter zone within the alternate evapotranspirative cover design 3 is addressed in Appendices C and E.

**10.3** **INTERROGATORY STATEMENT(S):** Page 3-3 includes this statement: "The candidate thick covers include capillary break, biointrusion, and bioturbation barriers that make the waste less accessible to plant roots after closure of the facility." Please explain how the proposed cover-system design 1 and design 2 include effective capillary barriers.

**ENERGY*SOLUTIONS'* RESPONSE:** The capillary barriers included in the proposed alternative evapotranspirative cover designs are addressed in Appendix C.

**10.4** **INTERROGATORY STATEMENT(S):** Page 16 of Neptune and Company, Inc. (2012) says, "Lateral drainage layers have high saturated hydraulic conductivities to promote lateral flow and have characteristics similar to capillary barriers."

Please revise and clarify this statement so that it is more fully consistent with current scientific and engineering knowledge concerning drainage or filter layers and capillary barriers.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 10.4 of Appendix F, the clarification is noted. The text "*...and have characteristics similar to capillary barriers*" in Appendix B of revision 0 of the updated Site-Specific Performance Assessment should not be included.

## 11.0 HYDRAULIC CONDUCTIVITY, INFILTRATION AND FLOW

**11.1** **INTERROGATORY STATEMENT(S):** Page 12 of the PA describes silty clay Radon Barrier material, saying, "Upper Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This layer has the lowest conductivity of any layer in the cover system. This is a barrier layer that reduces the downward movement of water to the waste and the upward movement of gas out of the disposal cell. Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This is a barrier layer placed directly above the waste that reduces the downward movement of water."

Page 39 of the PA says, "Upper Radon Barrier: The engineering design specification for a maximum hydraulic conductivity is $5 \times 10^{-8}$ cm/s ($4.32 \times 10^{-3}$ cm/day) for this clay barrier."

Page 39 also says: "Lower Radon Barrier: The engineering design specification for a maximum hydraulic conductivity is $1 \times 10^{-6}$ cm/s ($8.64 \times 10^{-2}$ cm/day) for this clay barrier."

In addition to the Upper and Lower Radon Barriers, the surface layer and evapotranspiration layer are considered in the PA model to consist of silty clay materials.

The PA model makes no attempt to consider any changes in hydraulic conductivity of these low-permeability soils subsequent to embankment construction.

Upper and Lower Radon Barriers should be constructed having the soil hydraulic conductivities given in the engineering design specifications described above but the soil hydraulic conductivities should be modeled over the long-term as being in the range of $8x10^{-6}$ to $6x10^{-4}$ cm/s. This complies with NRC guidance for long-term cover-system hydraulic conductivity values (Benson et al., 2011). Please conduct a sensitivity analysis in the PA model using the following three values for long-term cover-system silty-clay hydraulic conductivity: $8x10^{-6}$ cm/s, $6.9x10^{-5}$ cm/s and $6x10^{-4}$ cm/s.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 11.1 of Appendix F, the interrogatory comments are closely linked to the Benson et al (2011) report published by the NRC. While this is a useful report, the topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application.

Additionally, the alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty) require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling. There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. However, the need for these studies is not established.

11.2 **INTERROGATORY STATEMENT(S):** Page 42 of Neptune and Company, Inc. (2012) says, "not including the effect of soil crusts on infiltration will overestimate the actual net infiltration rate at the site."

Please revise or remove the statement. Alternatively, justify it.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 11.2 of Appendix F, since the information on the effects of biological and physical crusts on infiltration in inconclusive, it is premature to reach any conclusion about the effect of either crust type on vegetation. The effects of crusts on infiltration are not considered.

11.3 **INTERROGATORY STATEMENT(S):** Page 46 of Neptune and Company, Inc. (2012) says, "Average annual fluxes are small."

Please re-do the model with appropriate hydraulic conductivities, which will undoubtedly make average annual fluxes greater.

**ENERGY*SOLUTIONS'* RESPONSE:** See response to Interrogatory 11.1 presented in Appendix F.

## 12.0 AIR EXPOSURES

**12.1 INTERROGATORY STATEMENT(S):** Pages 3-1 and 3-2 say, "that after final placement of the waste and closure of the Embankment with a rock armored cover, the facility design prevents any further migration of radioactivity through the air pathway. Analysis of the longevity of the alternate evapotranspirative cover designs, which provide equivalent isolation of waste from the atmosphere, also demonstrates that no such air-related doses are projected following closure and institutional control."

As discussed earlier, there is significant concern that the cover system as proposed will suffer from erosion. Should erosion be substantial, waste could be exposed to the atmosphere. Accordingly, please do a complete analysis of air exposures associated with windblown transport of bulk waste particles exposed at the site via erosion.

**ENERGY*SOLUTIONS'* RESPONSE:** Erosion resistance inherent in the alternate evapotranspirative cover designs is addressed in Appendix D.

## 13.0 OTHER MODELING ISSUES

**13.1 INTERROGATORY STATEMENT(S):** Page 2-10 states, "the soil:plant ratio was only used where actual measured soil $K_d$ values are not available, and the published $K_d$ value from the soil:plant ratio was decreased by two orders of magnitude to be conservative. The radionuclide $K_d$ values used in this updated site-specific Performance Assessment are listed in Table A-4 of Appendix A." Relative to these comments, the DRC requests two items of information: (1) the names of the specific nuclides for which soil:plant $K_d$ values were utilized, and (2) justification for the use of soil:plant $K_d$ values in models for site contaminant transport.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.1 of Appendix F, the only $K_d$ values used in Appendix B of revision 0 of the updated Site-Specific Performance Assessment are a $K_d$ of zero for iodine-129 and default $K_d$ values from RESRAD-OFFSITE. None of the $K_d$ values used in Appendix B of revision 0 of the updated Site-Specific Performance Assessment were determined from soil:plant ratios. The $K_d$ values from the Whetstone Associates (2011) Table 27 were not used in and are not applicable to the modeling studies described in Appendix B of revision 0 of the updated Site-Specific Performance Assessment.

13.2 **INTERROGATORY STATEMENT(S):** On Page 3-8, it states, "Also, longitudinal dispersivity in the unsaturated and saturated zones was set at a larger value than that suggested by RESRAD default values (where larger values of longitudinal dispersivity reduce the potential arrival time of contaminants at the Point of Compliance well)."

Please reveal the value of longitudinal dispersivity in the saturated zone used in the model. Please also re-run the model with the suggested or default dispersivity value in the RESRAD model, or with another value chosen on a scientific basis and conservatively estimated, or else justify the use of the dispersivity value previously selected for use.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.2 of Appendix F, the value used for saturated zone longitudinal dispersivity is listed in Table 9, page 59 of Appendix B from revision 0 of the updated Site-Specific Performance Assessment. The use of a higher value for longitudinal dispersivity reduces the first arrival time for the modeled iodine inventory, which is the intended goal of the bounding RESRAD-OFFSITE modeling approach. The modeling approach does not evaluate radionuclide concentrations within the contaminant plume and within plume concentrations are not needed to demonstrate compliance with performance objectives.

13.3 **INTERROGATORY STATEMENT(S):** Page 30 of Neptune and Company, Inc. (2012) says that "in this case the combination of climate and cover layer properties may maintain flow in the cover system as one-dimensional." This result is in contrast to that for the current, approved design, which is modeled as having two- or three-dimensional flow since it employs rock armor or rip rap cover, as well as two underlying drainage layers. It is said in the report that 18 to 19 percent of infiltrated precipitation is expected to be removed from the cover system in this current, approved design by lateral conveyance through the upper drainage layer. Another statement made is "with more water removed from the upper layers of the covers it is less likely that water saturations at depth could increase to the point where the filter layer would laterally divert water."

The Licensee needs to revise and upgrade its model to be consistent with NRC guidance and improved assumptions, rerun the model, determine the fractional flow removed laterally from the drainage or filter system design (Design 2), and then assess whether or not a drainage or filter system design would be beneficial for actual construction. Doing so will be necessary to meet requirements found in applicable rules and regulations and guidance listed below. Specifically, please run the model using the geometric mean of the range of anticipated hydraulic conductivity values defined by Benson et al. (2011) in the NRC guidance for clay layers in the radon barrier.

Also, please use the lowest and highest values in that range as bounding values in sensitivity and uncertainty analyses. When modeling, also include all other modeling approaches and parameter changes requested in this Interrogatory, unless not using them is first negotiated with the DRC in writing. Please evaluate modeled drainage of water into the waste and the groundwater system using (i) no drainage or filter layer, and (ii) a drainage or filter layer comparable in performance to that in the old design. Assess the difference rill drainage occurring as a result, and the need for modeling conducted using two or more dimensions.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.3 of Appendix F, to provide the necessary input of net infiltration to the fate and transport model, variably saturated flow models were developed for two proposed Class A West embankment cover designs. However comparison of the performance of the ET and rock armor designs was not an objective of this analysis. The objective of the flow modeling was strictly to provide net infiltration values to the fate and transport model.

13.4 **INTERROGATORY STATEMENT(S):** Pages 31 and 32 of Neptune and Company, Inc. (2012) show conceptual cross-sectional diagrams for the numerical models used in the PA to assess whether horizontal components of flow exist through the side slopes of the cover system. These conceptual schematics show no-flow boundaries existing on seven of the eight sides of four model layers. That's all except one on the downgradient side of either the frost protection layer or the filter zone, depending on the model used. These no-flow boundaries are shown in the conceptual diagram as being vertical. Upslope boundaries are shown as being stacked vertically. Downslope boundaries also appear to be stacked vertically. There is no downslope termination of layers shown horizontally against the cell liner or the protective liner cover, as is depicted in design plans.

Please re-model flow using more realistic model-layer geometries and boundary conditions at the downslope and upslope boundaries of each layer so as to more accurately represent field conditions. Alternatively, provide justification for the existing geometry and boundaries.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.4 of Appendix F, the 2-D HYDRUS modeling was conducted to test whether any lateral flow is expected to occur out of the evapotranspiration cover system. The 2-D HYDRUS test models demonstrate the lack of lateral flow that would effectively remove water from the cover system before it flowed into the waste.

13.5 **INTERROGATORY STATEMENT(S):** The proposed model cross-sectional schematics on Pages 31 and 32 of Neptune and Company, Inc. (2012) show that a no-flow boundary, in addition to the no-flow boundaries at the ends of the surface layer, exists over approximately the downslope 23% (2.1 meters, or 7 feet) of the top of the modeled 9.1 meter-long (30-foot-long) surface layer.

This no-flow boundary along the surface does not correspond with physical conditions to be realized in the field once construction plans are implemented. Re-do the model to remove the artifice of imposing a no-flow boundary over the lower 2.1 meters, or seven feet, of the top of the surface layer. Also, fix other problems with the way the model is set up. Alternatively, provide justification for imposing this boundary.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.5 of Appendix F, the 2-D HYDRUS test models demonstrate that flow in a straight line from the soil surface to the observation node in these cover designs is not physically possible. Flow occurs in response to a gradient in total potential. Flow in the upper layers will be downward at an angle slightly different from 90 degrees to the surface expected for a horizontal surface since the cover has a 20% slope. Flow continues downward into the frost protection layer in Design 1 and into the filter zone in Design 2. These layers are both constructed above lower permeability clay layers. If the flow of water into the frost protection layer in Design 1 or into the filter zone in Design 2 is greater than the flow possible vertically downward through the clay layers, water can accumulate on the top of the clay layers and begin to flow laterally. The modeling strategy described in the PA ensures that infiltration (and ultimately dose), are not underestimated.

13.6 **INTERROGATORY STATEMENT(S):** The conceptual model for the proposed cover system as described on Pages 30 through 32 of the Neptune and Company, Inc. (2012) report appears to assume isotropic conditions for soils, wherein values of components of hydraulic conductivity in the x, y and z directions in the model are equivalent to each other. No mention is made in the text of any anisotropy having been modeled.

Please re-run the model without the assumption of isotropicity. Assume reasonable ratios of horizontal to vertical conductivity ($K_x/K_z$) ranges. Please also perform sensitivity and uncertainty analyses.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.6 of Appendix F, the 2-D HYDRUS simulations demonstrated no lateral flow in the cover systems. As the Summary of Basis for Interrogatory concluded, "*...the failure to account for anisotropy will tend to make flow in the model appear to be more vertically oriented than it actually is.*" With the flow vertically oriented, net infiltration through the waste is not underestimated (thereby conservatively bounding) since any lateral flow would not pass through the waste.

13.7 **INTERROGATORY STATEMENT(S):** Figure 8 (which purports to represent "daily precipitation") on Page 35 of the Neptune and Company, Inc. (2012) report shows many data points over a 100-year period with precipitation varying between 1.0 and 2.0 centimeters (0.4 to 0.8 inches). The average value, although not easily decipherable from the figure, appears to be in the range of 0.5 centimeters (0.2 inches).

Please explain, justify, or fix the data provided. If the model is affected, then please fix the model.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.7 of Appendix F, the 100-year daily record of precipitation for the site was generated using HELP's synthetic methodology. The mean annual value from the record generated by HELP is 21.4 cm and is consistent with the value suggested by DRC in the Basis for Interrogatory.

13.8 **INTERROGATORY STATEMENT(S):** Page 39 of Neptune and Company, Inc. (2012) states, "The saturated hydraulic conductivity of the filter layer had to be reduced to a value of 864 cm/day for the 2-D model in order to reach model convergence."

Please re-do the model using the Meyer et al. (1996) hydraulic conductivity of 86,400 cm/day. It is not acceptable to the DRC for the Licensee to artificially reduce modeled hydraulic conductivity for the filter layer 100-fold without first attempting other model modifications; the performance of the filter layer is critical to making decisions about the performance of cover system design. What other approaches can be taken to attain model convergence (e.g., changing time steps, changing spatial discretization, etc.) without artificially reducing hydraulic conductivity of an important component of the model?

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.8 of Appendix F, extremely large values of hydraulic conductivity result in nearly instantaneous desaturation of the layer and make the simulations unstable. The value of saturated hydraulic conductivity used is large enough to allow any lateral flow for the 2-D numerical experiment models to be simulated.

13.9 **INTERROGATORY STATEMENT(S):** Page 43 of Neptune and Company, Inc. (2012) says that "zero water flux was recorded through the seepage faces."

Page 45 says, "The results of these 2-D simulations demonstrate that water flow in the cover system for both designs is predominantly vertical with no significant horizontal component."

These conclusions are not justified. Please re-do the modeling with more appropriate boundary conditions and model assumptions. Alternatively, justify the existing modeling results.

**ENERGY*SOLUTIONS'* RESPONSE:** Responses to 13.9 can be seen in Interrogatories 13.4, 13.5, and 13.6 of Appendix F

13.10 **INTERROGATORY STATEMENT(S):** On Page 50 of Neptune and Company, Inc. (2012), it is said in regard to RESRAD-OFFSITE that "the runoff coefficient was set at a value of 0.99."

The value for Cr, the runoff coefficient, used in the model and described in the text appears to be high. Please change it so that it appropriately represents physical processes at the site. This will, of necessity, also force change of the evapotranspiration coefficient value used in the model.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.10 of Appendix F, DRC's comment concerns the value of the runoff coefficient used in RESRAD-OFFSITE. However, the runoff coefficient is simply a fitting parameter used to match the steady-state infiltration value provided from the HYDRUS code and does not represent the fraction of precipitation expected as runoff for the cover system (see the RESRAD-OFFSITE infiltration equation and discussion of equation parameters on page 50 of Appendix B of revision 0 of the updated Site-Specific Performance Assessment).

13.11 **INTERROGATORY STATEMENT(S):** Page 60 provides results of current modeling efforts. It states, "Iodine-129 did not reach the groundwater well within the 10,000-year time frame." Since iodine-129 is assumed to be conservative, it is concluded in the text that no radionuclide breaks through to a point of compliance within the 10,000-year time frame.

For protection of human health and the environment, and to comply with the rules and regulations listed below, please revise model input for long-term cover-system clay soil hydraulic conductivity in accordance with NRC guidance in Benson et al. (2011), re-run the model, and re-design the cover system for the site in order to provide for needed reductions in risk to human health and the environment. Please describe the changes in the text.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.11 of Appendix F, the objective of the revised modeling described in Appendix B of revision 0 of the updated Site-Specific Performance Assessment is to update model simulations of fate and transport of LLW contaminants from the disposal facility. These simulations were developed for two cover designs and provide steady state infiltration rates to the RESRAD-OFFSITE transport model. Bounding transport assumptions are used to demonstrate that the Clive disposal site meets regulatory requirements for radionuclide concentrations at Class A limits.

13.12 **INTERROGATORY STATEMENT(S):** Page 60 of Neptune and Company, Inc. (2012) provides results of current modeling efforts. It states, "Iodine-129 did not reach the groundwater well within the 10,000-year time frame." Since iodine-129 is assumed to be conservative, it is concluded in the text of the PA that no radionuclide breaks through to a point of compliance within the 10,000-year time frame.

However, iodine-129 does not appear to be the most conservative radionuclide with respect to transport in groundwater (i.e., it does not appear to have the lowest distribution coefficient, or $K_d$, value). After upgrading the groundwater transport model to reflect more accurate assumptions and data, please change the model to follow, at a minimum, the most conservative radionuclide solute. If that solute is found to break through to the above mentioned groundwater well within 10,000 years, then examine all other radionuclide solutes that may break through within 10,000 years. Alternatively, justify the current model approach.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.12 of Appendix F, the $K_d$ value used for iodine-129 in the RESRAD-OFFSITE modeling is zero (see page 49 and page 60 of Appendix B of revision 0 of the updated Site-Specific Performance Assessment). The combination of a zero $K_d$ and the long-half-life of Iodine-129 (15.7 million years) provides an acceptably bounding condition for the radionuclide transport studies described in Appendix B. Iodine-129 does not sorb and because of its long half-life, there is no significant reduction in the concentration of iodine-129 from radioactive decay during 10,000 years. The $K_d$ values from the Whetstone Associates (2011) Table 27 were not used in and are not applicable to the modeling studies.

13.13 **INTERROGATORY STATEMENT(S):** Page 61 of Neptune and Company, Inc. (2012) refers to www.conservationphysic.org/atmcalc/atmoclc2.pdf, from which several equations used in the model are obtained. Please find another reference for the equations, as the current reference contains errors that reduce its credibility. Please also correct the equation for saturation vapor pressure in the PA so that its units are equivalent on both sides of the equation. (The numerical value of the equation is correct; the units provided in the equation are incorrect.)

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.13 of Appendix F, there are no errors in the calculations used to convert the annual relative humidity values cited in Whetstone, 2011; Table 2, for the Clive, UT site to the annual average absolute humidity value in air required by the RESRAD-OFFSITE program.

13.14 **INTERROGATORY STATEMENT(S):** Sensitivity analyses in Neptune and Company, Inc. (2012) are limited in number, in the range of variables examined, and in quality. A sensitivity analysis is the evaluation of how changes in input parameter values affect model output. Uncertainty analysis is not carried out in the document.

**ENERGY*SOLUTIONS'* RESPONSE:** As is presented in Response 13.14 of Appendix F, the modeling study is a bounding deterministic performance assessment. Modeling parameters and modeling assumptions in the PA were all designed to maximize the potential for radionuclide transport from the disposal site (or conversely underestimate the performance of the disposal site). Additional sensitivity and uncertainty analyses would provide limited information to enhance understanding of the bounding modeling results. Moreover, modeling results using this approach show that the Clive site easily meets the regulatory requirements for disposal of Class A radioactive waste.

The PA emphasized the important components controlling the Clive disposal system: cover performance and its effect on the steady state infiltration rate, the radionuclide source term release and transport modeling and intruder dose calculations. The modeling approach for cover performance and infiltration justified and used a 1-D modeling approach and conservative modeling parameters that maximize the potential for higher rates of steady state infiltration. The source term release and transport model assumed an Iodine-129 source, no sorption of iodine-129 and radionuclide concentration limits equal to Class A waste limits. The dose calculations assumed standard NRC exposure scenarios despite non-potable groundwater at the disposal site and compliance points. The transport and intruder dose calculations are bounding and there is no justification for running additional sensitivity cases. Interrogatory 11.1 discusses issues with and the limited value in running additional simulations with HYDRUS using non-systematic changes in cover properties.

# 14.0 INADVERTENT INTRUDER ANALYSIS

**14.1 INTERROGATORY STATEMENT(S):** On Pages 1-2 and 1-3 of the PA, it speaks of U.S. NRC staff, and then states,

> *"In particular, staff recognized that current disposal at the Clive facility includes engineered barriers and increased depths that provide significant protection for an inadvertent intruder. Specifically, staff stated in their recommendation, 'The staffs preliminary independent analysis indicates that current practices at ... disposal facilities may safely accommodate an increase in the amount of disposed waste at or just below the Class A limits' (NRC, 2010)."*

The DRC would like to provide additional context directly from the NRC (2010) document so as to more fully clarify the meaning and intent of the statements given above.

**ENERGY*SOLUTIONS'* RESPONSE:** The Division's added context is appreciated.

**14.2 INTERROGATORY STATEMENT(S):** Also under R313-15-40 1: Periods of Performance, on Page 1-3, reference is made to the time frame for modeling of protection of a hypothetical inadvertent intruder. The Licensee is requesting a modeling period of 1,000 years. However, the duration for the period of performance acceptable to the DRC is 10,000 years.

**ENERGY*SOLUTIONS'* RESPONSE:** Analysis of the appropriate Periods of Performance and Times of Compliance applicable to demonstration of the protection from inadvertent intrusion includes the following promulgated requirements for disposal of Class A waste.

1. <u>500 YEARS</u>: Even though Energy*Solutions'* License limits disposal to only Class A Low Level Radioactive Waste, UAC R313-25 requires the use of a 500-year Period of Performance for robust engineered barriers used in the disposal of Class C waste [e.g., 10 CFR 61.52(a)(2)], to specifically ensure that the Class C waste can be protected from inadvertent intrusion until it decays to safe levels. The 500-year Period of Performance for engineered barriers used to limit inadvertent intrusion (e.g., 10 CFR 61.42) is not the same as the promulgated Period of Performance for protection of the general population from releases of radioactivity (e.g., 10 CFR 61.41). As such, NRC deemed the engineered barriers and concentration limits inherent with the Class A classification were sufficient to demonstrate protection of an inadvertent intruder.

2. <u>1,000 YEARS</u>: No specific Period of Performance of the closed Class A West Embankment has been promulgated in UAC R313-25-20, as related to the protection of a hypothetical inadvertent intruder. However, NRC guidance has historically assessed intruder scenarios for a time period equivalent to that indicated in UAC R313-15-401(4), (e.g., 1,000 years after facility closure), (NRC, 1986). Embankment performance for 1,000 years for the protection of an inadvertent intruder is also supported by the precedent time periods required by 10 CFR 20, Subpart E (for decommissioned sites), 10 CFR 40, Appendix A (for uranium mill tailings), and DOE Order

435.1. Therefore, consistent with federal guidance and precedence, the updated Site-Specific Performance Assessment has been revised to project expected exposures to a reasonable inadvertent intruder within a Time of Compliance of 1,000 years, following Class A West Embankment closure.

3. 10,000 YEARS: In their Round 1 Request for Information, the Division cited UAC R313-25-8(5)(a) as a basis for a Period of Performance of 10,000 years. However, this citation only applies to "*any facility that proposes to land dispose of significant quantities of concentrated depleted uranium,*" [UAC R313-25-8(5)(a)], and as such, is not applicable to the Updated Site-Specific Performance Assessment. NRC's environmental impact statement for 10 CFR 61 recognizes the need for a Period of Performance, "*commensurate with the persistence of the hazard of the source,*" (NRC 1981; NRC 1982; NRC 2000).

**14.3** **INTERROGATORY STATEMENT(S):** Page 1-5 claims that "UAC R313-25-20 requires assurance of protecting individuals from the consequences of inadvertent intrusion *into disposed waste*" [emphasis added]. Please revise this statement to make it consistent with UAC R313-25-20. An analysis of site-specific inadvertent intrusion as defined in UAC R313-25-20 is also needed.

**ENERGY*SOLUTIONS*' RESPONSE:** Section 1.4.2.2 has been expanded to clarify the regulatory basis for selection of appropriate inadvertent intruder scenarios in this Updated Site-Specific Performance Assessment.

**14.4** **INTERROGATORY STATEMENT(S):** Page 1-6 of the PA says that "NRC staff acknowledges that licensees are *not* expected to perform intruder dose analyses ... " [emphasis added].

This statement, standing alone, is somewhat misleading; it must be placed within its proper context to convey its full intent. The NRC staff actually states that exceptions to this general principle do occur, and that, in fact, separate "intruder scenario analyses may be necessary" in certain situations. In the opinion of the DRC, this is one of these situations. The reasoning is provided below.

The DRC requests that the Licensee submit separate intruder scenario analyses for the site as needed. For example, one scenario might be for drilling, one might be for building and habitation of residences with basements penetrating the base of the radon barrier, and one for industrial activities on the site. Alternatively, the licensee must demonstrate why these separate scenarios do not need to be conducted.

**ENERGY*SOLUTIONS*' RESPONSE:** Section 1.4.2.2 has been expanded to clarify the regulatory basis for selection of appropriate inadvertent intruder scenarios modeled in this Updated Site-Specific Performance Assessment.

14.5 **INTERROGATORY STATEMENT(S):** On Page 2-4, under Groundwater, the text says that groundwater at the site has high salinity and, "as a consequence, is not suitable for most human uses (NRC, 1993)." Please revise the statement in the PA to acknowledge the possibility, however likely or unlikely it is to happen, that both shallow and deep groundwater not contaminated by radionuclides at the site can be treated to remove its high salinity, and that the initial high salinity of the water before treatment per se therefore does not bar people from drinking treated groundwater or using it for other purposes.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 2.1.10 has been expanded to clarify modeled use of groundwater.

14.6 **INTERROGATORY STATEMENT(S):** It is stated on Page 3-1 of the PA that the assumption "that a member of the general public would build a residence near the edge of the Clive site and use local groundwater for potable needs is extremely unreasonable." The DRC disagrees. The DRC asks the Licensee conduct assessments of inadvertent intruder-resident and other scenarios with the probability of intrusion being considered to be greater than zero.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 3.1 has been expanded to include mortality results from the ingestion of groundwater and its comparison to the 4mrem/year dose standard.

14.7 **INTERROGATORY STATEMENT(S):** On Page 3-2 of the PA, it is stated, "The primary site characteristics that prevent public exposures via the groundwater pathway are the very poor groundwater quality at the site, the low population density, arid meteorology, and the low yield of the aquifers. The groundwater is not potable because of its very high concentration of dissolved salts. This characteristic alone prevents any consumption of the water by humans or livestock." Please modify the text to acknowledge that, while factors exist that make consumption of untreated groundwater highly unlikely, it is possible that, at somewhat high cost, the water can be treated via reverse osmosis or other desalination technology to be made potable, and that storage of contaminated groundwater prior to its treatment and storage or disposal of contaminated reject water after treatment could lead to human or animal exposure.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 3.1 has been expanded to include mortality results from the ingestion of groundwater and its comparison to the 4mrem/year dose standard.

14.8 **INTERROGATORY STATEMENT(S):** Page 3-4 states, "For purposes of demonstrating performance, it is important to note that occupation of the site by inadvertent intruders after site closure is not likely due to a lack of natural resources in the area, particularly a lack of potable water. As such, contacting the waste after site closure by an onsite resident is *highly unlikely* due to the lack of natural resources (no reason to drill or dig) and the design of the embankment cover system ..." [emphasis added].

Pages 3-9 and 4-1 state strongly, "there are *no* credible intrusion scenarios" [emphasis added].

The DRC does not accept the licensee's claim and asks the licensee to justify that "there are credible intrusion scenarios." Reasons given by the Licensee for an inadvertent intrusion not being worthy of any consideration are not considered valid by the DRC. For example, the argument that people cannot live on or occupy the site due to a perceived lack of potable water is not valid. Please revise the language in the PA to better reflect current relevant knowledge; please also conduct appropriate inadvertent intruder scenario analyses.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 1.4.2.2 has been revised to discuss applicable inadvertent intrusion scenarios in the update site-specific Performance Assessment.

**14.9 INTERROGATORY STATEMENT(S):** Page 3-4 says, "Several design features provide the required protection. Overall features include:

1) Site isolation and the resultant lack of nearby residential population;
2) Embankment cover systems (rock armored rip-rap, evapotranspirative bioturbation/biointrusion); and
3) Granite markers"

As previously mentioned, "rock armored rip-rap" (listed as a "design feature" above) does not exist in the preferred proposed designs shown in the PA. Please modify the text accordingly.

Also, please identify where the granite markers will be placed, and what, if anything, will be written on them, and in what language(s).

**ENERGY*SOLUTIONS'* RESPONSE:** Detailed description of the requested information regarding the proposed location for the granite markers has been presented in Sections 1.2.1, 1.2.3.9, 1.2.3.10, and 4.3.5 of the Radioactive Material License Renewal Application (Energy*Solutions*, March 6, 2013)

**14.10 INTERROGATORY STATEMENT(S):** Appendix A of the PA is entitled "Regulatory Basis for Selecting Reasonable Inadvertent Intruder Scenarios". Page A-2 of this appendix notes that the NRC associates the meaning of "reasonable assurance" with the meaning of "reasonable expectation." Page A-2 states that the NRC defined the term "reasonable" in the fourth point of 10 CFR 63.304, as "discouraging the modeling of unreasonably-extreme physical situations in the performance assessments".

The Licensee applies this line of thinking on Page A-5 of the appendix, where it says,

> *"The intruder-construction scenario involves direct intrusion into disposed wastes for activities associated with the construction of a house {(e.g., installing utilities, excavating basements, and similar activities [as described in Section 4.2.2 of NRC (1986)]). However, because there is no historic evidence of prior residential construction at the Clive site, the extreme salinity of Clive's soils, the unpotable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the*

*inadvertent intruder-construction scenario is not considered 'reasonable' for the Clive site nor included in this Report's site-specific Performance Assessment."*

Please correct the foregoing statements to make them accurate, or else defend and justify them.

**ENERGY*SOLUTIONS'* RESPONSE:** The discussion of reasonable inadvertent intruder in Section 1.4.2 has been clarified.

14.11 **INTERROGATORY STATEMENT(S):** Page A-3 of the PA lists five bulleted quotations from NRC (2007) that refer to scenarios that are physically reasonable and appropriate for a site, as well as consistent with regional practices and characteristics. Several bulleted items refer to regional practices. These are mentioned in the PA in providing a rationale for not performing an inadvertent intruder-resident analysis. The DRC requires that the Licensee conduct inadvertent intruder-resident analyses for this site.

**ENERGY*SOLUTIONS'* RESPONSE:** Inadvertent intruder scenarios modeled in the updated site-specific Performance Assessment are addressed in Section 1.4.2. The bulleted list of items referenced to NRC (2007) is a summary of guidance for NRC reviewers of performance assessments specific to identifying reasonable exposure pathways and land use scenarios. These items, and similar summaries or quotations from other NRC regulation, methodology, and guidance cited as rationale for focusing the inadvertent intrusion analysis on activities that are physically reasonable and consistent with regional practices and past/current land-use and behaviors.

The logic for the intruder analysis presented is fully consistent with NRC guidance and requirements. No changes are required without an established regulatory basis for the changes.

14.12 **INTERROGATORY STATEMENT(S):** On Page 21 of Neptune and Company, Inc. (2012), it says, "The intruder drilling scenario is highly unlikely due to the nature of the embankment design, which as a raised mound covered with rip rap would be a very difficult place to site a drilling rig."

Please correct the statement above, or justify it.

**ENERGY*SOLUTIONS'* RESPONSE:** Descriptions/justification for the inadvertent intruder scenarios modeled in the updated site-specific Performance Assessment have been clarified in Section 1.4.2. The quoted statement is in an introductory paragraph of Section 3.3 (Inadvertent Human Intruder exposure Scenarios) that provides a brief summary of applicability of the generic exposure scenarios described in NRC reports (NRC 1981; NRC, 1986) to the Clive facility. This statement is based on the low joint probability that a future well driller would be unaware of the non-potable nature of regional groundwater AND that the driller would attempt to locate a drill rig on the relatively inaccessible top of the embankment rather than on surrounding level ground. This is discussed on page 23:

*"The intruder-drilling scenario is assumed to be an initiating event for the intruder-discovery, intruder-construction, and intruder-agriculture scenarios (NRC 1986, Section 4.1.1.1). That potable groundwater is not present below the floor of the Great Salt Lake Desert where the disposal site is located is common knowledge today. However, there is a very remote but finite chance that someone in the future might drill a well to determine whether potable groundwater exists at the Clive, UT site. Even if this were to occur, it is also highly unlikely that a drilling rig would be sited upon the rip rap cap of the embankment, rather than on the flat-lying landscape surrounding the disposal facility. Nevertheless, the initiating scenario of intruder-drilling suggested as an example in NRC (1986) is evaluated in the IHI dose assessment."*

No changes are required for this topic.

**14.13 INTERROGATORY STATEMENT(S):** It says on Page 23 of Neptune and Company, Inc. (2012) that "Consistent with Section 4.1.1.1 of NRC (1986), the three subsequent IHI scenarios are not assessed in this report because the prospective resident will be unable to secure potable water and therefore will not initiate construction of a home."

Please assess the three subsequent IHI scenarios.

**ENERGY*SOLUTIONS'* RESPONSE:** Descriptions/justification for the inadvertent intruder scenarios modeled in the updated site-specific Performance Assessment have been clarified in Section 1.4.2. Section 3.3 of Appendix B of revision 0 of the updated Site-Specific Performance Assessment presents an assessment of the applicability of the generic exposure scenarios described in NRC (1986) to the Clive facility. This assessment concludes that only the initiating intrusion event (drilling) is physically plausible because the remaining intrusion scenarios are predicated on the successful completion of a drinking water well and potable groundwater is unavailable at the site. A broader discussion of the basis for identifying reasonable inadvertent intruder scenarios that are consistent with site history and regional practices and behaviors is provided.

The logic for the intruder analysis presented in Appendix B of revision 0 of the update Site-Specific Performance Assessment is fully consistent with NRC guidance and requirements. No changes are required without an established regulatory basis for the changes.

**14.14 INTERROGATORY STATEMENT(S):** Please revise the following statement found on Page 23 of Neptune and Company, Inc. (2012). It says, "*Because groundwater at the site is not potable, the groundwater exposure scenario is incomplete.*"

**ENERGY*SOLUTIONS'* RESPONSE:** Impacts to the general public from the consumption of Clive's groundwater are considered in Section 3.1. The quotation from Appendix B of revision 0 of the updates Site-Specific Performance Assessment is correct as stated because there is no reasonable exposure pathway for the non-potable groundwater at the site. Despite the non-potable condition of the groundwater, radionuclide concentrations in groundwater were compared with groundwater protection limits, derived from standards published in UAC R317-6-2, based on requirements of the Ground Water Quality Discharge Permit (Energy*Solutions*, 2010). No changes are required in response to this comment.

## 15.0 MISCELLANEOUS

**15.1 INTERROGATORY STATEMENT(S):** The PA is said on Page ES-l to demonstrate protection of the general public through consideration of transport via the following pathways:

1) atmosphere
2) site soils
3) groundwater
4) surface water
5) vegetation
6) burrowing animals

The DRC finds that these pathways are not fully evaluated in the current version of the PA. Some are hardly evaluated at all. The DRC therefore requires that the Licensee reassess the potential transport associated with each of these pathways and provide a thorough response on how the Licensee will prevent or mitigate these possibilities.

**ENERGY*SOLUTIONS'* RESPONSE:** The Executive Summary has been revised to clarify the discussion.

**15.2 INTERROGATORY STATEMENT(S):** Page ES-1 says that the

> "*Site-specific Performance Assessment also demonstrated that, because of the very low infiltration rates associated with the alternative cover designs, no water that infiltrates through the covers will reach the point of compliance within 10,000 years. Therefore, no class A radionuclide concentrations will arrive at the point of compliance well within the 10,000 year assessment period. As such, disposal of additional volumes of blended ion exchange resins in excess of 40,000 $ft^3$ annually does not compromise the Embankment's performance and protection of the groundwater resource.*"

The DRC finds that there is potential for much greater infiltration than that currently modeled in the PA. The DRC therefore requires that the Licensee reassess model inputs based on requests and information contained throughout this Interrogatory, re-run the model, describe the modified model output, and revise plans and proposals for embankment and cover system design as needed.

**ENERGY*SOLUTIONS'* RESPONSE:** Model assumptions, input, and results are addressed in Appendices A and G.

**15.3 INTERROGATORY STATEMENT(S):** Page 1-4 notes that NUREG-1573 states:

> *"As a matter of policy, the Commission considers 0.25 mSv/year (25 mrem/year) TEDE as the appropriate dose limit to compare with the range of potential doses represented by the older limits that had whole-body dose limits of 0.25 mSv/year (25 mremlyear) (NRC, 1999,64 FR 8644; see Footnote 1). Applicants do not need to consider organ doses individually because the low value of the TEDE should ensure that no organ dose will exceed 0.50 mSv/year (50 mrem/year). (NRC, 1999,64 FR 8644; see Footnote 1)."*

Please review the above quotation and revise it to make it consistent with original sources.

Additionally, this section of the PA includes a statement indicating that

> *"As such, this Performance Assessment does not consider organ doses individually because the low value of the total effective dose equivalent ensures that no organ dose will exceed the promulgated limitations."*

Please provide information to document that even though the Licensee is using a dose limit of 500 mrem/yr, which is 20 times the dose limit of 25 mrem/yr TEDE, there is no need for the Licensee to demonstrate that the organ doses found in R313-25-402 are not exceeded.

**ENERGY*SOLUTIONS'* RESPONSE:** The references in question have been expanded in Section 1.4.2.1. In their Round 1 Request for Information, the Division proposed that the dose criteria found in Sections R313-15-401 through R313-15-406 are applicable to demonstration of protection of an inadvertent intruder. However, for low-level waste disposal facilities licensed under R313-25, these criteria apply only to ancillary surface facilities that support current radioactive waste disposal activities and not the Class A West Embankment itself nor for time periods following the cessation of active waste management operations. Conversely, the performance standard for protection of individuals from inadvertent intrusion (UACR313-25-20) requires "*...protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste.*"

While NRC and the Division's regulations are silent on a specific dose standard to apply under this requirement, the standard that has historically been applied by NRC has been 500 mrem/yr. The 500 mrem/yr standard is the cited basis for NRC's low-level radioactive waste classification system; is used in the Branch Technical Position analysis; is cited in DOE's waste determinations implementing the 10 CFR 61 performance objectives (NUREG-1854); and was the standard proposed in 10 CFR 61 in 1981 (46 FR 38081, July 24, 1981b). A dose standard of 500 mrem/yr is also used as part of the license termination rule dose standard for intruders (10 CFR 20.1403). Consequently, the updated Site-Specific Performance Assessment reaffirms its initial uses a 500 mrem/yr threshold for purposes of applying the performance standard for protection of individuals from inadvertent intrusion.

15.4 **INTERROGATORY STATEMENT(S):** After referencing a number of instances in which the Federal government has set specific dose standards, including one or more indicated as being appropriate under license termination, Page 1-6 states that the Licensee will use a 500 mrem/yr threshold for purposes of applying the performance standard for the protection of individuals.

The DRC cannot accept a 500 mrem/yr threshold without the Licensee first having followed the provisions in Utah R313-14-403.5(b) i, ii, and iii (see also 10 CFR 20.1403). Unless these provisions are followed, the dose standard is set by rule in R313-14-403 at 0.1 rem/yr (100 mrem/yr). Please either revise the threshold to the 100 mrem/yr value, or demonstrate that provisions in' Utah R313-14-403.5(b) i, ii, and iii are followed.

**ENERGY*SOLUTIONS'* RESPONSE:** The Division proposed that the dose criteria found in Sections R313-15-401 through R313-15-406 are applicable to demonstration of protection of an inadvertent intruder. However, for low-level waste disposal facilities licensed under R313-25, these criteria apply only to ancillary surface facilities that support current radioactive waste disposal activities and not the embankment itself nor for time periods following the cessation of active waste management operations. Conversely, the performance standard for protection of individuals from inadvertent intrusion (UACR313-25-20) requires "*...protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste.*"

While the Division's regulations are silent on a specific dose standard to apply under this requirement, the standard that has historically been applied by NRC has been 500 mrem/yr. The 500 mrem/yr standard is the cited basis for NRC's low-level radioactive waste classification system; is used in the Branch Technical Position analysis; is cited in DOE's waste determinations implementing the 10 CFR 61 performance objectives (NUREG-1854); and was the standard proposed in 10 CFR 61 in 1981 (46 FR 38081, July 24, 1981). A dose standard of 500 mrem/yr is also used as part of the license termination rule dose standard for intruders (10 CFR 20.1403).

15.5 **INTERROGATORY STATEMENT(S):** On page 1-5, the PA says,

> "*Resin liners are placed in either the first or second layer of the CWF. The containers are placed in a honeycomb pattern of concrete silos and backfilled with sand. At some interior locations in the CWF, the containers are placed in a temporary steel silo. The silo is used to administratively ensure the honeycomb spacing pattern, including minimum distances between adjacent containers, is achieved. After the steel silo is removed, voids around the containers are filled with the sand backfill.*"

Please correct the statement here, as needed, as well as the statement on Page 3-6 that deals with disposal of resin, as needed, in order to make the two statements accurate and consistent.

**ENERGY*SOLUTIONS'* RESPONSE:** The discussions referenced have been clarified.

**15.6 INTERROGATORY STATEMENT(S):** On page 1-7, the Licensee states that NRC notes that (i) "to the extent practicable the waste should maintain gross physical properties and identify over 300 years, under the conditions of disposal", and (ii) "a site should be evaluated for at least a 500-year time frame to address the potential impacts of natural events or phenomena." In the sentence following the above assertion, the Licensee states that "a disposal site and cover design providing reasonable assurance that long-term stability will be achieved" have been implemented. Additionally, the Licensee indicates that "the best-available technology in setting design standards in the range from 200 to 1,000 years is appropriate to provide site stability to the extent practicable."

In a later section of the PA, the Licensee states that the disposal embankment is designed to perform for a minimum of 500 years.

Please resolve apparent timing-related conflicts between the NRC's stated assertions that a site should be evaluated for at least a 500-year timeframe, that the disposal embankment is designed to perform for a minimum of 500 years, and that "the best-available technology in setting design standards in the range from 200 to 1,000 years is appropriate." Please clarify how these statements are interrelated.

**ENERGY*SOLUTIONS'* RESPONSE:** As originally submitted, Energy*Solutions'* updated Site-Specific Performance Assessment includes:

a. Modeling of expected groundwater well concentrations and comparison to groundwater protection levels (GWPLs) for a Period of Performance of 500 years following Class A West Embankment closure, and of projected peak groundwater well concentrations for each individual radionuclide for a Period of Performance of 10,000 years, following Class A West Embankment closure; and

b. Modeling of expected exposures and resulting doses to hypothetical inadvertent intruders within a Period of Performance of 1,000 years, following Class A West Embankment closure.

Analysis of the appropriate Periods of Performance and Times of Compliance applicable to this updated Site-Specific Performance Assessment includes the following promulgated requirements for disposal of Class A waste.

1. 500 YEARS: Energy*Solutions'* Class A West Embankment is subject to performance limits on the release of groundwater contamination, as required by UAC R317-6-2 (delineated in Clive's Ground Water Quality Discharge Permit). However, UAC R317-6-3 classifies Clive's groundwater as Class IV, "*non-potable, saline ground water.*" Because of this, the Period of Performance for protection of Clive's groundwater resources from further degradation is set by Permit Condition I.D.1 as a Best Available Technology standard of 500 years.

2. <u>1,000 YEARS</u>: In addition to preservation of the current degraded condition of its groundwater resource, Energy*Solutions* is also required "*when calculating the total effective dose equivalent to the average member of the critical group, the licensee shall determine the peak annual total effective dose equivalent dose expected within the first 1,000 years after decommissioning.*" [UAC R313-15-401(4)]. While specifically referencing a time duration following decommissioning, these requirements specifically, "*apply only to ancillary surface facilities that support radioactive waste disposal activities,*" [UAC R313-15-401(1)] and not the Class A West Embankment itself. As such, the 1,000 year TEDE limit is a Time of Compliance and not applicable to the specific Period of Performance of the closed Class A West Embankment.

   Furthermore, no specific Period of Performance of the closed Class A West Embankment has been promulgated in UAC R313-25-20, as related to the protection of a hypothetical inadvertent intruder. However, NRC guidance has historically assessed intruder scenarios for a time period equivalent to that indicated in UAC R313-15-401(4), (e.g., 1,000 years after facility closure), (NRC, 1986). Embankment performance for 1,000 years for the protection of an inadvertent intruder is also supported by the precedent time periods required by 10 CFR 20, Subpart E (for decommissioned sites), 10 CFR 40, Appendix A (for uranium mill tailings), and DOE Order 435.1.

   The 500-year Period of Performance for engineered barriers used to limit inadvertent intrusion (e.g., 10 CFR 61.42) is not the same as the promulgated Period of Performance for protection of the general population from releases of radioactivity (e.g., 10 CFR 61.41). As such, NRC deemed the engineered barriers and concentration limits inherent with the Class A classification were sufficient to demonstrate protection of an inadvertent intruder.

3. <u>10,000 YEARS</u>: In their Round 1 Request for Information, the Division cited UAC R313-25-8(5)(a) as a basis for a Period of Performance of 10,000 years. However, this citation only applies to "*any facility that proposes to land dispose of significant quantities of concentrated depleted uranium,*" [UAC R313-25-8(5)(a)], and as such, is not applicable to the Updated Site-Specific Performance Assessment. Similarly, neither the Division's nor NRC's low-level waste disposal regulations specify a Period of Performance (UAC R313-25 and 10 CFR 61). However, NRC's environmental impact statement for 10 CFR 61 recognizes the need for a Period of Performance, "*commensurate with the persistence of the hazard of the source,*" (NRC 1981a; NRC 1982; NRC 2000). EnergySolutions also recognizes that a Period of Performance of 10,000 years was evaluated as part of the NEPA analysis in the Draft Environmental Impact Statement (DEIS) for 10 CFR 61 (NUREG-0782). Similarly, NRC's Performance Assessment Working Group (formed to provide information and recommendations on performance assessment methodology required by 10 CFR 61.41) also recommended a 10,000-year Period of Performance, considering it "*sufficient to capture the risk from the short-lived radionuclides (the bulk of the activity disposed) and the peaks from*

*the more mobile long-lived radionuclides, which tend to bound the potential doses at longer timeframes,"*(NUREG-1573).

The Division has required that an updated Site-Specific Performance Assessment be conducted that includes *"prediction of nuclide concentration and peak dose (at the time peak dose would occur) using updated dose conversion factors, and a suggested model time frame of 10,000 years, as well as any need to revisit/update the waste source term, receptor and exposure pathways,"* before being able to dispose of processed ion-exchange resin wastes at volumes greater than 40,000 cubic feet per year, (Lundberg, 2011).

Separate from requirements to preserve the groundwater resource for a 500-year Time of Compliance, the Utah Division of Drinking Water and U.S. EPA have promulgated radionuclide concentration limits (e.g., maximum contaminant levels of MCLs) in drinking water, based on the associated health effects from ingestion. EPA has developed MCLs for four groupings of radionuclides: (A) Ra-226 and Ra-228; (B) man-made beta and photon emitters; (C) gross alpha, excluding uranium isotopes and radon; and (D) U-234, U-235 and U-238, based on a maximum committed effective dose equivalent of 4 mrem/year. This dose standard is reflected in Division's requirement UAC R313-25-19, which states *"No greater than 0.04 mSv (0.004 rem) committed effective dose equivalent or total effective dose equivalent to any member of the public shall come from groundwater."*

In response to the Division's Round 1 Request, EnergySolutions' has addressed applicable requirements and guidance in revision of the Periods of Performance and Times of Compliance assessed in their Updated Site-Specific Performance Assessment, as follows:

- 500 YEARS: In compliance with groundwater resource protection standards of UAC R317-6 as implemented in Permit Condition I.D.1, the updated Site-Specific Performance Assessment projects expected groundwater well concentrations for a Period of Performance of 500 years, following Class A West Embankment closure.

- 1,000 YEARS: Consistent with federal guidance and precedence, the updated Site-Specific Performance Assessment project expected exposures to a reasonable inadvertent industrial intruder within a Time of Compliance of 1,000 years, following Class A West Embankment closure.

- 10,000 YEARS: In compliance with federal guidance and precedence, Energy*Solutions* has maintained the original 10,000-year Period of Performance for demonstration of protection of the general public. Similarly, in compliance with the Division's directive, the updated Site-Specific Performance Assessment continues to project a peak isotopic groundwater well concentrations for a Period of Performance of 10,000 years, following Class A West Embankment closure. While the Division is on record agreeing that the groundwater classification, level of its totally dissolved solids, and other naturally-occurring contaminants create completely unpotable groundwater, (thereby eliminating all reasonable possibility of any member of the public from receiving such a groundwater dose), EnergySolutions has revised the updated Site-Specific Performance Assessment to demonstrate that no members of the general public still alive following consumption of Clive's natural groundwater will receive a committed effective dose equivalent in excess of 4 mrem/year. The Periods of Performance and Times for Compliance cited have been clarified.

15.7 **INTERROGATORY STATEMENT(S):** On Page 2-2, under Temperature, it says that "data from the Clive facility from 1992 through 2011 indicate that monthly temperatures range from about -2°C (29°F) in December to 26°C (78°F) in July (MSI, 2012)." Please correct inaccurate text and data related to air temperature values for the site.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 2.1.3 has been revised.

15.8 **INTERROGATORY STATEMENT(S):** Page 3-2 says, "Additionally, the horizontal groundwater flow velocity is approximately 0.5 meters per year, resulting in groundwater travel times of approximately 60 years from the toe of the side slope region of the embankment to the Point-of-Compliance well." Please revise the statement to be more conservative in terms of estimated maximum groundwater velocities and more protective of human health and the environment as required by the rules and regulations listed below.

**ENERGY*SOLUTIONS'* RESPONSE:** The statement referenced by the Division on page 3-2 is a generalization of Clive's actual horizontal groundwater velocities and, as such, does not include any reference to human health. No revision is necessary.

15.9 **INTERROGATORY STATEMENT(S):** Page 3-7 includes the statement:

> "*As part of the Class A West license amendment application, EnergySolutions demonstrated that the disposal site, disposal site design, land disposal facility operations, disposal site closure, and post-closure institutional control plans are adequate to protect the public health and safety in that they will provide reasonable assurance of the longterm stability of the disposed waste and the disposal site and will eliminate to the extent practicable the need for continued maintenance of the disposal site through the compliance period following closure in accordance with the requirements of UAC R313-25.*"

While the existing design described in the Class A West license amendment application provides a cover design previously accepted by the DRC, the proposed design in the PA, as it is currently written, is unacceptable to the DRC. Please develop a workable cover-design plan to prevent, or minimize to the extent practicable, the potential for biointrusion, frost-heave, distortion, or erosion of cover-system soils.

**ENERGY*SOLUTIONS*' RESPONSE:** The ability of the alternate evapotranspirative cover designs to prevent, or minimize to the extent practicable, the potential for biointrusion, frost-heave, distortion, or erosion are addressed in Appendices B, C, and D.

**15.10 INTERROGATORY STATEMENT(S):** It is stated on Page 3-8

> "*In this site-specific Performance Assessment, net water infiltration through the two alternate covers (as computed using the HYDRUS and RESRAD platforms) is projected to be several orders of magnitude lower than calculated for the traditional rock armored cover (as presented in Table A-8 of Appendix A). The new analysis also demonstrates an optimal maximum evaporative zone layer thickness of30.5 cm (above which negligible improvement is seen with increased thickness).*"

And on Page 3-9, it is stated that

> "*The proposed disposal of large quantities (i.e., greater than 40,000 $ft^3$ per year) of blended ion-exchange resin waste has been evaluated in this site-specific Performance Assessment, which confirms that this waste can be disposed of safely and in compliance with all applicable regulatory requirements.*"

Statements above are not considered by the DRC to necessarily be accurate. Please update data and assumptions in the model, run the model with the new data and assumptions, and develop conclusions based on the updated model results. Then revise statements in the text to reflect any new findings.

**ENERGY*SOLUTIONS*' RESPONSE:** Results of the updated site-specific Performance Assessment described in Section 3 and Appendices A (of revision 0), A, and F support the text in question. No further revision is required.

**15.11 INTERROGATORY STATEMENT(S):** The PA application includes as Appendix B a document entitled, "Modeling report: fate and transport of contaminants from the Class A West Embankment and exposure to a post-closure traditional inadvertent human intruder at the Energy*Solutions* Clive, Utah facility" by Neptune and Company, Inc. (2012). Page 7 of that document states that "To the east and southeast, the site is bounded by the north-south trending Lone Mountains, which rise to a height of 5,362 ft amsl."

Please provide references for the name of the mountains and also the elevation that is provided. "Lone Mountain" is familiar to the DRC, but not "Lone Mountains."

**ENERGY*SOLUTIONS*' RESPONSE:** As is reflected in Response 15.1 of Appendix F, the description referred to in the Interrogatory Statement is from Bingham Environmental 1994. Hydrogeologic Report Mixed Waste Disposal Area Envirocare Waste Disposal Facility South Clive, Utah.

This site description has been updated by Energy*Solutions* in the License renewal application. Since the site description has no impact on the modeling approach or results, there is no need to revise the report.

**15.12 INTERROGATORY STATEMENT(S):** Page 7 of Neptune and Company, Inc. (2012) states "Alluvial and lacustrine sediments that fill the valley floor are estimated to extend to depths of greater than 500 ft with unconsolidated sediments ranging from 300 to over 500 ft."

Please review this text and revise it as needed.

**ENERGY*SOLUTIONS'* RESPONSE:** Sediments below 300 ft are described in the paragraphs following the text cited by DRC. No change is required.

**15.13 INTERROGATORY STATEMENT(S):** On Page 8 of Neptune and Company, Inc. (2012), it says, "The site aquifer system consists of a shallow unconfined aquifer that extends through the upper 40 ft of lacustrine deposits."

Please review this text and revise it as needed to indicate that the aquifer only exists from the top of the water table (which, on average, exists at a depth of about 15 feet below normal ground surface) down to about 40 feet below normal ground surface.

**ENERGY*SOLUTIONS'* RESPONSE:** The clarification is noted. This site description has been updated by Energy*Solutions* in the License renewal application. Since the site description has no impact on the modeling approach or results, there is no need to revise the report

**15.14 INTERROGATORY STATEMENT(S):** Page 29 of Neptune and Company, Inc. (2012) speaks of a "capacity flow rate of a drainage layer ... " as

$$Q^{cap} = K_s * T * i$$

Please fix the description of this equation, or justify its inclusion in the PA as is.

**ENERGY*SOLUTIONS'* RESPONSE:** In the Neptune report instead of stating:

"*The capacity flow rate of a drainage layer sloping at an angle β is given by Meyer et al. (1996)...*"

It would be more accurately presented as:

The capacity flow rate for a 2-D cross-section of a drainage layer sloping at an angle β is given by Meyer et al. (1996)...

Unit dimensions are provided below:

$Q^{cap}$ $[L^2 T^{-1}]$

Ks [L $T^{-1}$]

T [L]

i [dimensionless]

**15.15 INTERROGATORY STATEMENT(S):** Page 48 of the Neptune and Company, Inc. (2012) report refers to four tested cores having "slightly less than 50 percent clay and 50 percent silt and a small percentage of clay."

Please correct the statement on Page 48 quoted above by changing the last word to "sand". Please also address the mineralogical composition of on-site silts and clays since the use of these terms in the report as quoted above does not refer to mineralogical composition but only to grain size.

**ENERGY*SOLUTIONS'* RESPONSE:** The clarification is noted. The text "... *small percentage of clay" should read "...small percentage of sand.*" The paragraph cited describes a simulation conducted to examine the effect of using soil hydraulic properties associated with a coarser-grained soil than Unit 4. A coarser-grained soil was examined because the saturated hydraulic conductivity is significantly influenced by grain and aggregate size. Soil mineralogy is not considered as important a factor influencing soil hydraulic conductivity so it was not included in the discussion.

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# APPENDIX C

## SWCA Responses to

## First Round DRC Interrogatories

SWCA
ENVIRONMENTAL CONSULTANTS
Sound Science. Creative Solutions.

# Energy*Solutions* Updated Performance Assessment – SWCA's Response to First Round DRC Interrogatories

Prepared for

**Energy*Solutions***

Prepared by

**SWCA Environmental Consultants**

September 2013

# ENERGY*SOLUTIONS* UPDATED PERFORMANCE ASSESSMENT – SWCA'S RESPONSE TO FIRST ROUND DRC INTERROGATORIES

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September 25, 2013

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**Attachment A.** Reclamation and Revegetation Plan for an ET Cover System at Clive

# Introduction

## *SWCA's Background with EnergySolutions' Proposed Evapotranspiration (ET) Cover System*

The primary objective of ET cover systems is to use the water-balance components of soil and vegetation to hold precipitation and release it through soil-surface evaporation or plant transpiration without allowing water percolation into radon barrier layers. The ultimate goal of such systems is to prevent the movement or release of waste and contamination of soils, water, or biota.

In September 2010, SWCA Environmental Consultants (SWCA) was contracted by Energy*Solutions* to gather soil-turbation data at five sites in and around the Clive site (SWCA 2010). The field data were collected to support Neptune and Company, Inc.'s landscape modelto predict ecological conditions at and near the Clive site 10,000—2,000,000 years into the future for the Depleted Uranium Performance Assessment. Study sites were placed at elevations at and above the elevation of the Clive site as analogues of the ecological conditions that are most likely to exist there in coming millennia. One-hectare study plots were established in three locations at the Clive site and in two off-site locations, with each site representing a distinct vegetation association along soil and elevation gradients. Two of the five plots (Plots 3 and 4) were at elevational ranges that are representative of conditions on the Clive site. Only one of these was representative of natural vegetation conditions at Clive (Plot 3). Data were collected to document the diversity and composition of plant and animal species and to quantify soil turbation by burrowing mammals and ants associated with each vegetation community. In addition, excavations were conducted at six predetermined locations at the Clive site, some of which contained potential borrow soils for the proposed ET cover. At each excavation, the aboveground and belowground size of dominant plant species and maximum rooting depth and width of roots of dominant plant species were measured.

In March 2012, SWCA was contracted by Energy*Solutions* to conduct a literature and data review of ET cover systems and to develop a design for field studies of ecological analogues of the Clive site to support the development of an ET cover system at the facility (SWCA 2012).

In June 2012, SWCA conducted field studies to quantify the vegetation, small mammal distributions, and mammal burrow and ant mound size and densities at the Clive site and at ecologically analogous sites nearby. In addition, several excavations of the Unit 4 borrow soils were performed to determine average ant mound depth and volume of soil that ants typically transport to the soil surface (SWCA 2012). These data were used as input parameters for contaminant fate and transport models developed by Neptune and Company to analyze one conventional cover and two ET cover design scenarios (Neptune and Company, Inc., 2012). The modeling results were provided to the Utah Division of Radiation Control (DRC) as an appendix in Energy*Solutions*' Updated Site-Specific Performance Assessment (PA).

In October 2012, Energy*Solutions* submitted the Updated Site-Specific Performance Assessment and a License Renewal Application to the Utah Division of Radiation Control (DRC). These documents included analyses of, and a permit request for, two evaporative-cover designs for its proposed Class A West embankment at the Clive site, Utah, which were supported by SWCA's literature and data reviews and field studies (SWCA 2010, 2012).

In June 2013, Energy*Solutions* received the Round 1 Request for Information (RFI) from the DRC regarding the Updated Site-Specific Performance Assessment.

In August 2013, Energy*Solutions* retained SWCA to help respond to 22 of the approximately 111 interrogatories included in the DRC RFI. This report presents SWCA's responses to those DRC interrogatories.

## Organization of SWCA's Interrogatory Responses

SWCA's responses to the DRC RFI are organized according to the four interrogatory topical categories (as assigned by DRC) represented in the interrogatories designated to SWCA by Energy*Solutions*:

- Section 4.0 Erosion
- Section 5.0 Biointrusion by Mammals
- Section 6.0 Biointrusion by Plant Cover and Plant Roots, Model Plant Parameters
- Section 7.0 Transpiration

SWCA has further organized the interrogatory responses by the Energy*Solutions*' PA section number referenced by DRC:

- DRC RFI Section 4.0 Erosion
  - PA Section 2.2 Embankment Cover Designs
  - PA Section 3.1 Soil Pathway
- DRC RFI Section 5.0 Biointrusion by Mammals
  - PA Section 2.1.11 Ecology
  - PA Section 3.1.6 Burrowing Animal Pathway
  - PA Section 3.3 Protection of Individuals during Operation
- DRC RFI Section 6.0 Biointrusion by Plant Cover and Plant Roots, Model Plant Parameters
  - PA Section 2.1.11 Ecology
  - PA Section 3.1.5 Vegetation Pathway
  - PA Appendix B—Modeling Report (Neptune and Company, Inc., 2012)
- DRC RFI Section 7.0 Transpiration
  - PA Section 2.2 Embankment Cover Designs

SWCA's interrogatory responses are organized by DRC–assigned interrogatory categories. Each interrogatory response is preceded by: 1) the referenced section in Energy*Solutions*' PA, and 2) the DRC Interrogatory Statement. Full reference information for all cited literature is provided in Section 4.0, Literature Cited. Electronic copies of all public domain documents are available upon request.

## Ecological Basis for the Interrogatory Responses

The proposed ET cover design is based on published ET cover -system recommendations and site-specific climate and ecology as determined by multiple field study efforts (SWCA 2010, 2012). This approach is well-supported by published studies and guidance documents for ET cover systems (ITRC 2003; Peace et al. 2004; Rock et al. 2012; Scanlon et al. 2005). The target vegetation community for the ET cover is based on quantitative biotic and soils data collected at ecological analogs to the Clive site. The shrub species that dominate the vegetation at the site are small in stature compared to their conspecifics in deeper, more fertile soils and/or areas that receive greater annual precipitation. High soil salinity and pH, as well as the low fertility of local soils and aridity of the Clive site, drive the distributions, densities, and stature of plant species there, and these characteristics are the basis for the vegetation plan (Attachment A). Although the flora and fauna that exist on and near the Clive site occur at low densities and/or are generally small in size, there is the expectation that the local flora and fauna will penetrate soil layers in the ET cover. It is also expected that biointrusion of lower levels of the cover system could occur due to plant or animal penetration of the filter zone. Nevertheless, the amount of soil disturbance that could potentially occur on the ET cover is minute, compared to the total soil volume on the ET cover. Similarly, the amount of water infiltration that could occur in association with biointrusion of the ET cover is also minute. Estimates of expected vs. worst-case levels of soil displacement on the ET cover are included as part of the DRC interrogatory responses provided here.

# DRC Interrogatory Responses

SWCA's responses to DRC's interrogatories were developed based on reviews of existing field studies at and near the Clive site, review and analyses of literature cited by DRC, and review of other relevant scientific literature and supporting documents.

The DRC interrogatory responses are organized by the DRC RFI Section, with each DRC Interrogatory Statement preceding SWCA's response. The DRC Interrogatories are organized in numerical order.

# *DRC RFI Section 4.0 Erosion*

## EnergySolutions PA Section 2.2 Embankment Cover Designs

### *DRC Interrogatory 4.1*

**DRC Interrogatory Statement:**

***It is stated on Page 2-6 that "Long-term stabilization of the Embankment is accomplished through erosion control and flood protection."***

***The statement above that stabilization of the embankment is accomplished over the long-term using erosion control does not appear to be supported by existing data, as noted in the following photos [three photos illustrate rill and gully formation on sloped bare soils at Clive]. These photos show that existing erosion control for clay soils on site is in some places only partially effective, and that erosion control needs to be undertaken from year to year. Stabilization now does not necessarily indicate stabilization over time within the modeled timeframe (i.e., 10,000 years). Please either justify the statement above, or revise it to be consistent with existing data.***

**SWCA Response:**

Over the long-term (> 5 years), the top and sides of the cover system will be stabilized by biological soil crust organisms and native vegetation. Installation of the proposed ET cover design will include reclamation measures designed to quickly stabilize soils and initiate the development of a functioning native vegetation community. During the initial vegetation establishment period (0–2 years), the cover will be seeded with fast-growing species to stabilize soils and exclude invasive annuals. The seed mix will also include native perennial shrubs, forbs, and bunchgrasses (see Attachment A). The native vegetation will become established and develop into an early successional salt desert scrub community during the revegetation period (3–5 years). The establishment of a stable and functioning system comprised of native vegetation and soil biota will eliminate any near-term episodic erosional exposure of contaminated materials. A functioning native ecosystem will also provide long-term soil stabilization via soil development, plant roots in upper soil layers, and biological soil crusts.

The DRC interrogatory statement refers to a bare soil cover system in both the short- and long-term, which is not representative of conditions that will exist for either of the proposed ET cover system designs presented in the PA. The DRC cites Nelson et al. (1983), who address the use of riprap in ditches and on embankment slopes as a method to dissipate and slow flowing water and thereby limit or prevent erosional exposure of contaminated material. However, the cover designs evaluated in the PA include riprap-lined diversion ditches to direct water away from the ET cover, but the top and sides of the ET cover do not include riprap as part of the cover materials. Additional DRC references to exposed soil rilling and erosion on riprap cover systems (Abt et al. 1994; Johnson 2002) also have limited applicability to a functioning vegetated ET cover system because riprap will not be used on the top of the cover.

Energy*Solutions* recognizes that erosion may be a primary threat to the long-term stability of the ET cover. Both ET cover designs are comprised of native silt and clay soil layers that, if left exposed, might be susceptible to erosion, as shown in the photographs presented by DRC. However, functioning native ecosystems comprised of the borrow soils at the Clive site do not show erosion as the DRC suggests. Evidence of soil erosion at and near the Clive site is minimal: there was no evidence of water erosion and limited areas where aeolian movement of soils had created small berms over long periods of time (SWCA 2010, 2012). Rilling has not been documented in undisturbed soils at Clive (SWCA 2012).

The soil surface throughout the Clive site and environs is dominated by biological soil crusts with an average of 79.2% cover (Figure 1). Biological soils crusts have been demonstrated throughout region and elsewhere to reduce wind and water erosion and increase the stability of the soil surface (Belnap and Gillette 1998; Belnap et al. 2001). Further, the soil-stabilizing effect of biological soil crusts increases as the crust succeeds to a mature algal-fungal community (Belnap and Gillette 1998; Belnap et al. 2001). Establishment of cyanobacterial soil crusts can be achieved in less than one year, while development of diverse, mature soil crust structure can require several to 100's of years (Belnap et al. 2001). SWCA (2012) found no evidence of erosion induced by precipitation events or flooding on undisturbed soils at the Clive site, and soil-surface patterns indicated that aeolian processes (i.e., wind movement of soils) are the primary erosional force (see Figure 1), but aeolian movement of soils appears to be a long term process that is not detrimental to overall soil or vegetation stability.

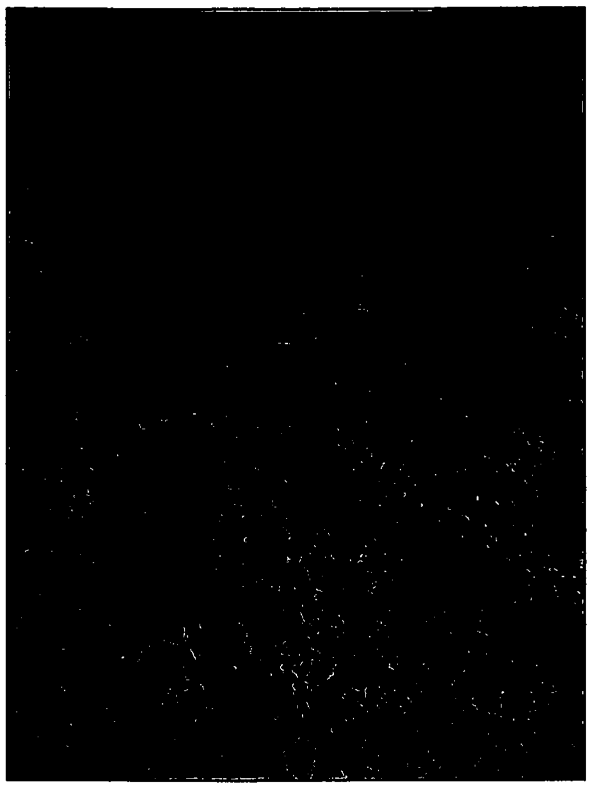

**Figure 1.** Biological soil crust cover and evidence of aeolian soil transport at Clive.

Figure 2 shows stable native soils on slopes analogous to the proposed 20% side slopes of the ET cover embankment. These stable native soils are located immediately west of the Clive site in one of the field study plot locations.

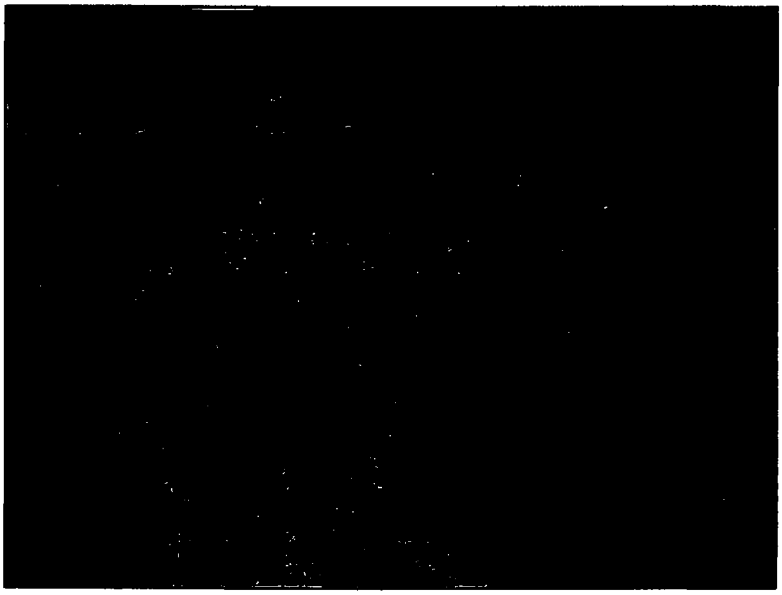

**Figure 2.** Stable native soil cover on an approximately 20% side slope west of Clive. The slope consists of biological soil crust and rocky soils similar to the 50% gravel admixture that will be used on the embankment slopes.

In the short-term, the top soil layers of a soil-based ET cover system will not have biological soil crust or vegetation cover to stabilize them and will be susceptible to wind and water erosion. The soil surface will need to be stabilized until soil crust and plant cover are established (2-5 year restoration period). Over the long-term, the top and sides of the cover system will be stabilized by biological soil crust organisms and native vegetation.

Installation of the proposed ET cover design will include reclamation measures designed to quickly stabilize soils and initiate the development of a functioning native vegetation community. Soils on the ET cover and embankment top and side slopes will be stabilized in both the short-term (0–5 years) and longer-term (> 5 years) using the following methods:

1. Use of a 15% gravel mixture for the uppermost soil layer. This method has been demonstrated to reduce erosion and facilitate evapotranspiration at Hanford (15% gravel in fine-grained sediment; Bjornstad and Teel 1993), and similar gravel layers have been effective at Monticello (8 inches [20 cm] gravel admixture; Waugh 2002, Waugh et al. 2008), Sandia National Laboratory (6 inches [15 cm] pea gravel admixture; Dwyer 1997; Scanlon et al. 2005); and Sierra Blanca (12 inches [30 cm] of 24% gravel mixture; Scanlon et al. 2005). Gravel admixtures help to limit erosion during initial vegetation establishment and enhance surface soil moisture, which enhances seed germination (Waugh et al. 2008).

2. Inoculation of the soil surface with locally sourced biological soil crust material to expedite crust recovery to within 3–5 years (Belnap et al. 2001; Bowker 2007) and to provide long-term stabilization of surface soils.

3. Seeding with fast-growing sterile grasses and native grass and forb species (Bainbridge 2007; see the Evapotranspirative Cover Revegetation and Maintenance Plan for the Clive Facility in Attachment A for target species mix). Seeding would occur during the initial vegetation establishment period (0–2 years). Vegetation management would be limited to the 5 year revegetation period (Sheley et al. 2008), during which a stable native community will have

become established on the ET cover that will naturally succeed with minimal or no management required for the life of the ET cover;

Initial establishment of fast-growing, sterile grasses will serve several functions:

a. Enhanced soil stabilization

b. Creation of dense vegetation cover to exclude invasive annuals (i.e., cheatgrass, halogeton, Russian thistle) by occupying soil interspaces until soil crusts and native species become established (Abella et al. 2011)

c. Maximization of plant water uptake and transpiration within 2 growing seasons (Waugh et al. 1994); dense vegetation cover was achieved at Rocky Flats in 2 years (Nelson 2007)

4. Establishment of native vegetation within 3–5 years to shield bare soils from raindrops, contribute to litter buildup and biological soil crust development, and reduce surface water flow and wind (Waugh et al. 2008); and

5. Installation of one or more mechanical erosion control devices:

a. A thin layer of 0.25-0.50 in [0.6-1.2 cm] fine gravel mulch to reduce soil movement by wind or water and create microsite conditions to enhance seed germination (Albright et al. 2010; Weand et al. 1999); and/or

b. Temporary erosion control using fabric, straw, or other soil stabilizing materials (Albright et al. 2010; Lutton 1987; Schuman et al. 1980) will be used if needed during the 0 to 2 year initial vegetation period and the3 to 5 year revegetation period.

Erosion and gullying of the ET cover system, and the soil-stabilizing and evapotranspirative functioning of native vegetation, will be monitored during a revegetation period of approximately 3–5 years, and well within the 100-year Institutional Control period. Development of a mature vegetation community generally requires 3–5 years (ITRC 2003). A similar revegetation time frame was instituted for the establishment and development of a steady-state plant community at Monticello (Waugh et al. 2008). Monitoring during the 3-5 year revegetation period and 100-year institutional review period will allow timely response to episodic damage to or gradual loss of soil stability or natural soil stabilization processes. Any and all maintenance required while the ET cover system is approaching steady state will be well within the initial 100-year Institutional Control period and of minor nature, such as regrading and reseeding erosional rills.

The proposed ET cover designs and associated installation procedures comply with UAC R313-25-8(4)(a) and (b); UAC R313-25-18; UAC R313-25-19; UAC R313-25-20; UAC R313-25-8(4)(d); and UAC R313-25-22 by establishing a stable and functioning system comprised of native vegetation and soil biota that minimizes any near-term episodic erosional exposure of contaminated materials. A functioning native ecosystem also provides long-term soil stabilization via soil development, plant roots in upper soil layers, and biological soil crusts.

## EnergySolutions PA Section 3.1.2 Soil Pathway:

***DRC Interrogatory 4.9***

**DRC Interrogatory Statement:**

***On Page 3-2, the PA claims, "After closure of the embankment, all waste is covered by a cover system designed to protect against erosion and losses of integrity due to waste settlement." Please revise the above statement as the DRC finds that, based on available evidence, adequate protection against erosion of proposed cover-system soils has not yet been demonstrated in the P A.***

**SWCA Response:**

See additional discussion of erosion in the Interrogatory 4.1 response.

No revision is needed to the statement in question from the PA because an abundance of evidence (see cited sources and associated discussion in the Interrogatory 4.1 response and below) indicates that there will be multiple levels of protection against erosion of proposed cover system soils.

Energy*Solutions* recognizes that erosion is a possible threat to the long-term stability of the ET cover. Both ET cover designs will be comprised of native silt and clay soil layers that, if left unaltered and exposed, would be highly susceptible to erosion. As discussed for DRC Interrogatory 4.1, functioning native ecosystems comprised of the borrow soils at the Clive site do not show evidence of significant erosion as the DRC suggests. SWCA (2012) finds no evidence of erosion induced by precipitation events or flooding on undisturbed soils at the Clive site, and soil-surface patterns indicated that long-term aeolian processes are the primary erosional force. In the short-term, the surface of a soil-based ET cover system will be highly susceptible to wind and water erosion and must be stabilized. Installation of the proposed ET cover design will include reclamation measures to quickly stabilize soils and initiate the development of a functioning native vegetation community. Soils on the ET cover embankment top and side slopes will be stabilized in both the short- and long-term using the methods outlined under DRC Interrogatory 4.1. Over the long-term, the top and sides of the cover system will be stabilized by biological soil crust organisms and native vegetation.

As part of 2012 field studies of ecological conditions at the Clive site, SWCA collected eight pooled soil samples from Unit 4 soils. The samples were collected as part of soil excavations. The resulting physical and chemical analyses (Utah State University Analytical Laboratories, Logan, Utah) indicate that the Unit 4 soil textures are silty clay to clay loam, and are comprised of an average of 52.0% silt, 35.4% clay, and 12.6% sand. Soils on the Clive site are Skumpah silt loam (0–2% slopes). Most of the field study sites, and the entirety of the Clive Facility, were on Skumpah silt loam soils, with one study site on Timpie silt loam (saline, 0–4% slopes) and one study site on Timpie-Toole complex (saline, 0–5% slopes) (see Figure 16 in SWCA 2012).

Excavations of stable walls and trenches in Unit 4 soils conducted in 2010 and 2012 suggest that these soils are cohesive (Figure 3). Although there may be some loss of cohesiveness once the Unit 4 soils are mixed with 15% gravel, there are multiple erosion control measures that will be implemented to stabilize the soil surface while vegetation and biological soil crusts become established (see the erosion control measures listed under the DRC Interrogatory 4.1 response). Denser gravel admixtures have been used on the soil surface at Monticello and other evaporative cover sites. However, a 15% gravel mixture in fine-grained sediment was demonstrated to reduce erosion and facilitate evapotranspiration at Hanford (Bjornstad and Teel 1993).

**Figure 3.** Excavated trench in Unit 4 soils at the Clive site (SWCA 2012).

The design and functioning of the proposed ET cover system requires actively growing vegetation. A 15% gravel admixture for the top slope has been selected in the ET cover designs to limit erosion without impeding cover functionality. Gravel admixtures also retain soil moisture near the surface and provide microsites for seed germination. However, because the system is designed to support native vegetation, compacting soils into rock interspaces will limit seed germination, plant growth, and rooting, all processes that are required for movement of water from soil layers and functioning of the ET cover system (ITRC 2003). There will be a tradeoff between initial stabilization of soils and limiting soil compaction to levels supportive of water storage, plant growth, and evapotranspiration, or soil bulk densities of approximately 1.7 $Mg/m^3$ or less (Warren et al. 1996). The demonstrated stability of undisturbed soils at the Clive site indicates the ability of soil biota and vegetation to limit erosional forces at the site. The objective of the ET cover design is to facilitate the development of these natural stabilizing mechanisms.

# *DRC RFI Section 5.0 Biointrusion by Mammals*

## EnergySolutions PA Section 2.1.11 Ecology

### *DRC Interrogatory 5.1*

**DRC Interrogatory Statement:**

***On Page 2-5, it says that, during a biological survey, there were "83 deer mice and one kangaroo rat trapped" at the Clive disposal facility site. Please remedy the cover design to prevent or minimize biointrusion by kangaroo rats and deer mice.***

**SWCA Response:**

The proposed design contains multiple structural and compositional features that have been demonstrated to limit or prevent biointrusion: 1) 18–30 inches (46–75 cm) of surface soils where most biointrusion would occur (Beyea et al. 1998; Bjornstad and Teel 1993); 2) a biointrusion barrier consisting of 18 inches (46 cm) of 10–16 inches (25–41 cm) cobble filled with gravel and fines (Fiedler et al. 2011; Rock et al. 2012); 3) capillary breaks at the top of the frost protection zone (12–24 inches (30–60 cm]) and filter zone (30–42 inches [60–107 cm]) (Fiedler et al. 2011); and 4) three compacted clay layers (Shuman and Whicker 1986).

As suggested by the DRC, the preferred cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively prevent biointrusion by small mammals (Fiedler et al. 2011; Rock et al. 2012). The primary biointrusion barrier proposed by Energy*Solutions* is the frost-protection zone, which consists of18 inches (46 cm) of 10–16 inches (25–41 cm) gravel and cobble mixture in-filled with small gravel, sand, and other fines (cobble and gravel to 16 inches [40.6 cm] diameter), which will also produce a capillary effect that will hold moisture in upper soil layers.

Figure 4 shows the preferred ET cover design, comprised of a thin covering of gravel mulch, 6 inches (15 cm) of soil/gravel mixture, 18 inches (46 cm) of soil (evaporative zone), 18 inches (46 cm) of soil and cobble (frost protection zone), 6–18 inches (15–46 cm) of coarse sand and gravel (filter zone), and 24 inches (61 cm) of compacted clay (upper and lower radon barriers) above a 12-inch (30 cm) temporary compacted clay cover.

## Proposed ET Cover Design and Literature-Supported Biointrusion Barrier Specifications

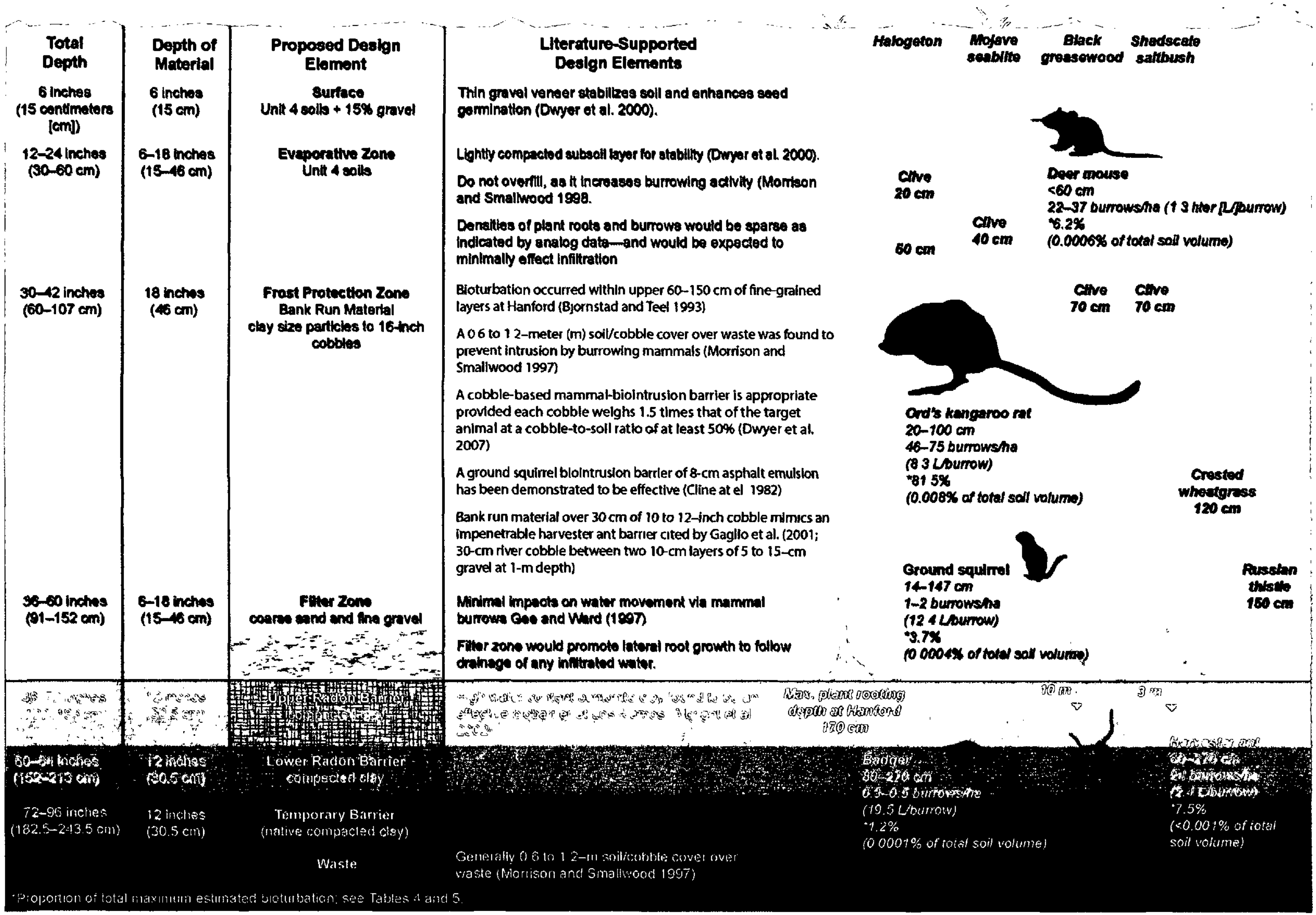


**Figure 4.** Cross-section of the preferred ET cover design at Clive.

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Based on the specifications given in the literature and designs currently in use in similar environments for ET cover systems, these layers provide multiple biointrusion barriers. As illustrated in Figure 4, the preferred ET cover design contains a biointrusion barrier that comprises the frost protection zone. The frost protection layer outlined in Energy*Solutions*' PA consists of fines with particles to 16 inches (41 cm) diameter, or bank run material. The screened bank run material to be used is illustrated in Figure 5.

**Figure 5.** Screened bank run material to be used for the ET cover system at Clive (particle sizes range from approximately 16 inches to gravel and fines).

This mixture of large (10–16 inches [25–41 cm]), medium (1–10 inches [2.5–25 cm]), and fines (< 10 inches [< 2.5 cm]) materials will function to prevent biointrusion by 1) large- and medium-sized cobble that is large enough that it cannot be moved by small animals; 2) pore sizes that cannot be circumvented by small animals; and 3) gravel and fines-filled interspaces that are a further deterrent to small burrowing animals. The bank run material provides a barrier of cobbles much larger than the prey species (mice, kangaroo rats, and ground squirrels) with pore sizes between the cobbles that are too small for these species to penetrate or inhabit or that are filled with gravel and fines that have been demonstrated to be unattractive to burrowing animals (Albright et al. 2002; Waugh et al. 2008; Fiedler et al. 2011; Rock et al. 2012). This small mammal biointrusion barrier limits badger foraging to the uppermost 24 inches (60 cm) of the ET cover. The evidence supporting this ET cover design includes effective biointrusion barriers at operational ET covers and demonstration sites, small mammal biology, and data from field studies at the Clive site. This evidence is detailed below.

EPA-recommended biointrusion barriers include 12 inches (30 cm) thick sand or gravel layers below the topsoil layer that discourage burrowing due to lack of material cohesion (Dwyer et al. 2007). Heavy rock or cobble and/or non-cohesive layers have been used in multiple ET cover systems (Bowerman and Redente 1998; Rock et al. 2012). Biointrusion barriers installed in operational ET covers consist of: 1) rock or cobble layers; 2) capillary barriers; 3) cobble/soil admixtures; 4) deep soil layers (16 feet [5 m]);

and 5) rock/soil-surface erosion treatments (Dwyer et al. 2007). Generally, a 2–4 feet (0.6 to 1.2 m layer of soil and cobble below soil layers has been shown to be effective in excluding burrowing mammals (Morrison and Smallwood 1997; Bowerman and Redente 1998). Because of the difference in particle size between the overlaying soil layer and rock layers, a cobble-based biointrusion layer also acts as a capillary break (Fiedler et al. 2011).

Biointrusion barrier specifications at sites regionally relevant to the Clive Facility based on annual precipitation, natural vegetation, and biota include:

- Hanford: 4 feet (1.2 m) of loose rock (particle sizes not specified) effectively excluded mice, but excluding pocket gophers required large cobble (particle sizes not specified) with high clay content soils in between (Bowerman and Redente 1998).
- Los Alamos: 2 feet (60 cm) of topsoil over 35 inches (90 cm) of bentonite clay, cobble, or a cobble/gravel mixture (particle sizes not specified; Bowerman and Redente 1998; Albright et al. 2002).
- Monticello, Utah: 1 foot (30.5 cm) of cobbles filled with fine soil (particle sizes not specified; Waugh et al. 2008; Fiedler et al. 2011).
- Rocky Mountain Arsenal: 16 inches (40.6 cm) of crushed concrete (Rock et al. 2012).
- Sandia National Laboratories: 1 foot (30.5 cm) of crushed rock (particle sizes not specified; Fiedler et al. 2011; Rock et al. 2012).
- Southeastern Wyoming: 1 foot (0.3 m) deep clay ET cover prevented burrowing by prairie dogs (Shuman and Whicker 1986).

Another important component of effective biointrusion barriers is an overlying soil layer that is sufficiently deep to allow for some burrowing and soil displacement without compromising underlying layers. It is not expected that the biointrusion prevention mechanisms included in the cover design will eliminate all biointrusion into lower soil layers or the frost protection zone, but that these measures will minimize any biointrusion to an insignificant level.

A minimum soil depth of 20–40 inches (0.5–1.0 m) has been shown to protect waste layers from most animal burrowing activity and allow for vertical and lateral movement of material (Beyea et al. 1998; Bjornstad and Teel 1993). At the Hanford Site, small mammals generally do not burrow below 10 inches (25 cm) depth (Bjornstad and Teel 1993; Cadwell et al. 1989). Bioturbation of soils at Hanford is limited to the upper 24–60 inches (60–150 cm) of fine-grained layers (Bjornstad and Teel 1993). However, overly deep soil layers are not desirable because soil overfill increases burrowing activity (Beyea et al. 1998; Gonzales et al. 1995; Morrison and Smallwood 1998; Reynolds and Laundre 1988). The proposed ET cover system provides 12–24 inches (30–60 cm) soil depth. Soils at 24 inches (60 cm) depth duplicate the native soil stratum at the Clive site and accommodate expected levels of bioturbation in the upper layers of the ET cover (detailed below).

**Summary of Evidence Supporting the Proposed Biointrusion Barrier at Clive**

1. The proposed biointrusion barrier system has been demonstrated to be effective at numerous operational ET cover systems identified in the bulleted list above.
2. The proposed design includes multiple layers of materials that function as biointrusion barriers:

   a. Frost Protection Zone: 18 inches (30 cm) of 10 to 16 inches (25–41 cm) cobble

   b. Filter Zone: 6–18 inches (15–46 cm) of unconsolidated material

   c. Radon Barriers: 24 inches (61 cm) of compacted clay

   d. Temporary Barrier: 12 inches (30.5) cm of compacted clay

3. The proposed ET cover vegetation composition and densities will limit densities of small mammals due to low shrub densities, and thereby limit predator foraging and the potential for biointrusion (see DRC Interrogatory 5.2 and 5.8 responses for additional discussion of potential soil movement).

4. The potential natural vegetation that will develop on the ET cover will not result in significant levels of soil disturbance in upper soil layers, or penetration of compacted clay layers due to the presence of multiple inhibitory layers (cobble, capillary barriers) that physically prevent root growth, or direct root growth laterally toward available water below the frost protection zone rather than vertically into clay barriers.

### *DRC Interrogatory 5.2*

**DRC Interrogatory Statement:**

***Also on Page 2-5, it says that, during the biological survey, burrows of badgers were observed at the Clive disposal facility site. This is in addition to the siting of multiple badgers on site (SWCA 2012). Please remedy the cover design to prevent or minimize biointrusion by badgers.***

**SWCA Response:**

As illustrated in Figure 4, the preferred ET cover design contains a biointrusion barrier as part of the frost protection zone. This cobble small mammal biointrusion barrier limits badger foraging to the uppermost 12–24 inches (30–60 cm) of the ET cover. The evidence supporting the ET cover design includes effective biointrusion barriers at operational ET covers and demonstration sites, reviews of badger and prey species biology, and data from field studies at the Clive site. Supporting evidence of biointrusion barrier designs from operational and demonstration ET cover system is summarized under DRC Interrogatory Response 5.1.

SWCA documented badgers and badger burrows at and near the Clive site during both 2010 and 2012 field studies, and concurs with the DRC's evaluation of the potential for biointrusion by badgers as reported by Hampton (2006) and others. However, Energy*Solutions* has incorporated design elements in the proposed ET cover system that have been demonstrated elsewhere to be sufficient to prevent significant release of contaminants by burrowing animals. Although badgers are capable of burrowing to depths over 6.5 feet (2 m), this behavior is restricted to pursuit of prey (Minta et al. 1992; Murie 1992). Therefore, preventing biointrusion by prey species is a key design element for the proposed ET cover system. In order to prevent badger foraging at depth, the cover design incorporates multiple elements that restrict small mammal burrowing below the evaporative soil layers (see Interrogatory 5.1 response for additional discussion of small mammal biointrusion barriers in the ET cover design).

The DRC cites potential for 4,000–6,800 badger burrows or pits per year at the Clive site (*sensu* Eldridge 2004). This level of soil disturbance is not demonstrated by either burrow survey data or observations of soil disturbance in ecologically analogous habitats at or near the Clive site in 2010 or 2012. Average badger density is one animal per square mile (Hygnstrom et al. 1994), with each animal having a 2 mile range (McKenzie et al. 1986). These estimates suggest that the badger burrows on and near the Clive site were created by one or a few animals. Badger burrows of any age within the elevational range of the Clive Facility and proposed ET cover (4,275–4,295 feet elevation) occurred at a density of 0.45 burrows per hectare (0.2 burrows per acre; SWCA 2012). Badger burrow density estimates based on the expected vegetation and associated prey densities are approximately 0.3 burrows per hectare (0.1 burrows per acre). At this density, the surface of the 132.2-acre (53.5-hectare) ET cover would contain a maximum of 16 burrows at any one time.

Eldridge (2004) estimated average badger burrow soil volume at 33.8 kg (33.8 liters) per mound. SWCA (2012) found an average burrow volume of 19.5 liters per badger burrow (SWCA 2012), which equates to 117 liters of soil disturbance caused by badger activity at any one time based on expected vegetation and small mammal densities. A conservative estimate based on Eldridge (2004) is 541–811 kg (or approximate liters) of soil disturbance caused by badgers on the ET cover at any one time. This is a miniscule level of soil disturbance that is highly unlikely to affect the functioning of the cover (*sensu* ITRC 2003). Although there is a possibility of water flow into animal burrows and root channels, Hauser et al. (2001) found that preferential flow is unlikely to contribute significantly to water flow into the cover. Test covers and natural analog studies indicate that a moderate amount of macrochannels do not compromise cover performance (Dwyer 2001).

Badgers, other predators (coyotes, foxes), and mammalian prey were documented at low densities on and near the Clive site, with predator burrows located in close proximity to dense vegetation and associated small mammal activity, as indicated by field data (Table 1). In total, four badger burrows were documented at analog study sites during 2012 field studies (SWCA 2012). The density of badger burrows at and near Clive corresponds to the density of small mammal densities and burrow densities (SWCA 2012). SWCA (2012) found approximately one badger burrow to every 12.8 burrows of potential prey species (deer mice, kangaroo rats, and ground squirrels) in ecological analog sites on and near Clive.

**Table 1.** Burrow and Small Mammal Densities Identified During 2010 and 2012 Field Studies of Ecological Analogs to the Clive Site

| Plot Number | Badger Burrows | Small Mammal Burrows | Small Mammals Trapped |
|---|---|---|---|
| 3 (2010) | 0 | 3 | 0 |
| 6 | 0 | 0 | 8 |
| 7 | 1 | 6 | 6 |
| 8[1] | 0 | 0 | 0 |
| 9 | 0 | 0 | 10 |
| 10 | 0 | 0 | 2 |
| 11 | 0 | 1 | 17 |
| 12 | 3 | 41 | 35 |
| 13 | 0 | 0 | 8 |
| | **4** | **51** | **86** |

[1] This plot was immediately north of a burrowing owl family with seven owlets (in an old badger burrow) Weeks of constant hunting by the parents had likely decimated small mammal populations in the immediate area

The relationship between shrub percent cover and density to small mammal densities is shown in Table 2. The relationship between badger burrows and prey activity found at Clive is supported by Eldridge (2004), who found badger mound density to be positively correlated with prey density (mounds) and vegetation density (shrubs). In general, the density of small mammals and burrows was greater in plots with higher shrub cover and plant densities (SWCA 2012).

**Table 2.** Shrub Vegetation and Small Mammal Densities at Clive

| Plot Number | Shrub[1] Cover (Density) per Hectare | Small Mammal Density per Hectare | Small Mammals Burrows per Hectare |
|---|---|---|---|
| 3 (2010) | 16.7% (40) | 10 | 0 |
| 6 | 20 7% (236) | 80 | 0 |

**Table 2.** Shrub Vegetation and Small Mammal Densities at Clive

| Plot Number | Shrub[1] Cover (Density) per Hectare | Small Mammal Density per Hectare | Small Mammals Burrows per Hectare |
|---|---|---|---|
| 7 | 24 8% (84) | 60 | 20 |
| 8[2] | 13 8% (121) | 0 | 0 |
| 9 | 8.7% (76) | 100 | 0 |
| 10 | 5.6% (30) | 20 | 0 |
| 11 | 10.4% (30) | 160 | 10 |
| 12 | 39.0% (47) | 340 | 150 |
| 13 | 22.7% (106) | 80 | 0 |
| | **18.0% (85.6)** | **94.4** | **20.0** |

[1] Shrub species comprise fourwing saltbush (*Atriplex canescens*), shadscale saltbush (*Atriplex confertifolia*), gray molly (*Bassia americana*), bud sage (*Picrothamnus desertorum*), black greasewood (*Sarcobatus vermiculatus*), and Mojave seablite (*Suaeda torreyana*)

[2] This plot was immediately north of a burrowing owl family with seven owlets (in an old badger burrow) Weeks of constant hunting by the parents had likely decimated small mammal populations in the immediate area

There are differences in plant species composition and cover between the plots that need to be considered for the ET cover vegetation community and long-term biointrusion potential. Vegetation at the Clive site consists of Inter-Mountain Basins Mixed Salt Desert Scrub and Inter-Mountain Basins Greasewood Flat communities (Lowry et al. 2007). Native vegetation on the soils that occur on the site is limited to shadscale saltbush, fourwing saltbush, gray molly, greasewood, and perennial grasses such as squirreltail (*Elymus elymoides*), Indian ricegrass (*Achnatherum hymenoides*), and Sandberg bluegrass (*Poa secunda*).

The target vegetation community on the ET cover consists of small stature native shrub species (*Atriplex* spp., *Bassia americana*, *Picrothamnus desertorum*, and *Suaeda torreyana*), and native forbs and grasses (see the Interrogatory 6.1 response and Attachment A for more detailed discussion of the proposed vegetation composition for the ET cover). Greasewood is not included in the target community due to the species deep-rooting habit, the affinity of badgers for larger stature shrub species (Eldridge 2004), and the demonstrated affinity of small mammals for higher shrub densities (SWCA 2010, 2012; see the Interrogatory 6.3 response for detailed discussion of greasewood potential on the ET cover). The affinities of the biota for denser vegetation is demonstrated by the levels of animal activity documented in plots 3, 6, 7, 12, and 13, all of which contain relatively large greasewood plants and have the highest total vegetation cover of the nine plots sampled (Table 3).

**Table 3.** Average Shrub Vegetation and Animal Activity at Plots with and without Greasewood Cover at Clive

| Plots | Shrub Cover (Density) per Hectare | Small Mammal Density per Hectare | Small Mammals Burrows per Hectare | Badger Burrows per Hectare |
|---|---|---|---|---|
| **11.5%–19.0% Greasewood (Plots 3, 6, 7, 12, 13)** | 24.8% (103) | 114.0 | 35 7 | 0 45 |
| **0% Greasewood (Plots 8, 9, 10, 11)** | 9.6% (64) | 70 0 | 2 5 | 0.30 |

The target vegetation community on the ET cover is based on local conditions and uses local plant materials. The shrub species that dominate the vegetation at the site are small in stature compared to their conspecifics in deeper, more favorable soils and with greater annual precipitation. The unique soil conditions and aridity of the site are considered in the vegetation plan, as it is unlikely that shrubs will achieve the sizes or rooting depths demonstrated in cooler, higher precipitation environments. For example, fourwing saltbush is excluded from vegetation seed mixes and plantings at Sandia because of the deep-rooting potential of the species there (Peace et al. 2004). At Clive, most saltbush roots are within the upper 12 inches (30 cm) of soil with a maximum rooting depth of 28 inches (70 cm; SWCA 2010). This shallow growth habit is likely due to the compacted clay layer at approximately 24 inches (61 cm) depth (SWCA 2010, 2012).

The average densities for the different shrub compositions identified at Clive as presented in Table 3 are used as estimates for expected versus worst-case scenarios for the ET cover. The expected vegetation composition on the ET cover is approximately 15% shrub cover, dominated by saltbush and gray molly with sparse grasses and forbs (see Attachment A). This vegetation system covering the entire 132.2-acre (53.5-hectare) ET cover is estimated to support approximately 3,745 small mammals, 134 small mammal burrows, and 10–16 badger burrows at any one time. A greasewood-dominated vegetation community will likely consist of 25% or greater shrub cover. This vegetation community will attract approximately 6,100 small mammals, with 1,820 small mammal burrows and 24–124 badger burrows.

Differences in the structure and composition of expected and worst-case vegetation communities and associate faunal activity are summarized in Table 4. The table demonstrates that mammalian soil excavations will disturb insignificant amounts of soil relative to the entire soil volume of the cover system. Total soil disturbance under expected vegetation conditions and associated mammal activity will be less than 1/100$^{th}$ of a percent of the total soil volume. Total soil disturbance under a worst-case scenario with the vegetation dominated by greasewood will result in a total of less than 1/10$^{th}$ of a percent of total soil volume, with disturbance limited to the upper 12–24 inches (30.5–61 cm) of soil layers.

**Table 4.** Predicted Mammal Burrowing Volume under Expected and Worst-Case Vegetation Scenarios at Clive

| Expected Vegetation Conditions (greasewood excluded) | | | | | |
|---|---|---|---|---|---|
| **Burrow Densities and Volume** | **Deer Mouse** | **Kangaroo Rat** | **Ground Squirrel** | **Badger** | **TOTAL** |
| **Average Burrows/ Hectare** | 22.4 | 46.2 | 1.4 | 0.3 | 70 3 |
| **Average Soil Volume Excavated/Burrow (L)** | 1.3 | 8 3 | 12.4 | 19 5 | 41.5 |
| **Total Soil Volume Excavated (L)** | 1,557.9 | 20,515.1 | 928.8 | 313.0 | 23,314.8 |
| **Percent of Total Soil Volume on the ET Cover** | 0 0004% | 0 0049% | 0.0002% | 0.0001% | 0.0056% |
| **Worst-Case Vegetation Conditions (greasewood dominant)** | | | | | |
| **Burrow Densities and Volume** | **Deer Mouse** | **Kangaroo Rat** | **Ground Squirrel** | **Badger** | **TOTAL** |
| **Average Burrows/ Hectare** | 36.48 | 75 24 | 2 28 | 0 45 | 114 45 |
| **Average Soil Volume Excavated /Burrow (L)** | 1 3 | 8 3 | 12 4 | 19.5 | 41.5 |
| **Total Soil Volume Excavated (L)** | 2537.2 | 33410.3 | 1512.6 | 469 5 | 254107.6 |
| **Percent of Total Soil Volume on the ET Cover** | 0.0006% | 0 0080% | 0.0004% | 0 0001% | 0.0609% |

Although the cover will be maintained to exclude greasewood during revegetation and monitoring periods, it is likely that greasewood will become established sometime during the life of the ET cover because of its occurrence in adjacent vegetation communities. Even under the worst-case scenario, with dense vegetation and high levels of associated burrowing animal activity, the multiple levels of biointrusion barriers in the cover design would minimize animal and root penetration into or beyond the cobble layer.

In addition, the compacted clay layers below the filter zone will move any percolated water laterally across the clay layers and will promote lateral root growth instead of penetration of clay layers. This effect was demonstrated at multiple soil excavations at the Clive site, where greasewood tap roots and other biotic activity (fine roots, tunnels) do not extend below the compacted clay layer at 24 inches (60 cm) depth (SWCA 2010, 2012). Both taproots and fine roots extend laterally across the surface of the compacted clay layer, presumably following any water that is perched above the clay (Figure 6).

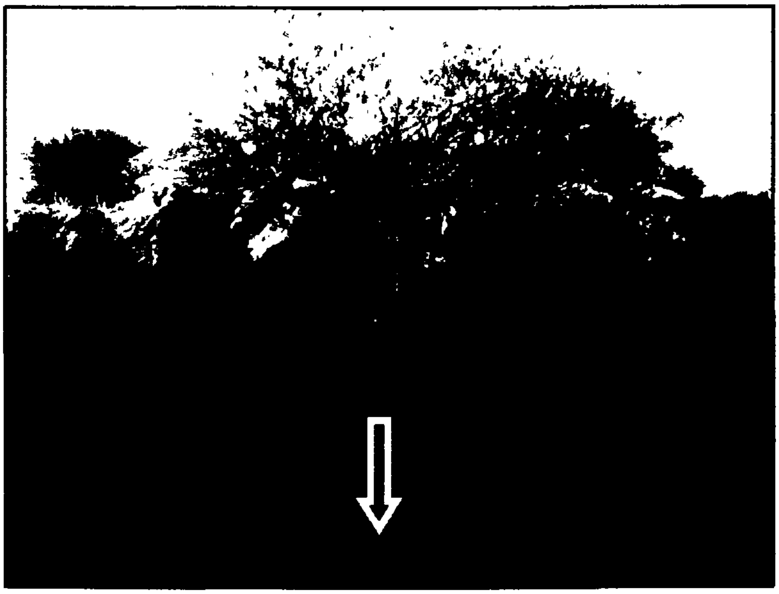

**Figure 6.** Borrow soil cross-section below a greasewood plant shows the compacted clay layer at approximately 60-cm depth (SWCA 2010). Roots extend laterally and do not penetrate the compacted layer.

The long-term functioning and sustainability of the proposed ET cover system requires that a resilient and diverse plant community is established on the ET cover (Waugh 1997; Waugh et al. 2008). Any vegetation on the ET cover will attract some degree of animal activity. As was demonstrated in SWCA (2012), denser vegetation was correlated with higher levels of animal activity at and near Clive. However, native plant species that are adapted to local climate and soils are the most likely to persist on the cover (ITRC 2003), and a naturally succeeding plant community will maintain or improve ET rates from soil layers (Waugh et al. 2008). As has been demonstrated at operational ET covers (Waugh et al. 2008), some deep-rooting plant cover is desirable because it increases water release from deep soil layers (Hauser et al. 2001; ITRC 2003). Deeply rooting vegetation stabilizes soils, reduces erosion, and increases water storage in the root zone (Hauser et al. 2001; ITRC 2003). Deep-rooting shrub species currently occupy functioning cover systems at Hanford (big sagebrush, rabbitbrush; Gee et al. 1997, 2002) and Monticello (big sagebrush, bitterbrush, rabbitbrush; Waugh et al. 2008).

In general, plant selection for the ET cover will be limited to species that are well-adapted to the borrow soils and/or amended soil composition, contribute to evapotranspiration from the ET cover, intercept precipitation and stabilize soils, and are ecologically resilient (Waugh et al. 2008). A diverse mix of native species and/or improved cultivars will be targeted for the cover system.

### *DRC Interrogatory 5.3*

**DRC Interrogatory Statement:**

***In addition to badgers, kangaroo rates and deer mice, it is said on Page 2-5 that ground squirrels were observed during field studies at the Clive facility site. Please provide an appropriate design to defend against biointrusion by ground squirrels.***

**SWCA Response:**

See responses to DRC Interrogatories 5.1 and 5.2.

Ground squirrel burrows were observed at two study locations during 2010 and 2012 field studies. No individuals were captured during small mammal trapping. Nevertheless, the same biointrusion barrier effectiveness rationale presented in the DRC Interrogatory 5.1 response also applies to ground squirrels. The cobble sizes and interspaces also apply to exclusion of the larger body sizes of ground squirrels compared to deer mice and kangaroo rats.

### *DRC Interrogatory 5.4*

**DRC Interrogatory Statement:**

***While badgers, ground squirrels, kangaroo rats, and deer mice are mentioned in the P A as burrowing mammals that live on or near the site, coyotes are not mentioned in the P A. Please provide an appropriate design to defend against biointrusion by coyotes.***

**SWCA Response:**

See DRC Interrogatory 5.2 response for additional discussion of predatory mammal potential for biointrusion into the cover.

Coyotes are known to occur in the vicinity of the Clive site, and dens were incidentally observed outside of study plots in both 2010 and 2012. The same rationale for biointrusion barrier effectiveness that is presented in the DRC Interrogatory 5.2 response also applies to coyotes:

As illustrated in Figure 4, the preferred ET cover design contains a biointrusion barrier as part of the frost-protection zone. This large, cobble, small mammal biointrusion barrier limits coyote foraging to the uppermost 12–24 inches (30–60 cm) of the ET cover. The evidence supporting the ET cover design includes effective biointrusion barriers at operational ET covers and demonstration sites, as well as reviews of burrowing mammal biology. Supporting evidence of biointrusion barrier designs from operational and demonstration ET cover system is summarized under DRC Interrogatory Response 5.1.

### *DRC Interrogatory 5.5*

**DRC Interrogatory Statement:**

***Not mentioned in the PA in this section describing burrowing animals on site are kit foxes. Kit foxes should be mentioned here. Please do so.***

**SWCA Response:**

See DRC Interrogatory 5.2 response for additional discussion of predatory mammal potential biointrusion into the cover.

Kit foxes were not documented on or near the Clive site during the 2010 and 2012 field studies, but the potential for this species to occur at the site is noted. The same biointrusion barrier effectiveness rationale presented in DRC Interrogatory response 5.2 also applies to kit foxes:

As illustrated in Figure 1, the preferred ET cover design contains a biointrusion barrier as part of the frost protection zone. This large cobble small mammal biointrusion barrier limits kit fox foraging to the uppermost 12–24 inches (30–60 cm) of the ET cover. The evidence supporting the ET cover design includes effective biointrusion barriers at operational ET covers and demonstration sites and reviews of burrowing mammal biology. Supporting evidence of biointrusion barrier designs from the operational and demonstration ET cover system is summarized under DRC Interrogatory Response 5.1.

### *DRC Interrogatory 5.6*

**DRC Interrogatory Statement:**

***Page 2-5 contains the following paragraph: "Although a vegetation community of sufficient diversity and density is desired to maximize transpiration from the soil, vegetation density was positively correlated with small mammal and burrowing activity. As such, bioturbation should be expected to increase with increasing vegetation. Furthermore, the presence of badgers and a large family of burrowing owls indicates that the biota can potentially move large volumes of soil. Because of this, the bank-run borrow material layer has been included in both of the evapotranspirative cover designs as a bio-intrusion and bioturbation barrier (also serving to minimize the penetration by ants through the cover layers)."***

***The DRC finds that the bank-run borrow material layer included in the proposed design is not likely to minimize biointrusion. The DRC accordingly requires a more effective and detailed plan than proposed.***

**SWCA Response:**

See detailed discussion of proposed biointrusion barriers in the DRC Interrogatory 5.1 and 5.2 responses.

The preferred cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively minimize or eliminate biointrusion by small mammals. The primary biointrusion barrier is the frost protection zone that will comprise 18 inches (46 cm) of 10–16 inches (25–41 cm) gravel and cobble mixture in-filled with small gravel, sand, and other fines (cobble and gravel to 16 inches [41 cm] diameter), which will also produce a capillary effect that will hold moisture is upper soil layers. A diagram of the proposed design and literature-supported design elements is given in Figure 4. The rationale and scientific basis for the biointrusion barrier proposed is detailed in the DRC Interrogatory 5.1 response. Detailed description of expected vegetation-animal burrowing interactions under different vegetation densities is described in detail in the DRC Interrogatory 5.2 response.

## EnergySolutions PA Section 3.1.6 Burrowing Animal Pathway

### *DRC Interrogatory 5.8*

**DRC Interrogatory Statement:**

***Page 3-4 says, "The site-specific Performance Assessment developed in support of the disposal of depleted uranium evaluated the impact of ant burrowing on the transport of contaminant and found no significant associated impact to the performance of the Embankment." That study and its conclusions are not found to be relevant to this PA. Please revise this PA to provide analysis of potential significant impact on embankment performance and effects on human health and the environment due to harvester ants burrowing through cover-system soils.***

**SWCA Response:**

The EPA-recommended biointrusion barriers include 30-cm-thick sand or gravel layers below the topsoil layer that discourage burrowing due to lack of material cohesion (Dwyer et al. 2007). Heavy rock or cobble and/or non-cohesive layers have been used in multiple ET cover systems (Rock et al. 2012). Biointrusion barriers installed in operational ET covers consist of: 1) rock or cobble layers; 2) capillary barriers; 3) cobble/soil admixtures; 4) deep soil layers (5 m); and 5) rock/soil surface erosion treatments (Dwyer et al. 2007). Because of the difference in particle size between the overlaying soil layer and rock layers, a cobble-based biointrusion layer also acts as a capillary break (Fiedler et al. 2011).

A 12-inch (30 cm) layer of cobble sandwiched between two 4-inch (10 cm) layers of chipped gravel has been demonstrated to be effective in excluding ants (Gaglio et al. 2001). This ant exclusion study at the Idaho National Laboratory (INL) found no ant corridors below the upper surface of the gravel-cobble-gravel biobarrier into the cobble layer. The barrier prevented intrusion below 20–40 inches (50–100 cm) depth (Gaglio et al. 2001). This design is very similar to the proposed biointrusion barrier in the frost protection zone that comprises 18 inches (46 cm) of 10–16 inches (25–41 cm) cobble below 12–24 inches (30–60 cm) (see Figure 4).

In addition to the proposed biointrusion barrier, the overlying soil layers are sufficiently deep to allow for ant activity and soil displacement without compromising underlying layers. It is not expected that the biointrusion prevention mechanisms included in the cover design will eliminate all biointrusion into lower soil layers or the frost protection zone over the long-term, but that these measures will minimize any biointrusion to an insignificant level.

SWCA found an average of 24 ant mounds per hectare (9.7 per acre), with anthills covering 4.6% of the ground surface in field study sites (SWCA 2012). Average harvester ant mound aboveground volume was 1.9 liters. In addition, four ant mounds were excavated in Unit 3 and Unit 4 soils to estimate belowground mound volume. The average aboveground and belowground volume of harvester ant nests is 2.7 liters and 28.3 liters, respectively. As is found for shrub rooting, most of the belowground ant nest volume is within 24 inches (60 cm) of the soil surface due to the presence of compacted clay and caliche layers. Ant nest volume and corridor densities generally decrease with depth, and most ant activity would occur in soil layers and interspaces of the frost protection zone, but penetration beyond the capillary break at 42 inches (107 cm) depth would be minimal.

Published harvester ant nest densities are 13 mounds per hectare (5.3 per acre), with a maximum nest depth of 9 feet (2.7 m). SWCA's field estimate of 24 nests per hectare is comparable to average densities found at INL in southeast Idaho (Gaglio et al. 2001). Nest densities at INL ranged from 0 to 164 nests per hectare (0–66 nests per acre) Gaglio et al. 2001). Mean depth of ant nests in soil at Hanford was 7.5 feet

(2.3 m) with an average of 1.8 liters excavated per nest (Fitzner et al. 1979). Other published soil excavation estimates per nest include 3.6 kg (liters) per nest with 0.1 new nests per year (Blom et al. 1991, as cited in Hampton 2006). Fitzner et al. (1979) reported ant nest volumes with depth estimates, with approximately 0.20 liters of soil excavated per 6 inches (15 cm) up to 35 inches (90 cm) depth, 0.9 liters excavated from 35 to 53 inches (90 to 135 cm). Table 5 gives a conservative estimate of total soil volume potentially excavated from soil layers on the proposed ET cover based on the Fitzner et al. (1979) estimate of 4.5 liters per nest. The total proportion of soil potentially excavated based on this estimator demonstrates the minute total soil excavation potential associated with average ant nest densities on the proposed ET cover. The total proportion of ET cover soils that could be excavated at 24 nests per hectare (270 nests total on the ET cover) is less that 0.001% of total soil volume.

Table 5. Harvest Ant Excavation Potential by Stratum in the Preferred Cover Design

| **ET Cover Stratum** | **Depth of Stratum** | **Soil Volume Excavated per Nest by Stratum per Fitzner et al. 1979*** | **Estimated Total Volume of Ant Nests by Stratum*** | **Total Soil Excavated as a % of Soil Stratum Volume** |
|---|---|---|---|---|
| Gravel mulch (0 4 in [1 cm]) | 0.4 in (1 cm) | – | – | – |
| Unit 4 soils + 15% gravel (6 in [15 cm]) | 6.3 in (16 cm) | 0.21 liters | 1,284 nests<br>269 6 L | 85,600,000 L soil<br>0 0003% excavated |
| Evaporative Zone (Unit 4 soils; 18 in [46 cm]) | 24 in (62 cm) | 0.42 liters | 539 3 L | 331,700,000 L soil<br>0.00002% excavated |
| Frost Protection Zone (10-16 in [25-41 cm] cobbles filled with gravel and fines) | 42 5 in (108 cm) | 1 05 liters | 20-40 in (50-100 cm) was the most effective depth for the ant biobarrier design at INL (Gaglio et al 2001) | |
| Filter Zone (6-18 in [15-56 cm] coarse sand and fine gravel) | 48-61 in (123–154 cm) | 0 60 liters | Mean nest depth at INL (50 in [128 cm]) (Gaglio et al. 2001) | |
| Upper Radon Barrier<br>(12 in [30 5 cm] compacted clay) | 61-74 in (154–188 cm) | | | |
| Lower Radon Barrier (12 in [30.5 cm] compacted clay) | 72-86 in (184–218 cm) | 0.40 liters | | |
| Temporary ET cover (12 in [30 5 cm] compacted clay) | 85-98 in (215–249 cm) | 0 30 liters | Maximum nest depth at INL (91 in [230 cm]) (Gaglio et al. 2001) | |
| **Total soil excavated** | | **2.4 liters per nest (Fitzner et al. 1979)** | **3081.6 L** | **417,300,000 L total soil volume on ET cover**<br>**<0.001% excavated** |

* The Fitzner et al (1979) soil volume estimates are for soil, not rock or mixed materials The total soil volume of 2 4 liters per nest (as estimated by Fitzner et al (1979) was used for the total soil excavation estimate, but this volume would be removed from upper soil layers, not from the filter zone layers

Other modes for minimizing ant activity on the ET cover are development of a shrub-dominated native plant community and control of annual weeds. Native plant communities on and near the Clive site have very low grass cover, so ant nests are not correlated with grass densities. SWCA (2012) documented less than 1.0% average grass cover across eight field study sites. Instead, harvester ant nest density was strongly associated with annual weed densities at Clive. As such, the vegetation plan for the ET cover includes methods for monitoring and controlling weeds on the cover during the initial vegetation establishment period and the 3–5 year vegetation maintenance period. Early control has been shown to be effective for reducing weed cover to allow dominance by native shrubs and grasses at ecologically relevant corollaries to the Clive site (Monticello; Sheader and Kastens 2007).

### *DRC Interrogatory 5.9*

**DRC Interrogatory Statement:**

***After mention of ants, it says on Page 3-4, "other burrowing animals at the site include jackrabbits, mice, and foxes." Please make this listing of burrowing animals at the site more complete by adding to the list kangaroo rats, ground squirrels, badgers and coyotes.***

**SWCA Response:**

The list has been revised to include kangaroo rats, ground squirrels, badgers and coyotes, and any additional fossorial mammals with potential to occur on or near the Clive site.

### *DRC Interrogatory 5.10*

**DRC Interrogatory Statement:**

***Page 3-4 refers to "other burrowing animals at the site" and lists among them "jackrabbits". Jackrabbits do not burrow, per se. Please correct the quoted statement.***

**SWCA Response:**

The list has been revised to not include black-tailed jackrabbits (*Lepus californicus*).

### *DRC Interrogatory 5.13*

**DRC Interrogatory Statement:**

***It says on Page 3-4 "After final placement of the cover, the design features of the facility, primarily the thick soil cover that isolates the waste from burrowing animals, will control releases and doses. Because of this, the likelihood of any animals burrowing through the entire cover and exhuming waste materials is sufficiently low that it was not included in the safety assessment calculations." The Licensee needs to recognize the potential problem here. The statement that "the likelihood of any animals burrowing through the entire cover and exhuming waste materials is" sufficiently low that the Licensee need not regard it in safety assessment calculations appears to be egregiously in error. The Licensee needs to develop in both its design and its modeling efforts effective measures to understand and prevent or minimize mammalian biointrusion into the radon barrier and waste. Any modeling that***

***assumes no changes in cover-system soil hydraulic conductivity, such as that resulting from biointrusion and other processes, is unacceptable to the DRC. The Licensee must consider biointrusion through the cover and into the waste in its safety assessment calculations.***

**SWCA Response:**

See detailed discussion of proposed biointrusion barriers in the DRC Interrogatory 5.1 and 5.2 responses.

The preferred cover design includes multiple layers of in-filled gravel and cobbles that have been demonstrated elsewhere to effectively minimize or eliminate biointrusion by small mammals. The primary biointrusion barrier is the frost protection zone that comprise 18 inches (46 cm) of 10–16 inches (25–41 cm) gravel and cobble mixture in-filled with small gravel, sand, and other fines. A diagram of the proposed design and literature-supported design elements is given in Figure 4. The rationale and scientific basis for the biointrusion barrier proposed is detailed in the DRC Interrogatory 5.1 response. Detailed description of expected vegetation-animal burrowing interactions under different vegetation densities is described in detail in the DRC Interrogatory 5.2 response.

## EnergySolutions PA Section 3.3 Protection of Individuals During Operation

***DRC Interrogatory 5.14***

**DRC Interrogatory Statement:**

***On page 3-7, it says, with respect to the current operational period, "Burrowing animals are prevented from contacting the waste materials." Please explain how this is currently being accomplished.***

**SWCA Response:**

Measures to prevent burrowing animals from contacting waste materials during ET cover construction would be the same as those currently in use at the Clive Facility.

## *DRC RFI Section 6.0 Plant Cover, Model Plant Parameters, and Biointrusion by Plant Roots*

## EnergySolutions PA Section 2.1.11 Ecology

### *DRC Interrogatory 6.1*

**DRC Interrogatory Statement:**

***It is said on Page 2-5 "The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses." The DRC requests the Licensee to specify whether they will attempt to plant flora on the engineered embankment as part of the proposed ET cover. If so, then the Licensee must describe the suitability of plants used, and the suitability of the soil properties and soil thickness for growing them. Also, if plants intended for planting (if that is to be done) have successfully been introduced during reclamation into other environments similar to the one at Clive, please describe and document this as well.***

**SWCA Response:**

The plant species selected for the vegetation community on the ET cover will comprise local, native shrub, forb, and grass species. These species are specifically identified in the paragraphs below and in Attachment A. The proposed ET cover design will mimic local, native ecosystems in that the upper soil layers will comprise 12–24 inches (30–60 cm) of borrow soils from the Clive site (Unit 4), which duplicates on site soil depths observed in association with the target vegetation community. In addition, these soils share the same properties as native soils sampled on and near the Clive site associated with the target vegetation community (see Table 6). Similar vegetated ET cover systems have been successfully established at the Monticello, Utah uranium mill tailings disposal site (Waugh et al. 2008), Los Alamos (Albright et al. 2002), Sandia National Laboratories (Fiedler et al. 2011), and elsewhere (Rock et al. 2012).

The vegetation communities that occur on and near Clive, and the shrub, forb, and grass species that comprise them were documented during 2010 and 2012 field studies (SWCA 2010, 2012). Inter-Mountain Basins Mixed Salt Desert Scrub (Lowry 2007) is the dominant vegetation cover type on analogs to the Clive site. The target vegetation community on the ET cover consists of approximately 15% cover of small stature native shrub species (*Atriplex confertifolia*, *Atriplex canescens*, *Bassia americana*, *Picrothamnus desertorum*, and *Suaeda torreyana*), with additional cover provided by sparse native forbs and grasses (see Attachment A for more detailed discussion of the proposed vegetation composition for the ET cover). Locally adapted plant materials will be used to the extent possible. Greasewood will not be included in the target community due to its deep rooting habit, the affinity of badgers for larger stature shrub species (Eldridge 2004), and the demonstrated affinity of small mammals for higher shrub densities (SWCA 2010, 2012; see the Interrogatory 6.3 response for detailed discussion of greasewood potential on the ET cover).

The target vegetation community for the cover is based on documented species cover and densities as well as plant materials adapted to local climate and soil conditions. Native plant species diversity at the site is low, with a total of less than 20 plant species documented in the study sites. The native plant species that occur at Clive are well-adapted to the saline, high pH, low-fertility soil conditions, and low average annual precipitation of less than 10 inches (25 cm). Plant species on and near Clive occur in silty clay soils that possess a naturally occurring compacted clay layer at approximately 24 inches (60 cm) depth. As such, the native shrub species are not found to root deeply, and appear able to take advantage of moisture perched above the compacted clay by extending root growth laterally instead of into the clay. Table 6 summarizes the soil characteristics for eight study plots sampled in 2012.

**Table 6.** Soil Characteristics of Native Soils in Study Sites at and near Clive (SWCA 2012)

| Parameter | Units | Plot 6 | Plot 7 | Plot 8 | Plot 9 | Plot 10 | Plot 11 | Plot 12 | Plot 13 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| **Texture** | | Silty Clay Loam | Clay Loam | Silty Clay Loam | Silty Clay Loam | Loam | Silty Clay Loam | Silt Loam | Silty Clay | – |
| **pH** | | 8.3 | 8.2 | 8.3 | 8.3 | 8 2 | 8.2 | 8.4 | 8.1 | **8.3** |
| **Organic matter** | % | 2.7 | 1.8 | 2.6 | 2.9 | 1 2 | 1.7 | 1.9 | 1.9 | **2.1** |
| **Nitrate-nitrogen** | mg/kg | 9 5 | 8 8 | 10.9 | 10.0 | 9.2 | 8.6 | 11.0 | 12.60 | **10.1** |
| **Phosphorous** | mg/kg | 11.6 | 8.5 | 7.4 | 5.4 | 6 8 | 5.6 | 8.6 | 6.9 | **7.6** |
| **Potassium** | mg/kg | 899 | 811 | 899 | 899 | 804 | 899 | 680 | 899 | **848.8** |
| **Clay** | % | 38 | 35 | 34 | 29 | 26 | 33 | 26 | 38 | **32.4** |
| **Sand** | % | 13 | 26 | 15 | 20 | 27 | 19 | 23 | 9 | **19.0** |
| **Silt** | % | 49 | 39 | 51 | 51 | 47 | 48 | 51 | 53 | **48.6** |
| **SAR** | | 72 2 | 92 7 | 68.8 | 81 9 | 37.8 | 40.2 | 28 9 | 67 3 | **61.2** |
| **>2mm** | % | 2 2 | 13 3 | 0.7 | 0.48 | 2.88 | 1 94 | 0.6 | 1.7 | **3.0** |
| **Salinity ECe** | dS/m | 16 0 | 16.4 | 10.8 | 10.9 | 6.0 | 6 8 | 3.3 | 12.7 | **10.4** |
| **Sulfate-sulfur** | mg/kg | 154 | 136 | 107 | 80 | 18 | 126 | 11 | 105 | **92.1** |

*Note dS/m = deciSiemens per meter, ECe = Electrical Conductivity of a saturated soil extract Mg/kg = milligram/kilogram, SAR = sodium adsorption ratio*

The shrub species that dominate the vegetation at the site are small in stature compared to their conspecifics in deeper, more fertile soils, and areas with greater average annual precipitation. The site's unique soil conditions and aridity are considered in the vegetation plan because it is unlikely that shrubs will achieve the sizes or rooting depths demonstrated in environments elsewhere. For example, fourwing saltbush was excluded from vegetation seed mixes and plantings at Sandia because of the deep rooting potential of the species there (Peace et al. 2004). At Clive, large individuals of the species had roots an average of 8–16 inches (20–40 cm) and a maximum of 28 inches (70 cm) long (SWCA 2010). This shallow growth habit is likely due to the compacted clay layer at approximately 24 inches (60 cm) depth (SWCA 2010, 2012).

## *DRC Interrogatory 6.2*

**DRC Interrogatory Statement:**

***It is said on Page 2-5 "The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses." Please provide an appropriate biointrusion defense design for the cover system effective against deep plant rooting, or account in modeling for increases over time in infiltration rates.***

**SWCA Response:**

Figure 4 shows the preferred ET cover design composed of a thin covering of gravel mulch, 15 cm of soil/gravel mixture, 18 inches (46 cm) of soil, 18 inches (46 cm) of cobble-fines, 6–18 inches (15–46 cm) of coarse sand and gravel, and 24 inches (61 cm) of compacted clay above a 12-inch (30 cm) temporary clay cover. Based on the specifications given in the literature and designs currently in use for ET cover systems, these layers provide multiple biointrusion barriers (see the DRC Interrogatory 5.1 and 5.2 responses above).

The preferred ET cover design contains a biointrusion barrier as part of the frost protection zone. The frost protection layer outlined in Energy*Solutions*' PA consists of fines with cobbles to 16 inches (41 cm) diameter. The biointrusion barrier comprises 10 to 16–inch (25-41 cm) cobble in-filled with gravel and fines. This material also will produce a capillary effect. The biointrusion barrier overlies a 6-18 inch (15–46 cm) deep filter zone that will act as a second capillary break. Any root penetration into the filter zone will likely consist of lateral root growth that will follow any available water and not penetrate the radon barriers. As such, root growth will be concentrated in the uppermost 24 inches (60 cm) of the ET cover, with some root penetration into the frost protection zone.

The presence of a capillary break at 36–60 inches (91–152 cm) depth was cited as an effective deterrent to plant biointrusion by DRC. The cover design contains multiple layers that will act as capillary breaks, including the dense cobble layer in the frost protection zone at 30–42 inches (60–107 cm) and the filter zone at 36–60 inches (91–152 cm). Provided that these capillary breaks are effective at holding moisture in upper soil layers, which is to be expected with actively growing vegetation and low average annual precipitation, the break should limit any root growth into the filter zone and radon barriers, as stated by Anderson and Forman (2002). The coarse sand and gravel mixture in the filter zone is expected to remain dry except for high precipitation or snowmelt events when infiltration is greatest.

The actively growing vegetation on the cover surface is an important design component. Transpiration from plants and movement of water from lower to upper soil layers by plant roots enhance the functioning of the ET cover system. Some areas of dense plant roots in the soil layers are desirable because they increase movement of any water stored in deeper soils, or in the interspaces of the frost protection zone.

## *DRC Interrogatory 6.3*

**DRC Interrogatory Statement:**

***It is said on Page 2-5 "The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses." The Licensee needs to account for the potential for greasewood, a native, salt-tolerant shrub presently growing on site, to grow roots to depths much deeper than the proposed thickness of the entire cover system. This has obvious implications for biointrusion into the radon barriers and waste and also speaks to an onsite need for effective plant-root biointrusion barriers. Please address these.***

***The PA, on Page 2-6, also says, "A few large, woody roots were encountered in deeper soils. Rooting depths were shallower than expected, with the maximum rooting depth of dominant woody plant species ranging from 16 to 28 inches." The Licensee needs to acknowledge that potential exists at site locations other than those excavated for black greasewood to root more deeply than 0.4 to 0.7 meters (16 to 28 inches), perhaps even down to depths of 3 to 9 meters (10 to 30 feet), and adjust modeling concepts and parameters accordingly.***

**SWCA Response:**

Energy*Solutions* acknowledges that greasewood has the potential to root at depths well below the depths of the soil layers, frost protection zone, and filter zone for the proposed ET cover system at Clive. Nevertheless, observations at the Clive site and ecological analogues demonstrate that the low fertility, alkalinity, and aridity of local soils limit plant growth and prevent the development of large, deep rooted plants. Use of local soil materials in the ET cover would reasonably be expected to elicit the same response from native plant materials. In addition, water storage in upper soil layers, and capillary breaks at the frost protection zone and filter zone have been demonstrated to effectively deter or limit penetration by deep rooting plants into protective layers (Groeneveld 1990; Dayvault et al. 2011).

Over the long term (> 5 years), it is to be expected that greasewood will become established on the ET cover. However, greasewood roots follow available water (Groeneveld 1990), which will be limited to upper storage layers, and any infiltration to the depth of barrier layers will be directed laterally across the filter zone. Because the water table levels below the ET cover are at depths beyond the maximum levels accessible by greasewood (> 33 feet [10 m]) and the functioning ET cover will prevent water infiltration below the depth of the filter zone (0.9–1.5 m), root penetration to the water table is not possible. There will be portions of the side slopes that are 24 feet (7.2 m) above the water table, but it is highly unlikely that greasewood can root to these depths at Clive for several reasons:

1. Deep rooting by greasewood and other shrub species is limited or absent at Clive because there is little or no capillary rise between the deep water table and upper soil layers. As stated in Neptune's 2011 biointrusion modeling report, extremely deep rooting by greasewood only occurs when precipitation infiltrates to groundwater, and greasewood roots cannot penetrate the very dry soil that occurs below the zone of infiltration.

2. Published data indicate that greasewood has a root-to-shoot ratio of 1.0 to 1.5 (Brown 1997), which translates to a root biomass that is approximately 66% of aboveground plant volume. Given that some of the largest representative greasewood plants at Clive were excavated in 2010, it is unlikely that any greasewood plants on or near the Clive site are of sufficient stature to root deeply (> 3m).

3. Greasewood root density decreases exponentially with soil depth (Groeneveld 1990), whereby the majority of root biomass will be concentrated in upper soil layers regardless of plant stature.

4. Nutrients tend to be concentrated in upper soil horizons and decrease with depth in desert soils, with declining efficiency of growth investment to nutrient return in soils with low nitrogen content (Groeneveld 1990 and references therein).

The exclusion of deep roots from below the filter zone is discussed in the Interrogatory 6.2 response. As stated above, the presence of a capillary break at 36–60 inches (91 to 152 cm) is cited as an effective deterrent to plant biointrusion by DRC. The cover design contains multiple layers that act as capillary breaks, including the dense cobble layer in the frost protection zone and the sand and gravel filter zone. Provided that these capillary breaks are effective at holding moisture in upper soil layers, which is to be expected with actively growing vegetation and low average annual precipitation, one or more capillary breaks will limit any root growth into the filter zone and radon barriers, as stated by Anderson and Forman (2002). The coarse sand and gravel mixture in the filter zone is expected to remain dry except for high-precipitation or snowmelt events when infiltration is greatest.

### *DRC Interrogatory 6.4*

**DRC Interrogatory Statement:**

***On Page 2-5, it says, "The plant species selected for the evapotranspirative cover system should consist of native and desirable non-native, salt tolerant shrubs and grasses." Please revise proposed plans accordingly to include only native plants, or justify inclusion of non-native species. If non-native species are included, then the licensee must provide the percent coverage of "desirable" non-native plants and their names to allow the DRC to assess vegetative cover design performance.***

**SWCA Response:**

The target vegetation community on the ET cover consists of approximately 15% cover of small stature native shrub species (see Attachment A), with additional cover provided by sparse native forbs and grasses. Locally adapted plant materials will be used to the extent possible. There are differences in plant species composition and cover at different locations on and near the Clive site that were considered for the target vegetation community and long-term biointrusion potential. Native vegetation on the soils that occur at the site is limited to shadscale saltbush, fourwing saltbush, gray molly, greasewood, and perennial grasses such as squirreltail (*Elymus elymoides*), Indian ricegrass (*Achnatherum hymenoides*), and Sandberg bluegrass (*Poa secunda*).

Locally-adapted plant materials will be required to create a functioning vegetation community on the ET cover. As stated in the Interrogatory 6.1 response, the target vegetation community on the ET cover consists of approximately 15% cover of small stature native shrub species (*Atriplex confertifolia*, *Atriplex canescens*, *Bassia americana*, *Picrothamnus desertorum*, and *Suaeda torreyana*), with additional cover provided by sparse native forbs and grasses. Although several of these shrub species have been documented to root very deeply along waterways or under wetter climatic conditions elsewhere, the soil and climate conditions on and near the Clive site clearly limit the sizes and densities of native shrubs. This pattern is demonstrated by the very low shrub densities that consistently occur on and near Clive (SWCA 2010, 2012). Native shrub species targeted for use on the ET cover occur at 0.1% to 3.9% average cover, and one to 16 stems per square meter (SWCA 2012). Greasewood, where it occurs, has much higher average cover of 11.5% to 19.0%. Greasewood will not be included in the target community due to its deep rooting habit, the affinity of badgers for larger stature shrub species (Eldridge 2004), and the demonstrated affinity of small mammals for higher shrub densities (SWCA 2010, 2012). See the Interrogatory 5.2 response for additional discussion of greasewood potential on the ET cover.

The target vegetation community for the cover is based on documented species cover and densities as well as plant materials adapted to local climate and soil conditions. Native plant species diversity at the site is low, with a total of less than 20 plant species documented in the study sites. The native plant species that occur at Clive are well-adapted to the saline, high pH, and low-fertility soil conditions and low average annual precipitation of less than 10 inches (25 cm). Plant species on and near Clive occur in silty clay soils that possess a naturally occurring compacted clay layer at approximately 24 inches (60 cm) depth. As such, the native shrub species are not found to root deeply and appear to be able to take advantage of moisture perched above the compacted clay by extending root growth laterally instead of into the clay.

The only non-native plant materials that will be included in the vegetation plan are non-invasive, fast-growing grasses used for initial soil stabilization (Quick Guard sterile *Triticale*; see Table A-1 in Attachment A). These grasses will be seeded in the fall or early winter to provide cover to stabilize soils and enhance soil development and biological soil crust cover. The sterile rye (Quick Guard sterile *Triticale*) will not persist beyond the first 1–2 years of vegetation cover development. Only approved reclamation materials from reputable seed suppliers will be used.

There are several invasive plant species that occur in the area: cheatgrass (*Bromus tectorum*), halogeton (*Halogeton glomeratus*), and kochia (*Bassia* species) that are expected to invade early in the revegetation process. Early seeding of high densitites of sterile rye and native squirreltail, which are good competitors with cheatgrass and other annual weeds, will help to exclude invasives. Invasive weed species will be targeted for control, particularly during the first 1 to 2 years of vegetation development to allow native species to dominate the cover system (see Weed Management Section in Attachment A).

## EnergySolutions PA Section 3.1.5 Vegetation Pathway

### *DRC Interrogatory 6.6*

**DRC Interrogatory Statement:**

***Page 3-3 includes this statement: "The candidate thick covers include capillary break, biointrusion, and bioturbation barriers that make the waste less accessible to plant roots after closure of the facility." Please explain how the proposed cover-system design 1 and design 2 include effective biointrusion barriers.***

**SWCA Response:**

The design and rationale for the preferred ET cover design biointrusion barrier is described under the DRC Interrogatory 5.2 response.

***DRC Interrogatory 6.7***

**DRC Interrogatory Statement:**

***The statement is made on Page 3-3 that "the overall scarcity of deep-rooted plant species in the site vicinity and the configuration of the earthen cover will offer an inhospitable environment for extension of these types of roots into the waste." This statement is not correct, since greasewood is relatively prevalent at Clive and it constitutes up to 14% of the plant community there. Please modify the PA text to reflect the facts that greasewood is not scarce on site, and that it can potentially root far more deeply than the top of the waste. Alternatively, justify the text as is. The configuration of the proposed cover seems to have little to do with whether greasewood roots can penetrate the waste, although the DRC is willing to consider an explanation.***

**SWCA Response:**

See the discussion of the preferred ET cover design biointrusion barrier under the DRC Interrogatory 5.2 response, and the discussion of greasewood potential on the preferred ET cover design under the DRC Interrogatory 5.2 and 6.3 responses.

## EnergySolutions PA Appendix B – Modeling Report

***DRC Interrogatory 6.9***

**DRC Interrogatory Statement:**

***Page 29 of Neptune and Company, Inc., (2012) speaks of "site characteristics influencing movement of water from precipitation through the vadose zone to the water table at the Clive site," and mentions one as "native vegetation." Please clarify whether proposed plans are to plant or transplant either native or non-native shrubs and grasses, or do proposed plans only envision establishment of native plants through natural succession? If a proposal is made to plant, please indicate the percent coverage intended.***

**SWCA Response:**

As stated in the DRC Interrogatory 6.1 response, the target vegetation community on the ET cover consists of approximately 15% cover of small stature native shrub species (*Atriplex confertifolia*, *Atriplex canescens*, *Bassia americana*, *Picrothamnus desertorum*, and *Suaeda torreyana*), with additional cover provided by sparse native forbs and grasses (see Attachment A for more detailed discussion of the proposed vegetation composition for the ET cover). Locally sourced seed and/or seedlings will be used to the extent feasible.

***DRC Interrogatory 6.11***

**DRC Interrogatory Statement:**

***Table 3 of the Neptune and Company, Inc., (2012) report shows mean values for black greasewood, Sandberg bluegrass, shadscale saltbush, and gray molly on SWCA vegetation survey plots on site to be 8.5%, 0.7%, 3.7%, and 1.5%, respectively.***

***Please fix, note and comment on, or justify all discrepancies associated with this and like statements in the PA. Part of the information about species is missing from the statement above, as discussed below. Please add it.***

**SWCA Response:**

The Neptune and Company, Inc., 2012 report is based on data collected across five 1-hectare study sites along an elevational gradient from the Clive site to the lower benches of the Cedar Mountains. The objective of the Neptune study, conducted in 2010, is to provide supporting information for long-term vegetation trajectories over geologic time periods. However, the SWCA 2012 plant species cover estimates were based on data collected in seven 1/10$^{th}$-hectare ecological analogs to the conditions on the Clive site. The average species cover and densities are not the same as the vegetation data collected during the Neptune (2010) study reported in 2012 because of the SWCA (2012) focus on salt desert scrub vegetation on the Clive site and ecological analogues to conditions on the Clive site.

Detailed discussion of vegetation cover and densities in ecological analogs to the Clive site is provided in the SWCA 2012 report.

***DRC Interrogatory 6.12***

**DRC Interrogatory Statement:**

***On Page 36 of Neptune and Company, Inc., (2012), there is mention of two excavations by SWCA Environmental Consultants (2011) from which data for Figure 11 rooting depths for shadscale and greasewood were obtained. Roots are claimed to only extend down to about 0.8 meters (2.6 feet) of depth. Elsewhere (SWCA, 2011), it is said that roots extend only to about 0.4 to 0.7 meters (1.3 to 2.3 feet) of depth, depending on location of excavation.***

***The DRC requests the Licensee provide a synopsis of research findings for greasewood rooting depths at other sites and compare the data to that found in these two excavations. Please provide an explanation for the anomalous on-site data, reconcile discrepancies, and assess the likelihood that the data from the limited number of excavations represents all land locally owned or leased by licensee, i.e., the entire site and surrounding area. Provide support or justification for all assumptions and claims.***

***The DRC specifically requests the Licensee discuss rooting depths for greasewood at the site in the context of (1) the shallow rooting of greasewood noted at a few locations at Clive does not necessary mean that rooting will be shallow at all locations at Clive, (2) greasewood is an obligate phreatophyte, with roots that almost always go down to within a short distance of the water table, and rooting depths for greasewood are noted at other sites to be as deep as 10 meters (33 feet) or more, (3) roots for greasewood at the site tend to terminate at or about at a thin, highly compressed layer noted to be present at an average depth of approximately 60 centimeters (2.0 feet) in several excavations, (4) thin, highly compressed layer will no longer exist locally once soil is mined for cover systems, (5) according to a recent NRC document (Benson et al., 2011), low-permeability cover system soil over time is likely to experience greatly increased hydraulic conductivity due to multiple potential causes, which may include plant root intrusion, and (6) in the absence of a perched aquifer or other biological barrier, greasewood roots growing down to typical depths reported in the literature could potentially extend down through the radon barrier, through the waste, and into the capillary fringe, or water table, which may be present at a substantial depth.***

***The DRC requests that the Licensee consider in modeling work that biointrusion by greasewood (1) may damage the cover system soils and increase their effective hydraulic conductivity values, (2) this could dramatically increase drainage of infiltrated water, (3) this could potentially increase radon emanations through the cover, and (4) biointrusion of greasewood roots into waste may also allow for the conveyance of contaminated water up through roots and then through stems and leaves of greasewood, resulting in transport of radionuclides to the surface.***

***The leaves may be eaten by foraging animals, such as cattle or sheep. Some of the animals may then be eaten by humans. This source of risk needs to be addressed fully in risk assessment and in the context of inadvertent intruder analysis.***

**SWCA Response:**

Energy*Solutions* acknowledges that greasewood has the potential to root at depths well below the depths of soil layers, the frost protection zone, and the filter zone in the proposed ET cover system. Deep rooting by greasewood is not observed on-site due to the presence of a naturally occurring compacted clay layer at approximately 24 inches (60 cm) depth on the Clive site. As cited by DRC, precipitation likely perches above the compacted clay and causes plant roots to grow laterally along the top of the layer. The root excavations in 2010 comprised two pits adjacent to large greasewood plants. Although this is a limited sample of rooting depths, the aboveground mass of greasewood on and near the site was represented in the two excavations performed. The aboveground mass of greasewood plants on and near Clive is consistent with low water availability. Because greasewood taproots typically penetrate to the capillary fringe overlying the water table (Groeneveld 1990), roots are expected to follow water availability and not penetrate compacted layers.

See the discussion of the preferred ET cover design biointrusion barrier under the DRC Interrogatory 5.2 response, and the discussion of greasewood potential on the preferred ET cover design under the DRC Interrogatory 5.2 and 6.3 responses.

## *DRC RFI Section 7.0 Transpiration*

## EnergySolutions PA Section 2.2.2 Cover Design 2: Evaporative Cover Design A

### *DRC Interrogatory 7.1*

**DRC Interrogatory Statement:**

***In regard to the Page 2-8 statement about the surface layer being "composed of native vegetated Unit 4 material with 15% gravel mixture", the DRC has concerns about plant growth and plant coverage on this layer and the ability of plants to provide as much transpiration as expected in the model. Based on information found in other interrogatories and concerns about the ability for plants to flourish and provide sufficient plant coverage on engineered embankments, as well as the potential for native shrub roots to biointrude past radon barriers and into the waste, the DRC requests that the licensee revisit sections dealing with transpiration and provide support or evidence for its assumed transpiration parameter values.***

**SWCA Response:**

The alternative landfill cover system at the Monticello, Utah, uranium mill tailings disposal site serves as a conservative demonstration site for the Clive ET cover system. The Monticello site is the closest ecologically-analogous operational ET cover system to Clive, and has similar seasonal precipitation and rainfall patterns and vegetation conditions (Waugh et al. 2008). The Monticello differs from the Clive site in several ecologically important ways:

1. Monticello receives approximately 50% greater average annual precipitation than Clive (15.4 in);
2. The Monticello ET cover is comprised of clay-loam to sandy-loam soils that are less alkaline and more fertile than the saline, alkaline silty-clay soils at Clive (Waugh et al. 2008); and
3. The native vegetation at Monticello is dominated by big sagebrush shrublands and grasslands that are more diverse and of larger stature – with greater target plant densities and cover for the ET cover – than those proposed at Clive;

The Monticello cover was seeded and planted in fall of 2000 with native vegetation. Monitoring through 2007 indicates that evapotranspiration levels closely tracked precipitation (Waugh et al. 2008). The same pattern is expected to occur at Clive, regardless of vegetation stature, as the size and densities of shrub and grass species at Clive reflects local soil conditions and water availability. There was no infiltration to the ET cover during the first 4 years, and the only infiltration detected was in response to precipitation greater than 250% of normal in 2004–2005. Overall, infiltration at Monticello is 100–1,000 times less than conventional cover systems (Waugh et al. 2008).

As is expected at Clive, plant cover from years 1 to 3 was dominated by invasive annual weeds. The Monticello site was reseeded with native bottlebrush squirreltail (*Elymus elymoides*) and shrub species in Year 4 to compete with cheatgrass. Initial invasion of newly placed soils by cheatgrass, halogeton, and other annual weeds is anticipated in the revegetation and management plan (Attachment A).

The total plant cover on the vegetated cover will be 15% shrubs with additional seasonal cover by forbs and grasses. This level of cover is expected to be achieved within 3–5 years of revegetation efforts. The mature cover will be dominated by biological soil crust cover, which will serve to stabilize soils and capture precipitation and hold it close to the soil surface. Low annual precipitation in the area limits water infiltration and storage, which is reflected in local plant communities. The vegetation cover and densities that exist on and near the Clive site reflect the volume of water that is available to be evaporated from the soil surface or transpired by actively growing plants. The vegetation diversity and density proposed for the ET cover is to the limit that local soils and climate can support and are thereby adequate to move available water from upper soil layers to the atmosphere.

Because of very low average annual precipitation and the chemistry and fertility levels found in native and borrow soils at the Clive site, the cover is unlikely to support vegetation cover above 15%. Climatic and edaphic limitations on plant sizes and densities were evident in the 2012 field study of ecological analogs to the Clive site (SWCA 2012). The potential diversity and density of small mammals and their predators are also limited by conditions on and near Clive, and that will occur on the vegetated cover system. Detailed discussed of vegetation and biointrusion potential on the ET cover is provided in the DRC Interrogatory 5.1 and 5.2 responses.

As discussed in the DRC Interrogatory 6.2 and 6.3 responses above, the proposed cover design includes a biointrusion barrier and multiple capillary breaks, which have been demonstrated to be effective at limiting root penetration beyond upper soil layers and in directing any deep root growth to follow the filter zone and not penetrate radon barriers.

# Summary and Conclusions

## *DRC RFI Section 4.0 Erosion*

The DRC's statements regarding erosion refer to a bare soil cover system in both the short and long term, which is not representative of conditions that will exist for either of the proposed ET cover system designs presented in the PA. The proposed ET cover designs will be composed of native silt and clay soil layers. Because of the very high cover of biological soil crusts, native soils that exist on-site have not been shown to erode as the DRC suggests.

Installation of the proposed ET cover design will include reclamation measures designed to quickly stabilize soils and initiate the development of a functioning native vegetation community. Soils on the ET cover surface and embankment slopes will be stabilized in both the short and long term by the following (detailed in Attachment A):

- Six inches (15 cm) of 15% gravel-soil mixture on the soil surface.
- Inoculation of the soil surface with locally-sourced biological soil crust material.
- Seeding with fast-growing sterile grasses and/or native grass and forb species.
- Establishment of native vegetation to shield bare soils from raindrops, contribute to litter buildup and biological soil crust development, and reduce surface water flow and wind.
- Installation of temporary erosion-control devices on embankment slopes.

Erosion and gullying of the cover system, and the soil-stabilizing and evapotranspirative functioning of native vegetation, will be monitored during a restoration period of approximately 5 years, and as part of the 100-year Institutional Control period.

Soil sample analyses indicate that the Unit 4 soil textures are silty clay to clay loam, and are composed of an average of 52.0% silt, 35.4% clay, and 12.6% sand (SWCA 2012). Although there may be some loss of cohesiveness once the Unit 4 soils are mixed with 15% gravel, there are multiple erosion control measures that will be implemented to stabilize the soil surface while vegetation and biological soil crusts become established.

The objective of the cover design is to facilitate the development of these natural stabilizing mechanisms. The design and functioning of the proposed ET cover system requires thriving vegetation. Gravel in surface soils has not been shown to limit plant growth, but compacted soils will not support sufficient plant density or growth for a functioning cover system. A 15% gravel admixture was selected to limit erosion without impeding cover functioning. The demonstrated stability of undisturbed soils at the Clive site indicates the ability of soil biota and vegetation to limit erosional forces at the site.

## DRC RFI Section 5.0 Biointrusion by Mammals

The proposed biointrusion barrier system has been demonstrated to be effective at numerous operational ET cover systems. The design includes multiple layers of materials that function as biointrusion barriers:

- Frost Protection Zone: 18 inches (46 cm) of 10–16 inches (25–41 cm) cobble filled with gravel and fines
- Filter Zone: 6–18 inches (15–46 cm) of unconsolidated material
- Radon barriers: 24 inches (61 cm) of compacted clay
- Temporary barrier: 12 inches (30.5 cm) of compacted clay

The soils above the biointrusion barrier will be sufficiently deep to allow for some burrowing and soil displacement without compromising underlying layers. It is not expected that the biointrusion prevention mechanisms included in the cover design will eliminate all biointrusion into lower soil layers or the frost protection zone, but these measures will minimize any biointrusion to an insignificant level.

The large cobble small mammal biointrusion barrier will limit predator (badger, coyote, kit fox) foraging to the uppermost 77 cm of the ET cover. The evidence supporting this ET cover design includes effective biointrusion barriers at operational ET covers and demonstration sites, reviews of mammal biology, and data from field studies at the Clive site.

Evaluation of expected and worst-case scenarios for potential vegetation communities and associated faunal activity indicate that mammalian soil excavations will disturb insignificant amounts of soil relative to the entire soil volume of the cover system. Total soil disturbance under expected vegetation conditions and associated mammal activity will be less than 1/100$^{th}$ of a percent of the total soil volume. Total soil disturbance under a worst-case scenario with the vegetation dominated by greasewood is projected to result in a total of less than 1/10$^{th}$ of a percent of total soil volume.

Although the cover will be maintained to exclude greasewood, it is likely that greasewood will become established sometime during the life of the ET cover. Even under the worst-case scenario, with dense vegetation and high levels of associated burrowing animal activity, the multiple levels of biointrusion barriers in the cover design will minimize animal and root penetration into or beyond the cobble layer. In addition, the filter zone will move any percolated water laterally across clay layers, and will promote lateral root growth instead of penetration of clay layers.

The long-term functioning and sustainability of the proposed ET cover system will require the establishment of a resilient and diverse plant community. Native species that are adapted to local climate and soils are the most likely to persist on the cover, and a naturally succeeding plant community will maintain or improve evapotranspiration rates from soil layers. In general, plant selection for the ET cover will be limited to species that are well-adapted to the borrow soils and/or amended soil composition, contribute to evapotranspiration from the ET cover, intercept precipitation and stabilize soils, and that are ecologically resilient. A diverse mix of native species and/or improved cultivars will be targeted for the cover system.

## DRC RFI Section 6.0 Plant Cover, Model Plant Parameters, and Biointrusion by Plant Roots

The target vegetation community on the ET cover will consist of approximately 15% cover of small stature native shrub species, with additional cover provided by sparse native forbs and grasses. Locally adapted plant materials will be used to the extent possible. Greasewood will not be included in the target community due to its deep rooting habit, the affinity of badgers for larger stature shrub species, and the demonstrated affinity of small mammals for higher shrub densities.

The target vegetation community for the cover is based on documented species cover and densities as well as plant materials adapted to local climate and soil conditions. The native plant species that occur at Clive are well-adapted to the saline, high pH, low-fertility soil conditions and low average annual precipitation of less than 10 inches. The shrub species that dominate the vegetation at the site are small in stature compared to their conspecifics in deeper, more fertile soils and areas with greater average annual precipitation.

Energy*Solutions* acknowledges that greasewood has the potential to root at depths well below the depths of soil layers, the frost protection zone, and the filter zone in the proposed ET cover system. The proposed biointrusion barrier and capillary breaks in the cover have been demonstrated to effectively deter or limit penetration by deep rooting plants into protective layers.

The presence of a capillary break at 36–60 inches (91–152 cm) depth was cited as an effective deterrent to plant biointrusion by DRC. The proposed ET cover system includes multiple capillary breaks and a biointrusion barrier based on specifications given in the literature and operational ET cover systems. The primary biointrusion barrier is the frost protection zone which comprises 18 inches (46 cm) of 10–16 inch (25–41 cm) cobble filled with gravel and fines. The biointrusion barrier overlies a 6–18 inch (15–46 cm) deep filter zone that will act as a capillary break. Any root penetration into the filter zone would likely consist of lateral root growth that will follow any available water and not penetrate the radon barriers. As such, root growth will be concentrated in the uppermost 12–24 inches (30–60 cm) of the ET cover, with potential for limited root penetration into the frost zone.

Transpiration from plants and movement of water from lower to upper soil layers by plant roots enhances the functioning of the ET cover system. Some areas of dense plant roots in the soil layers are desirable because they enhance movement of any water stored in deeper soils or in the interspaces of the frost protection zone.

The cover design contains multiple layers that will act as capillary breaks, including the dense cobble layer in the frost protection zone and the filter zone. Actively growing vegetation and low average annual precipitation minimize infiltration and allow retention of moisture in upper soil layers. However, the capillary break should limit any root growth into the filter zone and radon barriers.

## DRC RFI Section 7.0 Transpiration

The total plant cover on the vegetated cover will be 15% shrubs with additional seasonal cover by forbs and grasses. This level of cover is expected to be achieved within 3–5 years of revegetation efforts. The mature cover will be dominated by biological soil crust cover, which will serve to stabilize soils and capture precipitation and hold it close to the soil surface.

Because of very low average annual precipitation and the chemistry and fertility levels found in native and borrow soils at the Clive site, the cover is unlikely to support vegetation cover above 15%. The vegetation diversity and density proposed for the ET cover is to the limit that local soils and climate can support and are thereby adequate to move available water from upper soil layers to the atmosphere.

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# Attachment A.
# Evapotranspirative Cover Revegetation and Maintenance Plan for the Clive Facility

# Introduction

## *Project Description*

Evapotranspiration (ET) covers are increasingly being employed as an alternative cover design in arid and semiarid climates, where these systems limit water percolation by storing water within upper soil layers until it is removed by evaporation from the soil surface and transpiration from vegetation. The primary objective of ET cover systems is to utilize the water balance components of soil and vegetation to hold precipitation and release it through soil surface evaporation or transpiration without allowing water percolation downward into storage layers and waste. The ultimate goal of such systems is to prevent the movement or release of waste, and the contamination of soils, water, or biota. These cover systems have been found to be particularly effective in arid and semiarid regions (Scanlon et al. 2005).

The proposed ET cover at the Clive facility would be comprised of locally available soils, rock, and native vegetation. The forbs and grasses selected would be expected to mirror what would naturally develop as a stable community on new soil surfaces. This steady-state condition will endure for the life of the cap. The proposed ET cover design is based on published ET cover system recommendations, examples of successful construction of similar cover systems, and site-specific climate and ecology, as determined by multiple field study efforts (SWCA 2010, 2012). The proposed vegetated cover is well-supported by published studies and guidance documents for ET cover systems (ITRC 2003; Peace et al. 2004; Rock et al. 2012; Scanlon et al. 2005). However, several preparatory actions are required in order to ensure the effective arrival at an optimum steady-state.

The vegetation layer of an ET cover serves two primary functions: it rapidly and efficiently removes water from the entire soil cover, and it provides for effective and long-lasting control of wind and water erosion of the soil surface. Plant transpiration is the primary mechanism for removing water from the root zone to the atmosphere, and transpiration rates are greatest with high plant mass and growth rates (ITRC 2003; Sheley et al. 2008).

The ET cover will be installed incrementally with approximately 300,000 square feet (6 acres) finalized per year. This phased approach over up to 25 years will require clear revegetation and management protocols, because ongoing disturbance in the vicinity of recently established and developing vegetation cover will necessitate management to exclude any surface disturbance and associated weed introduction that can potentially disrupt BSC and vegetation establishment, and prevent weed introduction to restored areas.

## *Purpose of the Plan*

The purpose of this Evapotranspirative Cover Revegetation and Maintenance Plan for the Clive Facility (Plan) is to describe the preparatory measures to be implemented to ensure successful and sustainable vegetation establishment while maintaining the integrity and proper functioning of the ET cover system. Detailed construction and revegetation specifications will be defined once the ET cover design and implementation timeline have been finalized.

The native, locally adapted plant species and local materials will be specifically selected for the ET cover, to require little maintenance over the long term (beyond the 5-year revegetation period through the 100-year institutional review period). This Plan proposes that steady-state revegetation be accomplished by using native perennial shrubs and cool and warm season grass species for long-term vegetation cover. Native shrubs are a key component of the functioning ET cover for two reasons: 1) native perennial shrub cover will provide a longer season of ET capacity than grasses or forbs; and 2) root densities and potential for hydraulic lift in upper soil layers are essential for ET.

In order to encourage progression towards steady-state, the initial revegetation phase will entail installation of plant fast-growing grass cultivars to stabilize soils and initiate the ET process while the permanent vegetation becomes established. ET is effective soon after plants initiate growth and development, but a mature plant community can take 3–5 years or more to develop (ITRC 2003; Sheley et al. 2008). A locally-derived seed mixture will be used to ensure that a plant community that reflects the scale and diversity of native vegetation develops. Specifically, a plant community will be installed that is adapted to local soil and climate conditions, stable and self-sustaining, capable of providing transpiration for as much of the year as possible, protective against soil erosion, and that will maintain a functioning ET system over the long term.

The long-term, steady-state target vegetation community for the cap is based on quantitative biotic and soils data collected at ecological analogs to the Clive site. As such, conditions will be established encouraging the target vegetation community to reflect the diversity and density of native vegetation communities. The local, native shrub species that dominate the sparse vegetation on and near Clive are small in stature compared to their conspecifics in deeper, more fertile soils and/or areas that receive greater annual precipitation (Groeneveld 1990). The high salinity and pH, and low fertility of local soils and aridity of the Clive site drive the sparse distributions and low stature of native plant species and are the basis for this revegetation plan.

This Plan is based consideration of initial reclamation and plant establishment (0-2 years), the short-term 3 to 5 year revegetation period, and the long-term, steady-state (life of the cap) development of the vegetation community. These parameters have been based on:

1. Observations and field studies at the Clive site and adjacent ecological analogues, which have informed the plant materials used proposed for use on the ET cover;

2. Evidence from ecologically relevant operational ET cover systems (e.g., Monticello; Waugh et al. 2008);

3. The experience of subject-matter experts in arid and semi-arid land restoration (Bainbridge 2007; Monsen et al. 2004; Sheley et al. 2008); and

4. Guidance provided by ITRC (2003).

# Site Conditions

## *Existing Vegetation Communities*

SWCA performed vegetation sampling in June 2012 at eight analog study plots near the Clive site (SWCA 2012). Ten plant species were identified in the eight field plots. Biological soil crusts (BSCs) are a dominant feature of vegetation communities of the Great Salt Lake Basin, and were the dominant ground cover, with an average of 79.2% cover. This density of BSCs is typical of desert scrub ecosystems, which comprise generally small-stature shrub species with large interspaces between them that are dominated by BSC cover (Belnap et al. 2001).

Vegetation communities and land cover on and near the Clive site (SWCA 2012) consists of three cover types: 1) Inter-Mountain Basins Greasewood Flat; 2) Inter-Mountain Basins Mixed Salt Desert Scrub; and 3) Developed/Disturbed land cover. The vegetation in the study area is generally sparse, and comprises a matrix of greasewood-dominated to desert scrub–dominated habitats.

### Inter-Mountain Basins Greasewood Flat

In the western Bonneville Basin of the Clive site, this vegetation community occurs in association with sparsely vegetated playas. This association typically has saline soils and a shallow water table, and remains dry for most growing seasons. The vegetation consists of open to moderately dense shrublands dominated or co-dominated by black greasewood. Other shrub and forb species that are present in the study area are shadscale saltbush (*Atriplex confertifolia*), fourwing saltbush (*Atriplex canescens*), Mojave seablite (*Suaeda torreyana*), gray molly (*Bassia americana*), and bud sage (*Picrothamnus desertorum*). Non-native invasive species associated with this community include fivehorn smotherweed (*Bassia hyssopifolia*), herb sophia (*Descurania sophia*), halogeton (*Halogeton glomeratus*), and clasping pepperweed (*Lepidium perfoliatum*). Groundcover is dominated by BSCs, with limited cover of rock/cobble, litter, and bare ground.

### Inter-Mountain Basins Mixed Salt Desert Scrub

The Inter-Mountain Basins Mixed Salt Desert Scrub (Lowry et al. 2007) vegetation is characterized by an open to moderately dense shrubland composed of one or more *Atriplex* species. Shrub, forb, and graminoid species present in the study area consist of shadscale saltbush, fourwing saltbush, Mojave seablite, gray molly, and Sandberg bluegrass (*Poa secunda*). Halogeton can also occur as a dominant forb in this community type. Groundcover is dominated by BSCs with limited cover of litter and bare ground.

### Developed/Disturbed

Developed/disturbed landcover consists of areas with roads and impervious surfaces that account for less than 20 percent of total cover. On and near the Clive site, these areas comprise roadways, disturbed surface, and invasive and native vegetation (Lowry et al. 2007). Developed and disturbed conditions predominate on the Clive site, with small areas of greasewood and salt desert scrub vegetation intermixed with roads and facilities to the north and east. Impervious surfaces are limited to access roads and parking areas associated with the Clive Facility.

The average total vegetation cover documented in on-site vegetation communities is 2.9%, consisting of 8.6 total plant stems per square meter (SWCA 2012). Average total shrub cover is 4.2% with 3 shrubs per square meter, which reflects the small stature of most shrub species at the site at approximately 140 $cm^2$

per shrub. Average plant species cover consists of 14.3% black greasewood, 5.9% Sandberg bluegrass, and approximately 3% cover each of shadscale saltbush and Mojave seablite. Fourwing saltbush and gray molly occur in low densities with 1.6% and 1.3% cover, respectively. Ground cover is dominated by 79.2% average biological soil crust cover.

Plant establishment in the vegetation types at the Clive site presents challenges due to limited and unpredictable precipitation and the presence of dense populations of invasive annual weeds that will potentially outcompete desirable plant species. There are several methods that may be initially useful during the Institutional Control Period, to facilitate and maintain native vegetation establishment while excluding noxious and invasive weeds:

- Use of approved herbicides to control annual grasses and invasive forbs
- Use of fast-growing seed mixes to combat invasive weeds during vegetation establishment
- Mycorrhizal soil inoculation to enhance shrub establishment and growth
- Salvage and replacement of biological soil crust cover (inoculant) to stabilize soils and enhance native seed germination and growth (Belnap 2001; Bowker 2007; Bainbridge 2007)

## *Desired Vegetation Conditions*

Successful establishment of desired vegetation conditions on the ET cover system at Clive requires use of native vegetation, including perennial native shrub species, that are beneficial to long-term functioning for the following reasons:

1. Perennial shrubs have a longer growing season and greater biomass, and associated ET potential, than annual or ephemeral forbs and grasses;
2. Annual weeds increase fuel loading which contributes to fire probability and frequency;
3. Annual weeds have a limited growing season and will not maximize ET potential from storage layers; and
4. Native plant species are more likely to be ecologically resilient and maintain ET functioning over the life of the ET cover.

The desired species composition on the ET cover, and the targeted cover and densities for each are discussed in detail in the sections below. Methods for plant establishment and management are also detailed in the following sections.

Figure A-1 illustrates the sequence of cover installation, soil reclamation, soil inoculation and seeding, and plant establishment and succession over the initial revegetation period, vegetation establishment and monitoring period, and life of the ET cover.

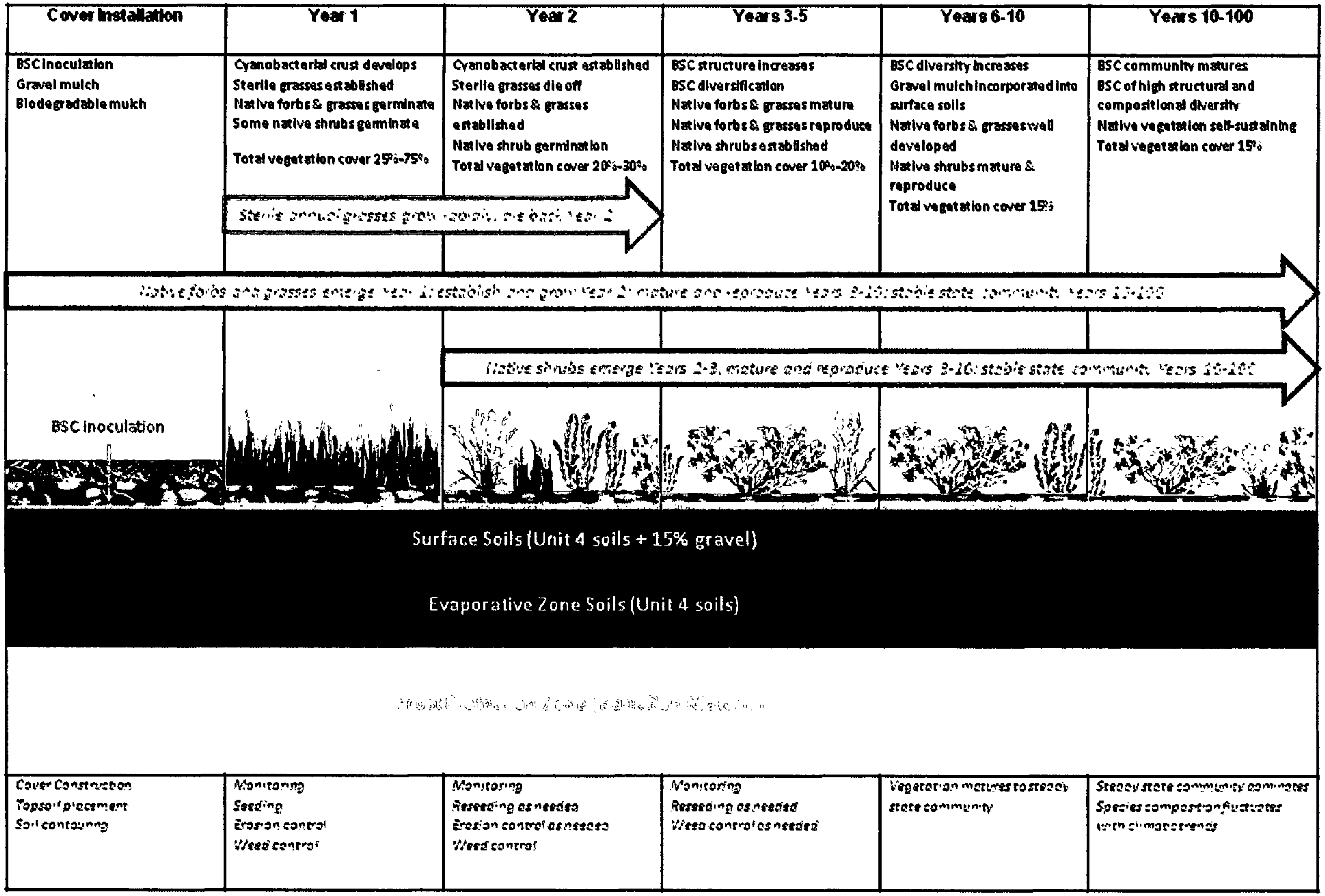


**Figure A-1.** Vegetation establishment and succession on the ET cover system for the Clive site.

# Restoration Approach and Revegetation Prescriptions

## *Restoration Approach*

Initial measures to be implemented during the Institutional Control Period to ensure successful long-term, steady-state vegetation establishment include BSC stockpiling, low profile surface recontouring, soil erosion control, seedbed preparation, application of appropriate seed mixes, plant establishment, weed abatement, and monitoring.

### BSC and Borrow Material Removal and Stockpiling

Borrow soils and BSCs should be surveyed for noxious and invasive weeds prior to removal from borrow sites to minimize the volume of noxious or invasive weed seeds and propagules in ET cover surface materials. Biological soil crusts should be salvaged from undisturbed, native soils associated with the target vegetation community. Soil crust salvage is usually from areas that are designated for clearing, though small areas of pristine crust could be salvaged to enhance the diversity of BSC organisms in the inoculation material. Recently disturbed BSCs are likely to be of lower diversity than undisturbed crust materials (Belnap et al. 2001). Biological soil crust propagules and native plant seeds are expected to occur in the top 1–2 inches of the soil surface, and should be salvaged and stored separately from other materials. The uppermost soil layer (and accompanied BSC) will be stripped and stockpiled separately from any subsoil stockpiles. Stockpiled BSCs can be stored for up to one year, but will retain more viable propagules with shorter storage periods. Certified weed-free erosion control blankets, straw bales, wood fiber, or straw wattles will be used as appropriate to limit erosion of soil or BSC stockpiles.

### Compacted Soils

The soils that will installed to serve as the storage layer will be partially compacted as part of theinstallation. Soils should be tested to determine that soil bulk density is sufficient to support vegetation. Areas that have a soil bulk density at least 25% greater than comparable non-disturbed soils in analog sites may need to be treated to promote plant growth and ET. Any overly-compacted soils can be decompacted to a depth of 6–12 inches (15–30 cm) prior to surface soil mixture placement. "Soil ripping" will occur along contours to minimize soil erosion and facilitate soil-water retention to aid revegetation (*sensu* Bainbridge 2007; ITRC 2003).

One key aspect of construction is avoiding over-compaction (greater than 80–90%) during placement. Higher bulk densities from over-compaction may reduce the storage capacity of the soil and inhibit plant growth (Chadwick et al. 1999; Hauser et al. 2001).

### BSC Inoculation

Inoculation with BSCs is necessary to stabilize soils and to speed the establishment and growth of desert vegetation (Bainbridge 2007). The stockpiled BSC inoculum will be distributed dry or in slurry over the ET cover after re-contouring is completed. A maximum dilution of 10 parts soil/mulch or water to 1 part inoculum is recommended (Belnap 1993). The surface soil mixture is expected to contain some native seed and soil microbiota that will assist in plant establishment, with the BSC inoculum placed on top of the topsoil to promote reestablishment of healthy soil crust cover and stabilization of soils. Recovery of BSCs on the site would be expected to take from 6 months to a year with inoculation, up to 10 years without (Belnap 1993; Bainbridge 2007).

### Mulch

Mulching during initial vegetation establishment will minimize soil erosion, conserve soil moisture, and moderate surface temperatures to improve the chances of seedling establishment (Sheley et al. 2008). Because of the limited precipitation of the site, and the undesirability of irrigation on a waste cover system, gravel mulch over the soil surface and/or biodegradable mulch to assist in moisture retention in upper soil layers and seed establishment, will be required during the initial vegetation establishment stage. Following initial plant establishment, mulching materials will be used as needed and may include certified weed-free straw, soil tackifiers, and fabrics, particularly on embankment slopes.

### Soil Erosion Control

The ET cover will be seeded with native plant species and fast-growing grass cultivars immediately after construction to stabilize soils. Mulch, tackifiers, or fabrics will be used to prevent erosion and seed loss until fast-growing vegetation and BSCs become established, which is to be expected within approximately 3-6 months of planting depending on climate and season of planting (well within the Institutional Control Period). Because native plants may be difficult to establish in cover soils and may grow slowly for the first 2 years or more, erosion controls should be employed for a minimum of 2 years.

Soil erosion control will occur through BSC inoculation, vegetation establishment, certified weed-free mulch, and soil tackifiers. Permanent plant cover will be established as quickly as possible following installation of the cap.

### Noxious and Invasive Weed Abatement

Noxious and invasive weed infestations will reduce the success of revegetation through competition for soil water, nutrients, space, and sunlight. Noxious and invasive weed monitoring and control will occur prior to topsoil and BSC removal and inoculation, and should occur annually during the initial 3-5 year vegetation establishment period.

Cheatgrass, halogeton, and kochia are anticipated to be the predominant invasive weeds that will impede revegetation success. Herbicides or mechanical removal may be used to reduce or eliminate annual weeds prior to seeding. Spot spraying or mechanical controls are recommended once the cap has been seeded to allow establishment of native plant species. A Pesticide Use Permit will be secured prior to any application.

## 3.2 Revegetation Prescriptions

As recommended in ITRC 2003, the following considerations were addressed while developing a seed mix for use on the ET cover system:

- Knowledge of the types of native vegetation and soils that occur on-site (SWCA 2010, 2012). Selected plant species are known to occur on the Unit 4 silt-clay soils to be used for cover soil layers.
- Selection of cultivars appropriate for the Clive site based on their potential survival (including drought tolerance) and whether they are considered weedy or invasive by local authorities.
- Use of seed developed from local sources (local or regional commercial vendors), when possible. Only high-quality, weed-free seed will be used. Shrub seeds will be purchased from commercial vendors and/or collected from local sources.
- Consideration of autecological and synecological characteristics of different plant species for determining the rates of seeding for each individual species. Species that are easily established

and very competitive with other species should be included in the mix at a lesser percentage than less easily established types. Seeding rates for each species will be based on recommendations by local U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) personnel or local data.

- Modification of seed mixes may be desirable based on position on the top or side slopes of the ET cover. Root anatomy and rooting depth of each species should be considered, with species that produce large, deep tap roots excluded from cover vegetation to the extent feasible, and an emphasis on species that produce fibrous root systems that will be concentrated in upper soil layers to facilitate movement of water away from waste layers.
- Consideration of species' potential leaf area index. Large plants with dense leaf cover will transpire larger amounts of water than small, less dense plant species. Because the target vegetation community comprises species adapted to very low precipitation and poor soils, there is limited potential to maximize plant growth or transpiration. Nevertheless, naturally occurring densities of mature vegetation are presumably at levels that the soils and annual rainfall can support. Both cool- and warm-season species will be included so that transpiration is active during most of the year.
- A mixture of bunchgrasses and rhizomatous species may be desirable and should be considered for optimum soil stabilization during initial ET cover vegetation establishment efforts.
- Availability of seed or plant materials.

A diverse stand of native vegetation is preferred due to its demonstrated abilities to withstand natural climatic variability and other natural disturbances, and to efficiently use available soil water (ITRC 2003). Non-native vegetation may also be suitable where fast-growing, sterile cultivars can be used to provide rapid soil stabilization and facilitate the development of the soil biota and vegetation.

Selection of appropriate vegetation is critical to the proper function of an ET cover design. Seed mixes were selected based on the factors listed above. Other potential resources for plant selection include the NRCS Plants Database (http://plants.usda.gov), and the Native Seed Network (http://www.nativeseednetwork.org).

The proposed seed mixtures were designed to be compatible with the dominant vegetation and land uses currently found at the Clive site. The entirety of the cover and embankment slopes will be seeded using the location-specific species at appropriate seeding rates to achieve the vegetation densities found in analogous communities at and near Clive. Seed will be obtained from commercial vendors or collected locally. The criteria used for selecting the seed mix were based primarily on the following:

- Erosion-control capability
- NRCS ecological site descriptions
- Availability of seed

Seeds will be tested for purity and viability, and certified as weed free to ensure compliance with local, state, and federal seed requirements.

## Seedbed Preparation

Seedbed preparation will consist of decompacting if needed, low-profile contouring to create swales and windbreaks, and topsoil and BSC replacement. The soil surface will be left in a roughened condition to enhance seed germination (Monsen et al. 2004). There are numerous methods and associated tools out there for contouring soils in desert ecosystems. Soil crimping and texturing have been demonstrated to significantly enhance seeding success on arid site – this is due to enhancement of moisture retention on the soil surface, elimination of sheet flow and rilling, and the creation of sheltered microsites for seed germination. At the least, methods that create low profile (i.e., 1-6") swales or punctures should be considered.

## Seed Mixes

The target vegetation community for the cover system is Inter-Mountain Basins Mixed Salt Desert Scrub consisting of saltbush species, gray molly, and other native shrub and grass species (Table A-1). Table A-1 provides the range of Pure Live Seed in pounds per acre for the overall seed mix. Detailed seed mix for each area of cover construction will be documented prior to the start of construction. Re-establishing vegetation in this arid vegetation type is challenging because of unpredictable precipitation and noxious or invasive weed competition (Monsen et al. 2004). Proper seedbed preparation, mulching, locally adapted seed mixes, mycorrhizal fungi inoculation, seeding during the late fall and early winter, and weed abatement will all improve plant establishment (Monsen et al. 2004; Sheley et al. 2008).

**Table A-1. ET Cover Vegetation Cover on Clive Analog Sites and Target Cover, Density, and Seeding Rates**

| Common Name / Scientific Name | Average % Cover on Analog Sites | Short-Term Target % Cover | Long-Term Target % Cover | Target Plants per Square Meter | Pure Live Seed (PLS) Pounds per Acre* |
|---|---|---|---|---|---|
| Fourwing saltbush<br>*Atriplex canescens* | 0 5 | < 1.0 | 2 0 | 1–2 | 0 3–0 5 |
| Shadscale saltbush<br>*Atriplex confertifolia* | 3 9 | < 1.0 | 4.0 | 1–2 | 1 0–2 0 |
| Gray molly<br>*Bassia americana* | 1.5 | < 1.0 | 2.0 | 2-4 | 1 0–2.0 |
| Bud sage<br>*Picrothamnus desertorum* | 0.1 | < 1.0 | < 1.0 | 1–2 | 0 5–1 0 |
| Sandberg bluegrass<br>*Poa secunda* | 0 7 | 2.0 | 1.0 | 1–2 | 2 0-4.0 |
| Mojave seablite **<br>*Suaeda torreyana* | 2.7 | < 1 0 | 2.0 | 2-4 | 1 0–2.0 |
| Bottlebrush squirreltail<br>*Elymus elymoides* | 0.0 | 5.0 | 1.0 | 1–2 | 4.0–5 0 |
| Thickspike wheatgrass<br>*Elymus lanceolatus* | 0 0 | 5 0 | 0.0 | 0 | 2 0-4 0 |
| Sterile rye<br>Quick Guard sterile *Triticale* | 0 0 | 5 0 | 0 0 | 0 | 8 0–15 0 |
| Indian ricegrass<br>*Achnatherum hymenoides* | 0 0 | 5 0 | 1 0 | 1 | 4.0–6 0 |
| **Total** | **10.0%** | **25.0%** | **15.0%** | **10–20** | **23.8–41.5** |

* Final seeding rates will be determined based on the seed availability and the seeding method used, with broadcast seeding requiring twice the seed quantities as drill seeding

** *Suaeda* species are difficult to establish and may be replaced by other native species cover during the initial revegetation period, but *Suaeda torreyana* is likely to become established on the ET cover by natural recruitment from local seed sources

Sources Monsen et al 2004, Ogle et al 2012a, Ogle et al 2012b, Granite Seed Company (www graniteseed com, accessed September 11, 2013)

## Seeding Methods

Seeding will occur immediately following soil contouring, BSC inoculation, and gravel mulching, and will be followed by the application of biodegradable mulch or other stabilizing materials. The main purpose of all seeding methods is to place the seed in direct contact with the soil at average depths of 0.5 inch, but not exceeding a depth of 1.0 inch, to cover the seed with soil, and to firm the soil around the seed to eliminate air pockets (Dreesen no date). Seeding will be used in all areas that have replaced topsoil or surface fines, which will include all disturbed areas of the disposal cell including the 50% gravel admixture on side slopes.

Direct (drill) seeding places seed into the soil at a uniform depth and will be used on slopes of less than 15%. However, because soil-gravel mixture on the soil surface may limit the efficacy of drill seeding, broadcast seeding will also be used to provide effective seed placement where slope or soil composition does not permit drill seeding. Additionally, broadcast seeding followed by harrowing may also be employed, where necessary.

Broadcast seeding may be accomplished with 1) a hand-operated, cyclone-type seeder; 2) a mechanical broadcast seeder attached to the imprinting device; or 3) a seed blower that distributes the seed on top of the surface without mulch. The seeds must be covered by raking or dragging a chain or harrow over the seedbed. Imprinting with straw punch treatment also may be used to place seed in the soil. The cyclone-type seeder can be used on any slope that can be reached by foot.

Hydroseeding and hydromulching use water with a slurry of seed, mulch, and tackifier that is sprayed over the restored topsoil surface. Hydroseeding alone sprays only the seed on the soil surface. This method often does not allow good soil-to-seed contact, leaves seed exposed to desiccating wind and temperatures, and increases seed loss by rodent and avian foraging. However, hydroseeding and hydromulching may be employed on side slopes as needed.

Application of water in the seed furrow is an inexpensive technique that can double the number of seedlings established compared to no water being applied in the seed furrow. This method was proven in field tests and improves stand establishment in either moist or dry conditions (ITRC 2003). Similar enhancement of moisture in seed microsites can be achieved through fall or early winter-timing of seeding efforts and mulching to conserve moisture in upper soil layers.

## Irrigation

In arid and semiarid regions, irrigation substantially improves plant establishment, but is problematic for ET cover systems where water infiltration is not desired. Nevertheless, early and rapid plant establishment protects barrier and waste layers from drainage water. Because native grasses should be planted less than 0.25 inch deep, frequent irrigation can be required to maintain moisture in the seed zone, which can dry below the wilting point in one day and limit the successful establishment of grasses. Therefore, irrigation can be used to maintain the surface soil in a wet condition during peak drying episodes for periods of up to least two weeks during initial plant emergence and establishment. Any irrigation would be of limited duration and would coincide with early plant growth and periods of high evapotranspiration. In the event that there is a need for irrigation, it will be managed to ensure that there will be no infiltration beyond upper soil layers.

## Seeding and Transplanting Timing

In arid and semi-arid conditions, seeds must be planted in the appropriate time of the year. The seeding window for woody desert species is early to late fall. Container-grown seedlings can be planted in fall or early spring. Fall is generally the preferred planting time for desert restoration, because it allows root establishment during cooler, often wetter, winter months, and allows for the establishment of healthy roots that result in greater aboveground biomass and growth the following growing season (Bainbridge 2007).

## Soil Amendments and Weed Control

Soil amendments will be used to temporarily improve the physical and chemical properties of surface soils during plant establishment (ITRC 2003). Soil amendments consist of fertilizers, wood or straw mulches, tackifying agents, or soil-stabilizing emulsions.

The need for the application of fertilizers is not anticipated as part of revegetation activities, because elevated levels of soil nitrogen is expected to encourage weedy plant colonization (ITRC 2003; Sheley et al. 2008). Cheatgrass is of particular concern in soils with elevated nitrogen. Mycorrhizal fungal inoculants are often used to facilitate shrub establishment, but the target halophytic shrub species for the ET cover are generally do not host mycorrhizal associations.

Pre-emergent herbicide may be used to minimize annual germination of weeds, particularly cheatgrass and halogeton, and allows time for the perennial herbaceous species to become established (Monsen et al. 2004).

# Monitoring, Maintenance, and Reporting Program

## *4.1 Monitoring Requirements*

Monitoring and maintenance will begin with implementation of the revegetation effort. The initial revegetation period from years one to two will require monitoring of seeding success, weed invasion, and erosion on the ET cover.

Vegetation inspections and monitoring will be conducted bi-annually in spring and fall during this period. The purpose of post-rehabilitation vegetative cover monitoring is to evaluate soil stability, vegetative cover and density, and noxious and invasive weed infestations.

Vegetative cover monitoring will include both qualitative and quantitative analysis. Bi-annual monitoring will continue for a minimum of five years. The objectives of monitoring are as follows:

- To quantify the effectiveness of temporary and permanent erosion-control structures.
- To ensure that the cap and embankments are stable and that runoff is naturally controlled in place, with no accelerated erosion or washouts. Any erosion issues should become apparent within the first 2 years or after the first significant runoff event.
- To quantify seeding success and transplant survival for 5 years. Establish permanent vegetation monitoring transects or plots to allow quantitative comparisons of plant cover and density, BSCs, bare ground, and litter cover over time and to native analogues.
- To identify and treat noxious and invasive weed infestations. With the exception of noxious and invasive weed control, vegetation maintenance is not anticipated.
- To identify any other disturbances that may hinder reclamation success, such as soil compaction, excessive grazing, and diseases or pests.

## *Revegetation Performance Criteria and Monitoring Parameters*

The long-term, steady-state vegetation community on the ET cover will be considered viable when it consists of native shrub, forb, and graminoids species at the target cover and densities required for a functioning cover system. Vegetation and erosion monitoring should continue for 5 years.

Where initial reclamation and plant establishment efforts fail to make progress toward meeting plant establishment standards after year two, reseeding or planting will take place. Areas will be reseeded where initial plant establishment efforts fail.

A quantitative vegetation monitoring program will document the revegetation progress on the cover. Monitoring transects will be systematically established in $1/10^{th}$-hectare plots scattered on the cover. Global positioning system coordinates will be recorded for all transects. The vegetation monitoring design will follow the methods used for collection of field study data (SWCA 2012) so that monitoring data are directly comparable to the data collected in ecological analogs.

Revegetation will be considered successful when herbaceous and woody plant cover is 80 percent of the target cover, and there is no significant soil erosion and minimal (<10%) cover of noxious or invasive weeds. Negligible disturbance to soils and vegetation will occur during annual monitoring.

## *Maintenance Activities*

While rarely expected, identified erosion problems will be addressed as soon as is practicable and will be performed as needed during the 5-year vegetation establishment period and 100-year Institutional Control Period. Temporary erosion control structures such as straw bales or sediment barriers will be removed when the ET cover is deemed stable.

Reseeding or replanting efforts, including supplemental mulching, if necessary, will occur where monitoring identifies a restoration failure. Noxious and invasive weed control is also included in maintenance.

## *Reporting*

Observations of restoration success will be documented annually based on field inspections and monitoring. Areas that need remedial action will be documented during monitoring, and recommendations for erosion controls or restoration work will be included in the report. Areas where control of noxious or invasive weeds is needed will also be reported.

## Adaptive Management Program

Adaptive management during the Institutional Control Period will be implemented to address unforeseen circumstances. Adaptive management is defined, for the purposes of this Plan, as a flexible, iterative approach to the successful development of a functional vegetated cover. The management of the cover system will be directed by the results of annual monitoring activities and observations of factors that are inhibiting the development of vegetation on the cap. Anticipated events and remedial measures are described below.

### *Prolonged Drought*

A review of Clive's meteorological history reveals that seasonal drought is anticipated to occur periodically. The native vegetation is composed of drought-tolerant plant species that are capable of withstanding seasonal fluctuations in available moisture. However, an extended drought could potentially occur during part or all of the 5-year vegetation development and monitoring period. Prolonged drought would entail low seasonal rainfall and high temperatures that reduce plant cover, increase plant mortality, increase pest infestations or herbivory, or otherwise limit the development and growth of vegetation on the cap. Remedial measures for prolonged drought would be limited to reseeding and irrigation, and extension of the 5-year monitoring and reporting period.

### *Storm Events*

High-precipitation storm events can damage soils and vegetation. If qualitative and/or quantitative monitoring of the vegetated cover indicates that stochastic events have impeded soil stability or vegetation growth within the first 2 years post-installation, remedial actions such as mulch applications, erosion control materials, and reseeding will be required.

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ENERGYSOLUTIONS

APPENDIX D

HAL Response to

DRC Erosion Interrogatories

# *DRC RFI Section 4.0 Erosion*

## EnergySolutions PA Section 2.2 Embankment Cover Designs

### *Section 2.2 DRC Interrogatory 4.2*

**DRC Interrogatory Statement:**

***While the licensee claims on Page 2-6 that "Long term stabilization of the Embankment is accomplished through erosion control and flood protection", the licensee must demonstrate through acceptable experiments and/or mathematical or numerical modeling that the proposed soil/gravel admixture with only 15% gravel in the surface layer will be adequate to prevent the formation of rills and gullies in the surface layer will be adequate to prevent formation of rills and gullies in the surface layer of the cover system throughout the mandated 10,000 - -year modeling time period. Alternatively, the Licensee can redesign the cover system to ensure appropriate levels of erosion protection. The procedure described by Anderson and Stonnont (2005) may be an appropriate starting place for this.***

**HAL Response:**

Erosion is a critical element to the design process and the basis for that design is given in this response. Methodologies are described in this response that addresses the DRC concerns about the adequacy of the erosion protection. The potential for the future erosion is projected using several different methods. The chosen methods for determining the adequacy of the erosion control for the proposed Evapotranspirative Cover are commonly used and have been accepted and recommended by the US Environmental Protection Agency (US EPA) and the US Nuclear Regulatory Commission.

In their interrogatory, the DRC identified various locations around the Clive facility that have experienced rill erosion. All of the sites shown in the examples are areas that have been disturbed, are non-vegetated and without any apparent effort to restore the slope to natural conditions. Natural conditions for the slopes can be defined as slope cover conditions (vegetation, biological soil crust, plant litter, etc) that exist in the Clive area on stable native slopes. The Evapotranspirative Cover that is contemplated by EnergySolutions includes such erosion control measures such as the establishment of native vegetation, gravel admixture, establishment of native soil crusts and plant litter, and appropriate compaction. Following its construction, EnergySolutions will have the 100-year institutional control period to ensure that the prerequisite long-term, steady-state conditions are established and that excessive rilling and gullying will not occur. There is a significant difference between the slope of the proposed Evapotranspirative Cover design and the DRC-photographed highly disturbed slope with bare-soil.

**AVERAGE SOIL LOSS EROSION RATES**

Two methods were utilized to project the long term effects of sheet erosion. The Revised Universal Soil Loss Equation (RUSLE) was selected because of its widespread acceptability within the engineering community and based on recommendations by the EPA (US EPA Seminar Publication, 1991). The Rangeland Hydrology and Erosion Model (RHEM), developed using recent data and methods by the Southwest Watershed Research Center, was chosen because of its direct applicability to the arid rangelands of the western United States. The use of the RHEM also serves to establish a range of projected soil loss rates between two methods.

**Revised Universal Soil Loss Equation (RUSLE)**

The RUSLE estimates average annual soil losses from erosion. This methodology is commonly used to determine the long-term stability of slopes and is an industry-standard means for design of erosion control. Guidance given by the EPA states that "The U.S. Department of Agriculture's (USDA's) Universal Soil Loss Equation is recommended as the tool to evaluate erosion potential" (US EPA Seminar Publication, 1991). The basis for this approach comes from the theory that "if adequate protection is provided to control sheet erosion, then rills and gullies will never form from rainfall" (Israelsen et al, 1984). Generally, the RUSLE equation is defined as:

**A = R*K*LS*C*P**

Where:

A = the average soil loss per unit area, expressed in tons/acre/year

*R = the rainfall/runoff factor, which is the number of rainfall units for rainfall energy and runoff and snowmelt*

*K = soil erodibility factor in tons per acre per year per unit of R*

*LS = topographic factor (length and steepness of the slope)*

*C = the cover and management factor (equivalent to the VM factor), which is the ratio of soil loss from an area with a given cover and management relative to that from an identical area in continuous fallow*

*P = the supporting conservation practice factor, in this case assumed to be equal to 1*

This procedure and site-specific factors are described in "Erosion and Sedimentation in Utah – A Guide for Control" (Israelsen, 1984) and "Design Hydrology and Sedimentation for Small Catchments" (C.T. Haan et al, 1994). The computed average sheet erosion soil loss is presented in the following table.

**EFFECTS OF EROSION – AVERAGE SOIL LOSS ANALYSIS USING RUSLE (TOP SLOPE WITH UNIT 4 CLAY W/ 15% GRAVEL ADMIXTURE AND SIDE SLOPE WITH UNIT 5 CLAY AND 50% GRAVEL ADMIXTURE)**

| Slope Segment | R (ft tons/ac/hr) | K (tons/ac/EI) | L (ft) | S (%) | C | A (tons/ac/yr) | | Total Soil Loss (mm/year) |
|---|---|---|---|---|---|---|---|---|
| Top Slope (4%) | 6 | 0.18 | 942 (4%) | 4% | 0.2 | 0.25 | 0.24 overall | 0.026 |
| Side Slope (20%) | 6 | 0.07 | 188 (20%) | 20% | 0.02 | 0.19 | | |

The R factor is selected based on the Utah-specific Iso-Erodent (R) mapping provided in the Utah Water Research Laboratory report (Israelsen, 1984). The K values are based on the Unit 4-specific material characteristics with the gravel admixture, using the Wischmeier nomograph as described in the methodology presented in the Israelsen and Hann procedures. The C factor for the top slopes is based on the sparse vegetative cover naturally found in the areas immediately surrounding the Clive facility. The above application of the RUSLE assumes that the vegetation on the ET Cover is already well established (which has been shown to occur early during the 100-year Institutional Control Period). The C factor for the side slope is based on the higher percentage of gravel in the Unit 4 gravel admixture (50% gravel). The 50% gravel admixture on the side slopes results in a pseudo-gravel mulch once some of the fines have been removed. The low projected average annual soil loss rates demonstrate stable slope conditions with losses an order of magnitude lower than the 2 tons per acre per year described as the minimum criteria for RCRA/CERCLA cover systems (US EPA Seminar Publication, 1991).

**The Rangeland Hydrology and Erosion Model (RHEM)**

RHEM offers a model specifically tailored for the unique conditions in the rangelands of the West (Nearing et al., 2011). The model is a process-based erosion model based on the Water Erosion Prediction Project (WEPP) model (Nearing et al., 2011), incorporating relationships specific to western rangelands. The model incorporates the impacts of splash erosion and thin sheet-flow transport (Wei et al., 2009). In developing and validating their model for western rangelands, Southwest Wastershed Research Center found that "on most undisturbed rangelands, rainfall splash and sheet erosion dominate erosion" and that "significant rilling does not occur readily under most undisturbed situations"(Wei et a., 2009). Nevertheless, even though "significant concentrated flow detachment causing small scour channels (rills) at the scale of the sheet erosion plot generally only occurs under disturbed or otherwise exceptional conditions" (Nearing et al., 2011), the RHEM model considers concentrated flow through the use of an excess shear stress equation. A flow chart of the RHEM model process is provided in Figure 1.

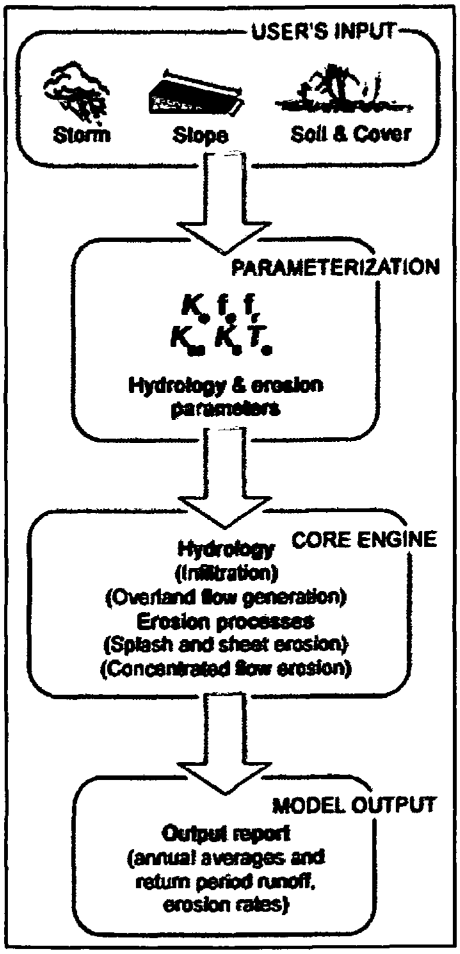


**Figure 1.RHEM Flow Chart (Southwest Watershed Research Center)** http://apps.tucson.ars.ag.gov/rhem

Since the RHEM model does not have a method for accounting for the gravel admixture it conservatively models the Unit 4 material unamended. The results of the RHEM model using Clive's conditions and a well-established vegetative cover are presented in the following table.

### EFFECTS OF EROSION – AVERAGE SOIL LOSS ANALYSIS USING RHEM (TOP SLOPE WITH UNIT 4 CLAY W/ 15% GRAVEL ADMIXTURE AND SIDE SLOPE WITH UNIT 5 CLAY AND 50% GRAVEL ADMIXTURE)

| Slope Segment | Climate Station | Soil Texture Class | Length (ft) | Slope (%) | Soil Loss (tons/ac/yr) | Total Loss (tons/ac/yr | Total Soil Loss (mm/year) |
|---|---|---|---|---|---|---|---|
| Top Slope (4%) | Dugway, Utah | Silty Clay | 942 | 4% | 0.03 | 0.14 | 0.016 |
| Side Slope (20%) | Dugway, Utah | Silty Clay | 188 | 20% | 0.11 | | |

Given the requirement to model the cover performance for 10,000 years, the average soil loss extrapolated over that period ranges from 1,400 tons per acre (equivalent to about 6 inches) to 2,400 tons per acre (equivalent to about 10 inches) using the RHEM and RUSLE, respectively. This constant sheet-erosive soil loss over time ignores any restrictive impacts of significant deposition of particulate by wind or plant litter which has been observed in the area. The RUSLE and RHEM analyses also do not account for the potentially significant erosion resistance (Mazor et al., 1996) qualities of a naturally-occurring biological soil crust observed in the Clive area.

**GULLY EROSION**

Gully erosion potential was checked based on the calculation of permissible velocities according to the method presented in NUREG-1623 "Design of Erosion Protection for Long-Term Stabilization". As opposed to the projection of the long-term effects of precipitation over time due to sheet erosion, the effects of gully erosion are determined by the consideration of a large single rainfall event. According to the procedure outlined in NUREG-1623, the first step is to determine the peak flow (Q) using the rational formula based on the intensity from the Probable Maximum Precipitation (PMP) event. The Probable Maximum Precipitation (PMP) was determined using the procedures outlined in the US Army Corps of Engineers publication Hydrometeorological Report No. 49 (HMR 49) which resulted in a 1-hour PMP rainfall intensity of 9.9 inches (Jones, 2012). The equation given in NUREG-1623 for the procedure for the computation of flow is:

$$\mathbf{Q = Fci\ A}$$

*Where:*
*Q = Runoff Rate, cfs/ft*
*F = Flow concentration factor, recommended to use a factor of 3 by NRC staff in NUREG-1623*
*c = dimensionless runoff coefficient*
*i = rainfall intensity, in/hr*
*A = catchment area, using a 1 foot wide strip along the length of the slope, acres*

Using this flow rate, a flow depth is calculated by solving the Manning Equation for normal depth on a one foot wide strip along the slope length. The Manning's n value was calculated to be 0.05 using an empirical equation for channels with gravel beds with shallow flow depths (Bray, 1979). The derivation of the Manning Equation to solve for depth is given in NUREG-1623 as:

$$\mathbf{y^{5/3} = Qn / (1.486\ S^{1/2})}$$

and $\mathbf{V = Q/y}$ where V is the flow velocity in ft/sec

The results for both the top slope and the side slope using the vegetated slope condition are summarized in the following table. Flow velocities on the top and side slopes during the PMP event (the largest probable storm event) are predicted to be 1.85 and 1.57 ft/sec, respectively. The acceptable Maximum Permissible Velocity (MPV) was selected from tables provided in NUREG/CR-4620. The permissible velocity method is a commonly applied method to determine channel stability. Under this method the slope is assumed stable if the calculated velocity (V, the velocity resulting from a PMP in this application) is less than the MPV. By contrast, if velocities exceed the MPV, it is assumed that the slope will experience excessive erosion that will lead to the formation of gullies. The methodology presented in NUREG-1623 then directs that the estimates for the MPV be adjusted downward to account for the influences of flow depth. The side slope gully analysis was completed independently of the top slope.

### GULLY EROSION POTENTIAL - VELOCITY ANALYSIS

| Slope Description | Length (ft) | Slope (ft/ft) | i (in/hr) | c | Q (cfs/ft) | y (ft) | V (ft/sec) | Adjusted MPV (ft/sec) |
|---|---|---|---|---|---|---|---|---|
| Top Slope (4% | 942 | 0.04 | 9.9 | 0.5 | 0.32 | 0.17 | 1.85 | 2.5 |
| Side Slope (20%) | 188 | 0.20 | 9.9 | 0.5 | 0.06 | 0.04 | 1.57 | 2.5 |

Therefore, all slope scenarios using the ET cover system are assumed to provide acceptable protection against gully erosion using these criteria by limiting the potential of gully formation from high velocity channelization.

### CONCLUSION

The above analyses demonstrate that the design of the proposed evapotranspirative cover system achieves sheet, rill and gully erosion control.

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# APPENDIX E

## HAL Response to

## DRC Freeze Depth Interrogatories

ENERGYSOLUTIONS

## *DRC RFI Section 9.0 Freezing of the Radon Barrier*

### EnergySolutions PA Section 2.1.3 Embankment Cover Designs

***Section 2.1.3 DRC Interrogatory 9.1***

**DRC Interrogatory Statement:**

***On Page 2-2, under Temperature, it says that "data from the Clive facility from 1992 through 2011 indicate that monthly temperatures range from about -2°C (29°F) in December to 26°C (78°F) in July (MSI, 2012)." An analysis of temperature data for the Clive site indicates that there is potential for freezing of the radon barrier, with adverse consequences. Please revise the proposed CAW cover-system thickness to prevent potential freezing of radon barrier clay at depth.***

**HAL Response:**

There are several methods for determining seasonal frost depth in soils. The variation of frost depths across the country is largely dependent on the temperature at the soil surface and the thermal properties of the soil. HAL chose to use the modified Berggren equation to calculate frost depth because of its long established use and acceptability by the engineering community. The method, first presented by Berggren in 1943 and further refined by Aldrich and Paynter in 1953, was later adopted by the US Army Corps of Engineers and other agencies as their preferred method for frost depth determination (Departments of the Army and Airforce, 1988). Frost depth calculated using the modified Berggren equation is as follows:

$$x = \lambda\sqrt{\frac{48k_{avg}nFI}{L}}$$

Where

*$x$ = depth of freeze (ft)*

*$\lambda$ = dimensionless coefficient that considers the effect of temperature changes in the soil mass*

*$k_{avg}$ = thermal conductivity of soil, average of frozen and unfrozen (BTU/hr-ft-°F)*

*$n$ = conversion factor for air freezing index to surface freezing index*

*$FI$ = air freezing index (°F-days)*

*$L$ = latent heat (BTU/ft$^3$)*

$\lambda$ is determined from the chart shown in Figure 1 based on the calculation of the fusion parameter, $\mu$ and the thermal ratio, $\alpha$. The fusion parameter and thermal ratio are defined by the following equations:

$\mu = (C_{avg}/L) * v_s$

where

$v_s = nFI/t$ with t being the length of the freezing period (taken as 120 days)

The latent heat equation is given as:

$$L = \frac{\left(144\frac{BTU}{lb}\right)(w)(\gamma_d)}{100}$$

The latent heat, just as the formula for the thermal conductivity, is a function of the moisture content and the dry density of the soil. The results are presented in the following table.

**LATENT HEAT FOR TOP AND SIDE SLOPES OF ET COVER SYSTEM**

| Slope | L ($BTU/ft^3$) |
|---|---|
| Top Slope (15% Gravel) | 374.0 |
| Side Slope (50% Gravel) | 604.8 |

or unfrozen soils,

$Cu = \gamma_d(0.17+w/100)$

And for frozen soils,

$C_f = \gamma_d(0.17+0.5w/100)$

And $C_{avg}$ is the average of $C_f$ and $C_u$

The w in the equation is the soil moisture content in % and $\gamma_d$ is the dry soil density. The establishment of the soil characteristics is important to the accuracy and reliability of the depth calculation. The dry density of the Unit 4 clay with gravel admixture (15% for the top slope and 50% for the side slope) was determined by taking a weighted average of the properties for the two materials. The dry density of the clay was assumed to have a dry density of 100 $lb/ft^3$ and the gravel 140 $lb/ft^3$ based on general soil descriptions. When these materials are combined in the gravel admixture for the top slope and side slope the resulting dry densities are 106 $lb/ft^3$ and 120 $lb/ft^3$, respectively. The moisture content for the clay was assumed to be 2% based on soil tests completed by EnergySolutions on the Unit 4 material. A moisture content of 5% was assumed for the gravel based on a general assumption. It is recommended that the dry densities and moisture content data of the admixtures be acquired to refine the soil characteristic assumptions.

The thermal ratio is computed with the following equation:

$\alpha = v_o/v_s$

Where $v_o$ is the absolute value of the difference between the mean annual temperature and 32°F.

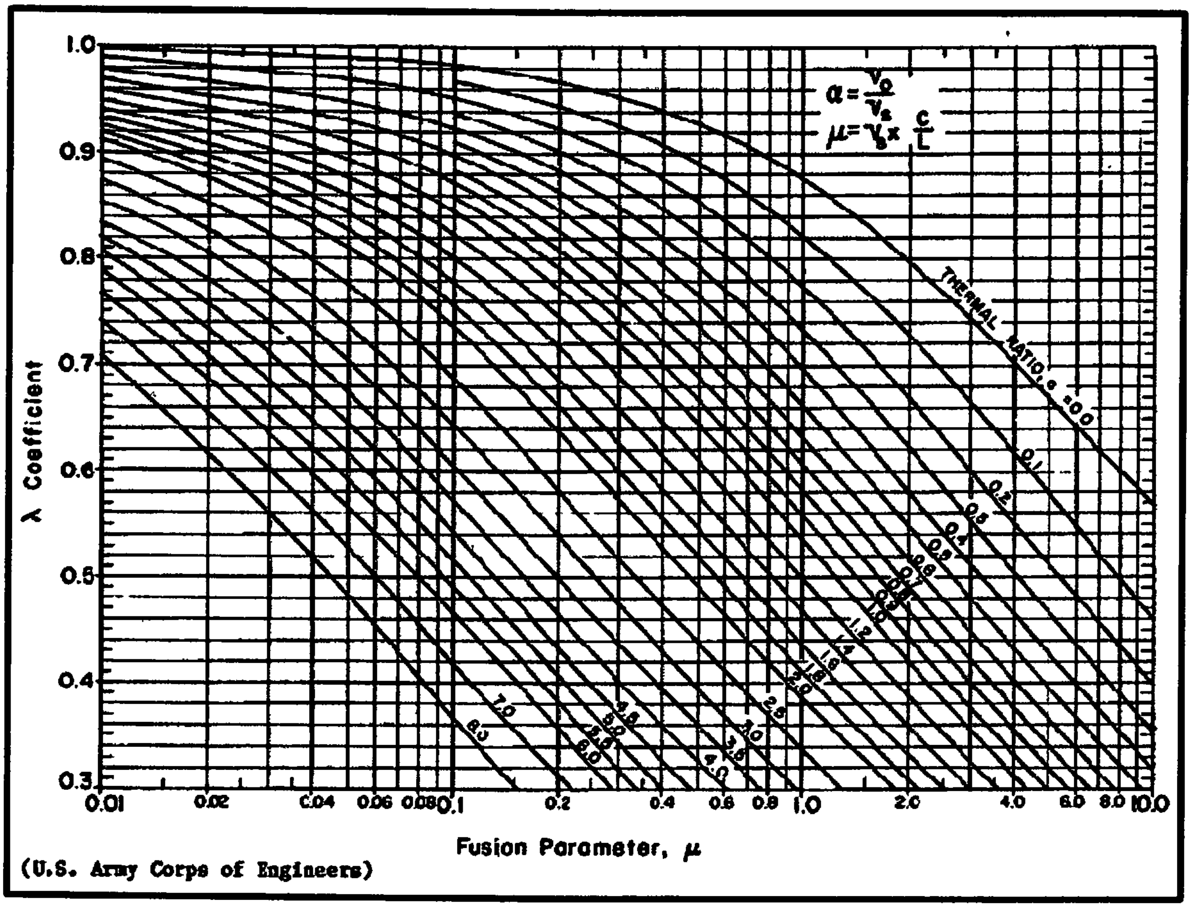


Figure 1. λ Coefficient in the modified Berggren Formula (Departments of the Army and Airforce, 1988)

### LAMBDA COEFFICIENT FOR TOP AND SIDE SLOPES OF ET COVER SYSTEM

| Slope | μ | α | λ |
|---|---|---|---|
| Top Slope (15% Gravel) | 0.32 | 3.82 | 0.41 |
| Side Slope (50% Gravel) | 0.24 | 3.82 | 0.45 |

$k_{avg}$ is determined from the average of the k values for frozen conditions and the k value for unfrozen conditions from the following equations:

$k_f = (0.0833)[(0.01(10^{0.022\gamma_d}) + 0.085(10^{0.008\gamma_d})(w)$

$k_u = (0.0833)[(0.9 \log w - 0.2)(10^{0.01\gamma_d})$

The results of the calculated thermal conductivity (k) values are presented in the following table.

### THERMAL CONDUCTIVITY (k) FOR TOP AND SIDE SLOPES OF ET COVER SYSTEM

| Slope | $k_u$ (BTU/hr ft °F) | $k_f$ (BTU/hr ft °F) | $k_{avg}$ (BTU/hr ft °F) |
|---|---|---|---|
| Top Slope (15% Gravel) | 0.068 | 0.279 | 0.17 |
| Side Slope (50% Gravel) | 0.094 | 0.463 | 0.28 |

The freezing index (FI) for both the 10-year and 100-year freezing season are given as 693 and 1037 °F-Days by NOAA's National Climate Data Center (NCDC) based on over 60 years of data from the Dugway weather station. These values are based on the probabilities calculated by the NCDC from the Dugway dataset where 10-year freezing season has a 10% chance of being reached or exceeded in any given year and the 100-year is a 1% chance in any given year.

Using the Modified Berggren Equation using the parameters and variables described previously gives the following results.

### 10-YEAR AND 100-YEAR FROST DEPTHS (x) FOR TOP AND SIDE SLOPES OF ET COVER SYSTEM

| | 10-Year Frost Depth | | 100-Year Frost Depth | |
|---|---|---|---|---|
| Slope | x (ft) | x (inches) | x (ft) | x (inches) |
| Top Slope (15% Gravel) | 1.53 | 18.3 | 1.87 | 22.4 |
| Side Slope (50% Gravel) | 1.89 | 22.7 | 2.32 | 27.8 |

An additional method was used in order to provide a comparison to the modified Berggren equation. The Utah Department of Transportation (UDOT) gives a simplified method for estimating frost depths in its publication "Pavement Design Manual of Instruction" (UDOT, 2012) and provides an Excel spreadsheet for performing calculations. The spreadsheet relies on climate data, specifically maximum average temperatures (monthly) and minimum average temperatures (monthly). These data are used to calculate the freezing index which is the sum of all months with average temperatures below 32 degrees. The frost penetration is then calculated with the following equation:

$$\text{Frost Penetration} = 1.482(\text{Freezing Index})^{0.4911}$$

Using the Dugway, Utah climate data (Western Regional Climate Center), this value was calculated to be 15.6 inches after applying a reduction factor of 0.7 of the calculated value (UDOT, 2012, Excel Spreadsheet) presumably to account for the difference between air temperature and surface temperature (n factor). Due to the use of average temperature data to calculate the Freezing Index, the resulting frost penetration depth can be seen as an average year depth. This appears to correspond well with the 10-year and 100-year frost depths calculated using the modified Berggren equation.

**CONCLUSION**

The frost depths calculated as part of this analysis give results that are in line with the depths of cover and frost protection proposed in the EnergySolutions ET Cover system design. The proposed radon barrier begins at depths ranging from 30-inches to 42-inches which provides frost protection for the calculated 100-year frost penetration depth of 22.4 inches to 27.8 inches for the top slope and side slope, respectively.

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# APPENDIX F

## Neptune's Responses to

## DRC Modeling Interrogatories

## 3.0 WASTE AND SOURCE TERM

**3.8 INTERROGATORY STATEMENT(S):** Please provide an analysis of the potential for generation of hydrogen from buried metals under the proposed evapotranspirative cover with subsequent fire or explosion.

**ENERGY*SOLUTIONS'* RESPONSE:** The issue of hydrogen generation associated with subsurface radioactive waste has been a topic of investigation in the waste management literature. Most of the references are concerned with TRU and High-Level radioactive waste and the potential for hydrogen generation in sealed containers (Flaherty et al., 1986).

Studies have been conducted by Brookhaven National Laboratory (Siskind 1992) of hydrogen gas generation from LLW for water-bearing waste in sealed containers in response to review concerns raised by the ACNW of the NRC. The Electric Power Research Institute (EPRI) has evaluated hydrogen diffusion from low-level radioactive waste containers (EPRI, 1989) during waste storage, transport, or disposal. An international workshop on safety-case issues associated with gas generation and migration from disposal of radioactive waste was convened jointly by the European Commission and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD, 2001). The workshop examined gas generation for a range of repository host rocks, and engineered and geologic barriers (bentonites, indurated and non-indurated clays/mudstones, crystalline rock and salt) for high-level, transuranic and low-level radioactive waste. Most of the disposal sites involve deep geologic disposal in saturated rocks; the one exception is the Yucca Mountain site which investigated disposal of high-level radioactive waste in the unsaturated zone. The workshop concluded there is reasonable confidence that, for a range of disposal settings and waste categories, gas generation would not compromise the safety case for disposal of radioactive waste (OEDC, 2001, p. 11). The French Agency for the Management of Radioactive Waste has examined hydrogen migration associated with deep disposal of intermediate-level radioactive waste in clay formations 1500 ft below ground surface (Talandier et al., 2006).

The dominant mechanisms for generation of hydrogen gas associated with disposal of low-level radioactive waste are the combined processes of metal corrosion and radiolysis; microbrial degradation is not significant for most settings but may contribute to rates of metal corrosion. Following generation, hydrogen gas may dissolve in pore water and be transported by diffusion/advection; hydrogen additionally is transported by advection and diffusion in the gas phase in the unsaturated zone.

The DRC comment focuses on hydrogen generation from corrosion of buried metals and cites safety concerns with hydrogen generated from K-basin sludge at the Hanford site including accumulation and ignition of hydrogen gas. The updated performance assessment by

EnergySolutions is concerned with currently disposed waste and the impact of disposal of increased volumes of blended and reformed ion-exchange resin. This resin waste has been processed through pyrolysis and steam reforming; the resulting reformed resin consists of metal oxides, spinels, aluminates and residual fixed carbon with little risk of gas generation through radiolysis (Harrison, et al., 2004).

The K-basin sludge cited in the DRC comment is composed of debris from degraded spent fuel canisters, corrosion products, partially dissolved transuranic and fission products, and aeolian sand and concrete fragments that have accumulated in the basins from multiple decades of spent-fuel storage; the sludge has high U-metal contents (up to and exceeding 50%), dose rates up to 5 rem/hour and sufficient fissile content to require controls for nuclear criticality (Mellinger et al., 2004; Knollmeyer et al., 2006). The K-basin sludge waste is classified as TRU waste (>100 nCi/gram; Patterson, 2005). This waste stream is distinctly different from the Class A low-level radioactive waste at the Clive site.

Finally, while limited hydrogen generation associated with disposed LLW is possible, significant accumulation of hydrogen gas is generally regarded as a minor concern for disposal of Class A low-level radioactive waste under shallow unsaturated zone conditions similar to Clive. More specifically, the reformed resin waste are disposed using the Clive Containerized Waste (CWF) design (see pages 1-5 to 1-6 of the EnergySolutions performance assessment; EnergySolutions 2012). The resin containers are placed in a honeycomb pattern of concrete silos, void spaces are backfilled with sand and covered with sand, silt and clays. There is sufficient porosity in the backfill and cover material for efficient diffusion of hydrogen gas. The likelihood of significant accumulations of hydrogen gas is extremely low.

## 4.0 EROSION

4.10 **INTERROGATORY STATEMENT(S):** Page 53 says that the model uses the rainfall and runoff factor of 0.01, whereas the default value in RESRAD-OFFSITE is 160. The rainfall and runoff factor is said to be "*set to 0.01 to produce a negligible erosion rate.*"

Existing evidence of serious erosion potential on site refutes the concept that the model should have rainfall and runoff factors "set to 0.01 to produce a negligible erosion rate." Please develop and support by documented evidence an appropriate design for a cover system for the Class A West embankment that protects against erosion while still enhancing evaporation and transpiration. Please also make relevant and appropriate changes in the model and the PA text. Alternatively, provide justification for the existing plans.

**ENERGY*SOLUTIONS'* RESPONSE:** This comment results from how the RESRAD-OFFSITE modeling code is used in the Neptune studies (Appendix B). The HYDRUS net infiltration values cannot be input directly into RESRAD-OFFSITE. The PA makes adjustments to the

RESRAD-OFFSITE allowed inputs to mimic the HYDRUS model results. The purpose of this part of the modeling is purely to mimic the HYDRUS modeling. For example, the runoff factor is adjusted to match the RESRAD-OFFSITE infiltration rates to the HYDRUS results and does not represent actual model conditions or expected runoff fractions.

The processes of surface erosion are considered separately from the RESRAD-OFFSITE modeling. The RESRAD-OFFSITE PA model uses infiltration input from the HYDRUS code at the base of the cover system (see page 49; Appendix B); the interface between the codes provides the upper boundary condition for the RESRAD-OFFSITE model. The runoff coefficient, Cr and precipitation rate, Pr, are used in RESRAD-OFFSITE as fitting parameters to match the HYDRUS steady-state infiltration rate. Erosion potential is not considered in the RESRAD-OFFSITE model (see the RESRAD-OFFSITE infiltration equation and discussion of equation parameters on page 50 of Appendix B).

## 6.0 PLANT COVER, MODEL PLANT PARAMETERS AND BIOINTRUSION BY PLANT ROOTS

**6.8 INTERROGATORY STATEMENT(S):** Page 19 of Neptune and Company, Inc. (2012) says, "Parameters for describing root water uptake were available from vegetation surveys at the site."

Please specify exactly which parameters were used and which values were obtained for these parameters, along with specific reference information.

**ENERGY*SOLUTIONS'* RESPONSE:** All of the root water parameters including references are described in Section 5.3.2 of Appendix B and the values used in the model are provided there.

**6.9 INTERROGATORY STATEMENT(S):** Page 29 of Neptune and Company, Inc. (2012) speaks of "site characteristics influencing movement of water from precipitation through the vadose zone to the water table at the Clive site" and mentions one as "native vegetation." Please clarify whether proposed plans are to plant or transplant either native or non-native shrubs and grasses, or do proposed plans only envision establishment of native plants through natural succession? If a proposal is made to plant, please indicate the percent coverage intended.

**ENERGY*SOLUTIONS'* RESPONSE:** The cited text is in Section 5.1 of Appendix B. The quoted section of the report is a general discussion of the conceptual model of the hydrology of the site, not a specific description of the cover revegetation plans. The model projects 10,000 years into the future, and assumes that the closure cover is natively vegetated for the duration. Regardless of the starting mix of plant species being native vs. non-native, over this timeframe natural succession dominates. The composition of the vegetation on the cover is insignificant in any case as soil evaporation is the dominant process for water loss from the cover to the atmosphere.

**6.11 INTERROGATORY STATEMENT(S):** Table 3 of the Neptune and Company, Inc. (2012) report shows mean values for black greasewood, Sandberg bluegrass, shadscale saltbush, and gray molly on SWCA vegetation survey plots on site to be 8.5%, 0.7%, 3.7%, and 1.5%, respectively.

Please fix, note and comment on, or justify all discrepancies associated with this and like statements in the PA. Part of the information about species is missing from the statement above, as discussed below. Please add it.

**ENERGY*SOLUTIONS'* RESPONSE:** Percent cover is tabulated for 16 species or cover types in Table 2 of SWCA (2012).

The percent cover data used in the PA model consisted of values for each of the 16 species or cover types for Plots 6 through 12 which are identical to those in Table 2 of SWCA (2012) and percent cover data for each of the 16 species or cover types for Plot 3 from SWCA (2011). The PA model used an average percent cover value of 8.5 percent for black greasewood not 14.3 percent as stated in the Basis for Interrogatory.

These data were used in the model to estimate the partitioning of potential evapotranspiration into potential soil evaporation and potential transpiration. The DRC has argued in Interrogatory Statement 7.2 that this approach provides only a rough estimate.

The partitioning of the total potential evapotransiration (PET) into potential soil evapoaration and potential transpiration can be calculated using the leaf area index (LAI) of the plant canopy. In Iterrogatory Statement 6.9 the DRC recommends a value for LAI of 0.082 as suitable for the Clive site. Potential soil evaporation is then calculated as

$$E_p = PET(exp(-a_{bl}*LAI)$$

With the value of the extinction coefficient set at its normal default value of 0.5

$$Ep = PET(0.96).$$

That is, using this value for the LAI, 96 percent of the total potential evaporation is allocated to potential soil evaporation. These calculations indicate that the plant characteristics at the site do not significantly influence net infiltration. Plants and biological soil crusts, however do provide increased soil stability.

The total percentage of cover for Plots 6 through 12 exceeds 100 percent with percent cover ranging from 108 percent to 134 percent. It is common to see percent cover estimates exceed 100 percent due to the presence of a shrub overstory (see http://www.webpages.uidaho.edu/veg_measure/Modules/Lessons/Module%208(Cover)/Pix&Others/Daubenmire_Exerpts_Sampling_Vegetation(2).pdf)

6.12 **INTERROGATORY STATEMENT(S):** On Page 36 of Neptune and Company, Inc. (2012), there is mention of two excavations by SWCA Environmental Consultants (2011) from which data for Figure 11 rooting depths for shadscale and greasewood were obtained. Roots are claimed to only extend down to about 0.8 meters (2.6 feet) of depth. Elsewhere (SWCA, 2011), it is said that roots extend only to about 0.4 to 0.7 meters (1.3 to 2.3 feet) of depth, depending on location of excavation.

The DRC requests the Licensee provide a synopsis of research findings for greasewood rooting depths at other sites and compare the data to that found in these two excavations. Please provide an explanation for the anomalous on-site data, reconcile discrepancies, and assess the likelihood that the data from the limited number of excavations represents all land locally owned or leased by licensee, i.e., the entire site and surrounding area. Provide support or justification for all assumptions and claims.

The DRC specifically requests the Licensee discuss rooting depths for greasewood at the site in the context of (1) the shallow rooting of greasewood noted at a few locations at Clive does not necessary mean that rooting will be shallow at all locations at Clive, (2) greasewood is an obligate phreatophyte, with roots that almost always go down to within a short distance of the water table, and rooting depths for greasewood are noted at other sites to be as deep as 10 meters (33 feet) or more, (3) roots for greasewood at the site tend to terminate at or about at a thin, highly compressed layer noted to be present at an average depth of approximately 60 centimeters (2.0 feet) in several excavations, (4) thin, highly compressed layer will no longer exist locally once soil is mined for cover systems, (5) according to a recent NRC document (Benson et al., 2011), low-permeability cover-system soil over time is likely to experience greatly increased hydraulic conductivity due to multiple potential causes, which may include plant root intrusion, and (6) in the absence of a perched aquifer or other biological barrier, greasewood roots growing down to typical depths reported in the literature could potentially extend down through the radon barrier, through the waste, and into the capillary fringe, or water table, which may be present at a substantial depth.

The DRC requests that the Licensee consider in modeling work that biointrusion by greasewood (1) may damage the cover system soils and increase their effective hydraulic conductivity values, (2) this could dramatically increase drainage of infiltrated water, (3) this could potentially increase radon emanations through the cover, and (4) biointrusion of greasewood roots into waste may also allow for the conveyance of contaminated water up through roots and then through stems and leaves of greasewood, resulting in transport of radionuclides to the surface.

The leaves may be eaten by foraging animals, such as cattle or sheep. Some of the animals may then be eaten by humans. This source of risk needs to be addressed fully in risk assessment and in the context of inadvertent intruder analysis.

**ENERGY*SOLUTIONS'* RESPONSE:** It is well documented that Black Greasewood is a phreatophyte that routinely extends taproots to significant depths to extract water from the capillary fringe above the water table. Branson et al (1976) found average greasewood rooting depths at a site in CO to be 1.3 meters, though maximum depth extended to 3.6 meters, which was the same depth as groundwater at the site. Donovan et al, (1996) reported greasewood root depths ranging from 3 to 5 m, while both Robertson (1983) and and Shantz and Piemeisel (1940) report root depths of 5 to 6 meters. Greasewood has been reported to extend taproots up to 19 meters to reach groundwater (SWCA Environmental Consultants, 2000, p. 2), though this extreme situation will only occur when precipitation can infiltrate to groundwater, as greasewood roots cannot penetrate the very dry soil that occurs below the zone of infiltration.

The three greasewood plants excavated by SWCA at the Clive Site found roots extending a maximum of 0.8 m. Rooting depth at the Clive site appeared to be influenced by a compact clay layer about 60 cm below the surface, as excavations documented greasewood roots spreading laterally on top of this clay layer. This compact clay layer, where it exists, likely serves as a barrier to infiltration. Work conducted by Groenveld (1989) illustrated an important point about downward growth of phreatophyte roots. Although roots grow downward, they do so into zones of retained water and do not actually "follow" a retreating water table. Mata-Gonzalez (2012) suggests that even those plants traditionally considered groundwater dependent, such as greasewood, only depend on groundwater when surface water is not available, and that when both water sources are available, topsoil water is preferentially used over groundwater.

The shallow rooting depths of the greasewood plants excavated in Clive Plot 3 were likely due to the fact that a saturated layer forms on top of the clay layer, and the greasewood roots exploit this layer. The vegetative survey of the Clive site found that the majority of greasewood plants are less than one meter tall, and studies have found that greasewood of that size tend not to produce taproots (Robertson, 1983). Still, larger plants do occupy parts of the Clive site, especially where precipitation runoff is concentrated, and these plants may extend taproots to exploit deeper water. In that regard, it cannot be stated equivocally that the three excavated greasewood plants at the Clive Site are representative in form of all greasewood at the site. Version 1.0 of the Clive Goldsim Model used a maximum rooting depth for greasewood of 5.7 meters (from Robertson, 1983) to reflect the uncertainty in the representativeness of the SWCA excavations. However, it is important to note that on the engineered cover systems, roots will only be able to penetrate 0.6 – 0.75 m before encountering similar low permeability layers in the engineered covers. These low permeability layers may influence greasewood morphology in the same way as the natural clay layer currently beneath parts of the Clive Site.

6.13 **INTERROGATORY STATEMENT(S):** It states on Page 36 of Neptune and Company, Inc. (2012) that "root density was modeled as decreasing linearly with depth" and that maximum depth was 80 centimeters (0.80 meters, or 2.6 feet)).

Please explain, justify or fix the function characterizing root density as a function of depth.

**ENERGY*SOLUTIONS'* RESPONSE:** The root density data acquired by SWCA (2011) show a distribution with generally higher root density near the surface decreasing with depth. As noted by DRC, this was represented in the HYDRUS model as a linear function with root density decreasing with depth.

The root density data acquired by SWCA (2011) show a distribution with generally higher root density near the surface decreasing with depth. As noted by DRC, this was represented in the HYDRUS model as a linear function with root density decreasing with depth.

A different function could have been used, however, given the similarity in results between vegetated and non-vegetated simulations (3.5 percent difference; see Section 5.4.2), changing the root density function has very little effect on model results. For example, using an exponential function puts more root mass near the surface, which reduces the depth of moisture penetration and increases efficiency of transpiration. Water loss from the cover system is dominated by soil evaporation. As described in the response to Interrogatory Statement 6. using the value of LAI suggested by the DRC 96 percent of the total potential evaporation is potential soil evaporation. These calculations indicate that the plant characteristics at the site are unlikely to significantly influence net infiltration.

**6.14 INTERROGATORY STATEMENT(S):** Figure 11 of Neptune and Company, Inc. (2012) is entitled "Root Density with Depth." The abscissa axis is labeled "Root Density [roots/ern]."

Please explain, justify or fix root density data. Please explain the significance of the values in Figure 11 [roots/cm] from a physical and biological standpoint. Please explain how the root density values are used in the Hydrus-ID model. Does the input for root density in the Hydrus-ID model match the definition of root density given by SWCA (2011)? Are the units the same? Is the meaning of root density the same? Please document all of this.

**ENERGY*SOLUTIONS'* RESPONSE:** Traditional methods of measuring root densities such as profile wall and soil corer methods require separation of soil and roots, and root-length measurement using the line-intersect method. This can be a time-consuming process. More recent methods such as measurement of spectral reflectance require specialized equipment. All of these standardized methods yield good, reproducible estimates of root density. The approach used during the SWCA excavations was not intended to replace these standard methods. The SWCA approach was intended to provide a simple way to get relative root densities in a linear cross section at specific depth intervals. Two plots were chosen by SWCA for characterization of root density and rooting depths. Plot 3 was located in the Northern portion of the Clive Facility site and was dominated by black greasewood and halogeton.

Plot 4 was located in the Southern portion of the Clive Facility and was dominated by scattered native shrubs and halogeton. Three trenches were excavated in each of these plots. Once the roots were exposed horizontal transects across the entire width of the cross-section of the rooting mass were established at 10 cm depth increments until roots could no longer be observed. Measurements were then taken of the width of the entire rooting mass along the horizontal transects. Visible roots were then counted along each horizontal transect for a sample of the width or the entire width. For each horizontal transect, the number of roots observed was divided by the length of the transect, which was either a portion of the entire width or the entire width, to provide an estimate of root density at that depth.

The HYDRUS root water uptake spatial distribution model describes the spatial variation of the potential root water extraction term $S_p$ over the root zone:

$$S_p = b(z)\, T_p$$

where

$b(z)$ = spatial distribution of the potential water uptake over the root zone

$T_p$ = potential transpiration.

The distribution $b(z)$ is of arbitrary shape but is normalized in the model over the root zone $L_R$ such that

$$\int_{LR} b(z)dz = 1$$

since the root water extraction can never exceed the potential transpiration.

The root density data from the three excavations were averaged for each depth from Plot 3 for Black Greasewood and from Plot 4 for Shadscale Saltbush. The general trend for both species showed the highest root density at the surface and the lowest at the maximum rooting depth.

The PROFILE module can be used in HYDRUS-1D to specify the root distribution in the cover profile. The portion of the mesh from the top of the cover to the maximum rooting depth is selected and relative density at the top and bottom nodes of the selected region are specified. For a linear distribution with a maximum at the surface and minimum at the maximum rooting depth the relative density at the top node is set to 1 and to 0 at the bottom node.

Alternatively relative root densities at a depth (root density at a depth divided by the maximum density observed) can be specified for each node in the profile in the Soil Profile Summary Pre-Processing Menu.

The representation of root density in the HYDRUS models is a simplification of the data. While there was some non-linear variation in the mean values of the data with depth, the general trend in root density was approximated as linear with the highest density at the surface decreasing with depth to zero at the average maximum rooting depth. Sensitivity analyses would be required to determine the influence of this simplification on estimated net infiltration.

**6.15 INTERROGATORY STATEMENT(S):** On Page 37 of Neptune and Company, Inc. (2012), it says, "osmotic stress is assumed to be negligible for these simulations so $h_\varphi$ is zero."

Please justify this assumption, or correct the model, as needed.

**ENERGY*SOLUTIONS'* RESPONSE:** This Interrogatory Statement describes the potential reduction in transpiration due to osmotic stress induced by soil salinity. As has been described in the response to Interrogatory Statement 6.11 the water fluxes in the cover system are overwhelmingly controlled by soil evaporation. Minor reductions in transpiration have little effect on the overall water balance.

Vegetation surveys of three field plots on or adjacent to the Clive Site were conducted by SWCA (2011). The three low desert vegetation associations were characterized as black greasewood, Plot 3; halogeton-disturbed, Plot 4; and shadscale-gray-molly, Plot 5. The dominant shrub in Plot 3 was black greasewood with a percent cover of 4.5% and the dominant forb was halogeton with a percent cover of 0.7%. In Plot 4 the dominant shrub was shadscale saltbush with a percent cover of 2.3% and the dominant forb was halogeton with a percent cover of 3.3%. In Plot 5 the dominant shrub was shadscale saltbush with a percent cover of 12.5% and the dominant forb was Halogeton with percent cover of 0.9%.

Black greasewood, shadscale saltbush, and halogeton are all classified as facultative halophytes (Anderson, 2004; Simonin, 2001; and Pavek, 1992). A definition of Halophytes is provided by Shabala (2013) :

> "*Halophytes are defined as plants that naturally inhabit saline environments and benefit from having substantial amounts of salt in the growth media.*"

Halophyte adaptations to saline environments are described by Shabala (2013):

> "*Halophytes have evolved a range of adaptations to tolerate seawater and higher concentrations of salts. These include adjustment of their internal water relations through ion compartmentation in cell vacuoles, the accumulation of compatible organic solutes, succulence, and salt-secreting glands and bladders.*"

Conditions for optimal growth are described by Shabala (2013):

> "*Optimal halophyte growth is achieved at a concentration of around 50 mM NaCl for monocots, and between 100 and 200 mM for dicots.*"

For the optimum range for dicots of 100 to 200 millimoles per liter (mM), the corresponding range of electrical conductivity for a NaCl solution is 9.7 to 18.3 mmho/cm (CRC, 1985).

Depending on the extent of the area defined on and adjacent to the Clive Site, approximately 80 to 90 percent of the soils are mapped as the Skumpah silt loam on 0 to 2 percent slopes (NRCS, 2013).

This Unit is characterized as having maximum salinity ranging from 8.0 to 16.0 mmhos/cm. The top end of this range of maximum salinity does not exceed the maximum of the range of salinity considered optimum for halophyte growth of 18.3 mmho/cm. Given the similarity in ranges of salinity in the surface soils at the Clive Site and for optimum halophyte growth, the influence of the osmotic head reduction in the root-water uptake water stress response function is considered negligible and was, consequently, not included in the model.

However, the borrow soils consisting of Unit 4 and on-site excavations from the borrow pits have higher levels of salinity. Electrical conductivity measurements of these soils acquired by SWCA (2012) range from 12.6 to 55.6 dS/m with a mean value of 26.3 dS/m. This corresponds to an osmotic head of -134 m. As described abo the top of the optimum range for halophytes is 0.2 mol/L (Shabala, 2013). This corresponds to an osmotic head of -99 m. Thus, the additional osmotic head below this value for the Unit 4 borrow pit soils is -35 m. While initially exceeding the optimum range of the facultative halophytes, salts in the surface layers of the cover may be leached downward with time reducing the osmotic effects.

## 7.0 TRANSPIRATION

**7.2 INTERROGATORY STATEMENT(S):** Page 33 of Neptune and Company, Inc. (2012) says "Where the $a_{bl}$ coefficient accounts for radiation intercepted by vegetation and is given the default value of 0.5 (Varado et aI. 2006). Estimates of LAI are not available for the site so $E_p$ and $T_p$ were calculated using the method of SirnUnek et al. (2009). This method uses an estimate of vegetated soil cover fraction (SCF) to calculate $E_p$ and $T_p$ as

$$T_p = PET*SCF$$

$$E_p = PET * (I\text{-}SCF)$$

The soil cover fraction was estimated from vegetation surveys conducted in the vicinity of the site."

The Licensee must find another approach to account for $T_p$ and $E_p$. Otherwise, the model will produce non-viable output, not being in harmony with the objectives and requirements found in the rules and regulations listed below.

**ENERGY*SOLUTIONS'* RESPONSE:** The use of percent cover obtained from vegetation surveys at the Clive site was used in an initial approach for partitioning potential evapotranspiration (PET) into transpiration and soil evaporation in the absence of other data.

This method provides only a rough approximation.A more suitable method for the Clive Site is that described by Varado (2006), which partitions PET based on the absorption of transmitted light through a plant canopy with the absorption of light by the canopy being parameterized by the leaf area index (LAI). This approach was not used in the initial analysis because site-specific LAI data were not available at the time this analysis was done.

The method described by Varado (2006) uses Beer's Law to partition soil and plant evaporation as:

$$T_p = PET(1\text{-}exp(-a_{bl}LAI))$$

$E_p = PET(exp(-a_{bl}LAI))$The fraction of PET represented by soil evaporation is calculated in the response to Interrogatory Statement 6.9 using a value of LAI considered representative of the Site by DRC. The result of the calculation is that 96 percent of PET is found to be due to soil evaporation. The results of these calculations demonstrate that adjustments of plant parameters in the HYDRUS model have little influence on the modeled net infiltration.

7.3 **INTERROGATORY STATEMENT(S):** Page 48 of Neptune and Company, Inc. (2012) discusses use of a soil cover fraction (SCF) of 0.18, which corresponds to a leaf area index (LAI) of 0.4. The claim is made that this value is low relative to literature values.

Please modify the model to use a more appropriate lower value for the SCF and the LAI, and also change the PA text to give an SCF value correlating to an LAI value that is comparable to relevant field-based values for LAI in the Great Basin area, obtained from the literature.

**ENERGY*SOLUTIONS'* RESPONSE:** See response to Interrogatory Statement 7.2.

7.4 **INTERROGATORY STATEMENT(S):** Page 48 states that "the influence of plant transpiration on the long-term annual net infiltration into the waste was examined by modeling net infiltration for design 1 with a 6 inch thick Evaporative Zone with no root water uptake. The long-term annual net infiltration rate into the waste for the cover system without vegetation is shown in Table 8. A comparison with the results for design 1 with a 6 inch Evaporative Zone thickness shown in Table 5 indicates only a 3.5 percent increase in long-term net infiltration when the cover is not vegetated. The I-D HYDRUS models and the associated input and output files are provided in the attached electronic files."

Research findings indicate that the absence of vegetation generally tends to result in greatly increased rates of infiltration. This is in contrast to results claimed for modeling. Please provide justification for the model results discussed above in light of these apparently conflicting published research findings, or review the model and re-run it with more appropriate parameter values (as discussed elsewhere in these comments) to obtain results consistent with published research findings.

**ENERGY*SOLUTIONS'* RESPONSE:** For a site with the characteristics of the Clive site, water balance models show the minimal impact of vegetation on net infiltration. These characteristics include nearly six times greater mean annual potential evaporation than mean annual precipitation, cover layers with material properties that tend to hold the water in storage in the near surface where it is available for evaporation, and sparse vegetation. Under these conditions where potential evaporation greatly exceeds precipitation a decrease in actual transpiration by not including root water uptake in the model can be compensated by an increase in actual evaporation.

As pointed out by the DRC, the removal of vegetation can lead to increased rates of drainage. While this relationship is well documented for coarse textured soils, it does not hold for finer textured soils. Soil texture can be a controlling factor in water balance even when vegetation is absent. For example, consider the observations at three western desert sites described in work by Gee et al. (1994) cited in the Basis for Interrogatory. These authors examined the variations in water balance for different soil and vegetation conditions. The three sites are located in western deserts. These authors found increases in water storage at all three sites when soils are coarse textured and plants are removed from the surface. For a silt loam site at Hanford, however, deep drainage did not occur either with or without the presence of plants. The authors attributed this result to the hydraulic properties of the silt loam that allowed water to be conducted upward to the soil surface for a long enough period to dry the near surface soil profile. the silty clay used for the surface layers in the cover at the Clive Site behaves similarly.

## 8.0 EVAPORATION

8.1 **INTERROGATORY STATEMENT(S):** On page 2-2, the Licensee discusses "the 17-year average annual evaporation rate at the Clive site", provides a value for it, and mentions that it is based on exclusion of two years of reported instrument malfunction. In the same paragraph, the Licensee states that "Pan evaporation measurements are taken from April through October ..."

However, on Page 10 of the attached Modeling Report, reference is made to pan evaporation measurements having been made at the NOAA station at BYU. The text says, "Mean monthly values of pan evaporation measured at the BYU NOAA station in Provo, Utah over the period 1980 to 2005 are shown in Figure 2. Mean annual pan evaporation over this time period is 49.94 inches. This station is located 83 miles to the southeast of the Clive facility. Data from this station are used because pan evaporation data are not available for the Dugway station."

Please provide clarification regarding the apparent conflict between PA Section 2.1.6, which implies that pan evaporation measurements were taken at the Clive site, and latter references on Page 10 of the attached Modeling Report, which refers to use of pan evaporation measurements made at the NOAA Station at BYU.

**ENERGY*SOLUTIONS'* RESPONSE:** The discussion of average annual pan evaporation rates from measurements made at the Clive site on page 2-2 and the discussion of average annual pan evaporation rates made by NOAA are descriptions of two datasets included to provide insight into the climate at the site. These discussions are not in conflict. They describe two different data sets. These are annual mean values included in the discussion to inform the conceptual model of the site. These data are not used as input to the infiltration model. The daily PET values used as atmospheric boundary conditions for the infiltration model are calculated on a daily basis from radiation and temperature data using the Hargreaves method described by Neitsch et al. (2005). These model inputs are described in Section 5.3.1 of Appendix B.

The short-term record described on page 2-2 provides site-specific information on recent conditions. The data from the BYU NOAA station at Provo is included because it provides a continuous and a longer record of 25 years that is useful for comparison with other sites. The annual average pan evaporation rates are not used as direct input to either the HYDRUS or the RESRAD models.

8.3 **INTERROGATORY STATEMENT(S):** Page 11 of Neptune and Company, Inc. (2012) says, "Assuming pan evaporation is approximately equal to potential evapotranspiration (PET) the ratio of annual average precipitation to PET is 0.17."

Please recalculate the annual average pan evaporation in a way more consistent with current professional practice. Please use one of several equations developed and available in published sources to account for transfer of energy through the sides and bottom of the pan to re-calculate the estimated ratio between average annual precipitation and PET. Then, recalculate the ratio of annual average precipitation to PET. Alternatively, justify the calculation made in the quote above.

**ENERGY*SOLUTIONS'* RESPONSE:** The P/PET ratio is often used as a climate indicator for sites where evaporation and transpiration may be important factors affecting the net infiltration. For example Benson et al. (2011) lists P/PET ratios as a climate characteristic of the ACAP study sites in Table 2.1. P/PET ratios are used in the PA discussion to maintain compatibility for comparison with data from other sites. These ratios are used only to provide information for the conceptual site model, they are not used as input to the HYDRUS or RESRAD models. The annual PET value is approximated by the mean annual pan evaporation. The mean annual pan evaporation value used to calculate the ratio was obtained from NOAA from the 25 year average of mean pan evaporation at the BYU NOAA station at Provo, UT. This ratio is calculated to provide insight into the climate at the site, it is not used as direct input into any of the models.

8.4 **INTERROGATORY STATEMENT(S):** Please fix the apparent misstatement copied below and clarify the message to make it consistent with other discussion in Appendix A. On Page 13 of Neptune and Company, Inc. (2012), it says, "*References in this report to ... evaporative zone depth refer only to the function and characteristics of a layer in the ET cover system designs.*"

**ENERGY*SOLUTIONS'* RESPONSE:** The clarification is noted. The text should read "*If the vertical percolation layer is located within the EZD of a HELP model, evaporation is modeled as an extraction and can only occur until the specified wilting point moisture content has been reached.*"

8.5 **INTERROGATORY STATEMENT(S):** Please provide clarification of apparent inconsistencies between various Licensee consultant reports relative to evaporation and use of rip rap. On one hand, the Whetstone Associates (2011a) document argues at length in its Pages 6 and 7 that significant evaporation would occur from the rip rap surface layer. On the other hand, it says on Page 13 of Neptune and Company, Inc. (2012) that "*the rip rap surface layer inhibits evaporation, so more water is available for infiltration.*"

**ENERGY*SOLUTIONS'* RESPONSE:** The two statements are not contradictory. The presence of a rip rap cover inhibits evaporation over what it would be from a vegetated soil cover, however that doesn't mean that evaporation is insignificant in the case of the rip rap surface.

The observations of Gee et al (1994) described in the response to Interrogatory Statement 7.4 on the influence of soil texture on drainage demonstrate how in their case the silty loam soil and for Clive the silty clay have a greater capacity to hold water at the surface making it available for evaporation longer than water in riprap or coarse soils.

The presence of vegetation engages an additional process, root water extraction, which removes water from the root zone of the cover system while evaporation is also occurring. In the period following a rainfall event, both processes act to extract water from the soil with rates diminishing as soil suction increases.

This conceptual model is supported by the acceptable infiltration-limiting performance of the traditional rip rap cover system as compared with the improved infiltration-limiting performance of an ET cover system.

8.6 **INTERROGATORY STATEMENT(S):** As stated earlier in Chapter 7.0, Transpiration, Page 33 of the Neptune and Company, Inc. (2012) report gives an equation for potential evaporation as

$$E_p = PET * (1-SCF)$$

This equation is not appropriate for the Clive, Utah site. The Licensee must find another approach to account for $E_p$. Otherwise, the model will produce non-viable output.

**ENERGY*SOLUTIONS'* RESPONSE:** Please see the response to comments 7.2 and 7.3.

**8.7** **INTERROGATORY STATEMENT(S):** Page 37 of Neptune and Company, Inc. (2012) indicates that "osmotic stress is assumed to be negligible ..."

However, relatively high salinity causes osmotic stress leading to diminished evaporation. Please account for this when calculating infiltration in the model.

**ENERGY*SOLUTIONS'* RESPONSE:** A previous interrogatory statement (6.15) addressed the issue of the influence of elevated salinity on root water uptake. This interrogatory statement addresses the influence of elevated salinity on soil water evaporation.

Salhotra et al. (1985) and many other studies document a decrease in evaporation due to salinity in open water. Other studies of the effects of salinity on evaporation from soil are more appropriate for this discussion. For example, and Horton (1999) describe the effects of salinity on evaporation from soil in column studies for a silty clay loam (Fayette soil) which is very similar to the silty clay used for the evapotranspiration surface cover layer. They found that the ratio of evaporation loss from the salinized soil columns to the amount of water evaporated from solute-free soil columns increased with time from 0.90 to 0.95 for the Fayette soil, where the salinized soils had a concentration of KCl of 0.92 mol/kg, which is equivalent to a molarity of NaCl of about 0.71 M.

The mean value of salinity of the borrow soils for the CAW is 26.26 dS/m (SWCA 2012, Table 11) which is equivalent to a NaCl molarity of 0.3 M (CRC 1985, page D-269).

So Nassar and Horton (1999) describe a small reduction in evaporation for a study with more than twice the salinity than in CAW borrow soils. Therefore any reduction in evaporation due to salinity is small enough to be neglected given all other uncertainties in the modeling.

Rad and Shokri (2012) report a greater decrease in evaporation as a function of salinity compared to Nassar and Horton (1999), but their study is for sand rather than silty clay loam.

## 10.0 CAPILLARY BARRIER

**10.4** **INTERROGATORY STATEMENT(S):** Page 16 of Neptune and Company, Inc. (2012) says, "Lateral drainage layers have high saturated hydraulic conductivities to promote lateral flow and have characteristics similar to capillary barriers."

Please revise and clarify this statement so that it is more fully consistent with current scientific and engineering knowledge concerning drainage or filter layers and capillary barriers.

**ENERGY*SOLUTIONS'* RESPONSE:** The clarification is noted. The text "*...and have characteristics similar to capillary barriers.*" should not be included.

## 11.0 HYDRAULIC CONDUCTIVITY, INFILTRATION AND FLOW

**11.1 INTERROGATORY STATEMENT(S):** Page 12 of the PA describes silty clay Radon Barrier material, saying, "Upper Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This layer has the lowest conductivity of any layer in the cover system. This is a barrier layer that reduces the downward movement of water to the waste and the upward movement of gas out of the disposal cell. Lower Radon Barrier: This layer consists of 12 inches of compacted clay with a low hydraulic conductivity. This is a barrier layer placed directly above the waste that reduces the downward movement of water."

Page 39 of the PA says, "Upper Radon Barrier: The engineering design specification for a maximum hydraulic conductivity is $5x10^{-8}$ cm/s ($4.32x10^{-3}$ cm/day) for this clay barrier."

Page 39 also says: "Lower Radon Barrier: The engineering design specification for a maximum hydraulic conductivity is $1x10^{-6}$ cm/s ($8.64x10^{-2}$ cm/day) for this clay barrier."

In addition to the Upper and Lower Radon Barriers, the surface layer and evapotranspiration layer are considered in the PA model to consist of silty clay materials.

The PA model makes no attempt to consider any changes in hydraulic conductivity of these low-permeability soils subsequent to embankment construction.

Upper and Lower Radon Barriers should be constructed having the soil hydraulic conductivities given in the engineering design specifications described above but the soil hydraulic conductivities should be modeled over the long-term as being in the range of $8x10^{-6}$ to $6x10^{-4}$ cm/s. This complies with NRC guidance for long-term cover-system hydraulic conductivity values (Benson et al., 2011). Please conduct a sensitivity analysis in the PA model using the following three values for long-term cover-system silty-clay hydraulic conductivity: $8x10^{-6}$ cm/s, $6.9x10^{-5}$ cm/s and $6x10^{-4}$ cm/s.

**ENERGY*SOLUTIONS'* RESPONSE:** The DRC provided, in their Interrogatory Statements and basis, numerous comments and suggestions for a range of topics that could be considered in an enhanced sensitivity analysis of cover performance. However, there are two important limitations to their suggestions.

First, the comments are closely linked to the Benson et al (2011) report published by the NRC. While this is a useful report, the topic of cover performance is complex with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. An expanded assessment of cover design components and assigned physical properties in models of cover performance must be carefully designed for applicability to the climate and hydrogeological setting of the Clive disposal facility.

Second, The DRC comments span two topics: alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). Enhanced investigations of these components of uncertainty require both different approaches in the structure of the modeling studies and application of methods of global sensitivity and uncertainty using probabilistic modeling. There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. However, the need for these studies has not been established. The deterministic modeling results for the revised PA show that the Clive site easily meets regulatory requirements for Class A waste.

11.2 **INTERROGATORY STATEMENT(S):** Page 42 of Neptune and Company, Inc. (2012) says, "*not including the effect of soil crusts on infiltration will overestimate the actual net infiltration rate at the site.*"

Please revise or remove the statement. Alternatively, justify it.

**ENERGY*SOLUTIONS'* RESPONSE:** Noted. Since the information on the effects of biological and physical crusts on infiltration in inconclusive, it is premature to reach any conclusion about the effect of either crust type on vegetation. The effect of crusts on infiltration are not considered.

11.3 **INTERROGATORY STATEMENT(S):** Page 46 of Neptune and Company, Inc. (2012) says, "*Average annual fluxes are small.*"

Please re-do the model with appropriate hydraulic conductivities, which will undoubtedly make average annual fluxes greater.

**ENERGY*SOLUTIONS'* RESPONSE:** Please see response to comment 11.1 above.

## 13.0 OTHER MODELING ISSUES

13.1 **INTERROGATORY STATEMENT(S):** Page 2-10 states, "the soil:plant ratio was only used where actual measured soil $K_d$ values are not available, and the published $K_d$ value from the soil:plant ratio was decreased by two orders of magnitude to be conservative. The radionuclide $K_d$ values used in this updated site-specific Performance Assessment are listed in Table A-4 of

Appendix A." Relative to these comments, the DRC requests two items of information: (1) the names of the specific nuclides for which soil:plant $K_d$ values were utilized, and (2) justification for the use of soil:plant $K_d$ values in models for site contaminant transport.

**ENERGY*SOLUTIONS'* RESPONSE:** This comment is similar to comment 13.12. The only $K_d$ values used in Appendix B are a $K_d$ of zero for iodine-129 and default Kd values from RESRAD-OFFSITE. None of the $K_d$ values used in Appendix B were determined from soil:plant ratios. The $K_d$ values from the Whetstone Associates (2011) Table 27 were not used in and are not applicable to the modeling studies described in Appendix B.

13.2 **INTERROGATORY STATEMENT(S):** On Page 3-8, it states, "Also, longitudinal dispersivity in the unsaturated and saturated zones was set at a larger value than that suggested by RESRAD default values (where larger values of longitudinal dispersivity reduce the potential arrival time of contaminants at the Point of Compliance well)."

Please reveal the value of longitudinal dispersivity in the saturated zone used in the model. Please also re-run the model with the suggested or default dispersivity value in the RESRAD model, or with another value chosen on a scientific basis and conservatively estimated, or else justify the use of the dispersivity value previously selected for use.

**ENERGY*SOLUTIONS'* RESPONSE:** The value used for saturated zone longitudinal dispersivity is listed in in Table 9, page 59 of the Neptune and Company, Inc., report. The value used in the RESRAD model is 0.99 versus the RESRAD default value of 0.030. The justification for the selection of this value is in Table 9 notes and referenced to Gelhar et al, 1992.

The use of a higher value for longitudinal dispersivity reduces the first arrival time for the modeled iodine inventory, which is the intended goal of the RESRAD-OFFSITE modeling approach. The modeling approach does not evaluate radionuclide concentrations within the contaminant plume nor are the necessary to demonstrate compliance with performance objectives.

13.3 **INTERROGATORY STATEMENT(S):** Page 30 of Neptune and Company, Inc. (2012) says that "in this case the combination of climate and cover layer properties may maintain flow in the cover system as one-dimensional." This result is in contrast to that for the current, approved design, which is modeled as having two- or three-dimensional flow since it employs rock armor or rip rap cover, as well as two underlying drainage layers. It is said in the report that 18 to 19 percent of infiltrated precipitation is expected to be removed from the cover system in this current, approved design by lateral conveyance through the upper drainage layer. Another statement made is "with more water removed from the upper layers of the covers it is less likely that water saturations at depth could increase to the point where the filter layer would laterally divert water."

The Licensee needs to revise and upgrade its model to be consistent with NRC guidance and improved assumptions, rerun the model, determine the fractional flow removed laterally from the drainage or filter system design (Design 2), and then assess whether or not a drainage or filter system design would be beneficial for actual construction. Doing so will be necessary to meet requirements found in applicable rules and regulations and guidance listed below. Specifically, please run the model using the geometric mean of the range of anticipated hydraulic conductivity values defined by Benson et al. (2011) in the NRC guidance for clay layers in the radon barrier.

Also, please use the lowest and highest values in that range as bounding values in sensitivity and uncertainty analyses. When modeling, also include all other modeling approaches and parameter changes requested in this Interrogatory, unless not using them is first negotiated with the DRC in writing. Please evaluate modeled drainage of water into the waste and the groundwater system using (i) no drainage or filter layer, and (ii) a drainage or filter layer comparable in performance to that in the old design. Assess the difference i!11 drainage occurring as a result, and the need for modeling conducted using two or more dimensions.

**ENERGY*SOLUTIONS'* RESPONSE:** The objectives of this work included development of new analyses that required simulation of subsurface fate and transport of LLW contaminants from the Class A West embankment. To provide the necessary input of net infiltration to the fate and transport model, variably saturated flow models were developed for two proposed Class A West embankment cover designs. These evapotranspiration (ET) cover designs featured top layers composed of vegetated soils designed to enhance evapotranspiration. These designs differed from an earlier cover design used at the site that featured a 2-foot thick top layer of rock armor. The characteristics of the top layers of the earlier and proposed designs are very different. These differences would be expected to lead to differences in water movement in the top layers, however comparison of the performance of the ET and rock armor designs was not an objective of this analysis. The objective of the flow modeling was strictly to provide net infiltration values to the fate and transport model.

The DRC provided, in their summary basis for the interrogatory, numerous comments and suggestions of topics for consideration in an enhanced sensitivity analysis. Many of these comments are useful and can be incorporated into future modeling studies. However, there are two important limitations in their suggestions. First, the comments are closely linked to the Benson et al (2011) report published by the NRC. While this is a useful report, the topic of cover performance is a complex topic with a wide range of research and programmatic applications (for example, ongoing work in the NRC, DOE, CERCLA/RCRA and international communities). Any modifications in data and model assumptions used for cover properties and cover performance should be based on information from multiple referenced sources. More importantly, the long-term performance and changes in cover performance over time are strongly dependent on the type of closure cover (for example, engineered, ET cover) and the climate setting for the cover application. The cover design components and assigned physical properties in models of cover performance must be carefully chosen for applicability to the climate and hydrogeological setting of the Clive disposal facility. Second, the DRC comments span two topics: alternative assignments of initial cover properties (parameter or knowledge uncertainty) and alternative approaches to degradation models for changes in cover properties over time (conceptual uncertainty). These different components of uncertainty require different approaches for representation in probabilistic models.

If a more comprehensive sensitivity analysis is needed for the infiltration modeling, it should not be based on selective and non-systematic changes in physical properties of cover materials. Instead what is required would be refined modeling of closure cover performance using probabilistic cover parameters and multiple model simulations designed so that the output from the multiple simulations can be abstracted into a probabilistic performance assessment model.

13.4 **INTERROGATORY STATEMENT(S):** Pages 31 and 32 of Neptune and Company, Inc. (2012) show conceptual cross-sectional diagrams for the numerical models used in the PA to assess whether horizontal components of flow exist through the side slopes of the cover system. These conceptual schematics show no-flow boundaries existing on seven of the eight sides of four model layers. That's all except one on the downgradient side of either the frost protection layer or the filter zone, depending on the model used. These no-flow boundaries are shown in the conceptual diagram as being vertical. Upslope boundaries are shown as being stacked vertically. Downslope boundaries also appear to be stacked vertically. There is no downslope termination of layers shown horizontally against the cell liner or the protective liner cover, as is depicted in design plans.

Please re-model flow using more realistic model-layer geometries and boundary conditions at the downslope and upslope boundaries of each layer so as to more accurately represent field conditions. Alternatively, provide justification for the existing geometry and boundaries.

**ENERGY*SOLUTIONS'* RESPONSE:** The 2-D HYDRUS modeling was conducted to test whether any lateral flow is expected to occur out of the evapotranspiration cover system and if not, to justify the use of 1-D HYDRUS for the final infiltration simulations used with RESRAD.

The 2-D HYDRUS test models were set up as a truncated portion of the actual cover, only for the purposes of evaluating lateral flow and not intended to physically represent the edges of the cover design.

The 2-D HYDRUS simulations were used to demonstrate the lack of lateral flow that would effectively remove water from the cover system before it flowed into the waste. If indeed, lateral flow were to occur in a model that more accurately represents the actual cover design, then the 1-D HYDRUS results used with RESRAD do not underestimate infiltration through the evapotranspiration cover.

See additional responses below adjacent to specific DRC comments:

The 2-D HYDRUS model includes accurate atmospheric boundary conditions, hydraulic conditions, and layer slopes. The remaining boundary conditions are set such that lateral flow is not underestimated. A seepage face and observation node are assigned in order to observe any lateral flow that might occur.

The 2-D HYDRUS model is not intended to physically represent the edges of the cover design.

The 2-D HYDRUS model geometry is set up specifically to evaluate whether lateral flow occurs. The no-flow boundary at the downslope end of the top of the model domain precludes infiltration from occurring beneath this boundary. Therefore, increases in water contents at the observation node beneath this boundary, and outflow observed at the seepage face can only occur as a result of lateral flow.

The 2-D HYDRUS model is not intended to physically represent the edges of the cover design. The seepage face boundary is assigned simply to evaluate whether or not lateral flow is occurring.

The 2-D HYDRUS model is not intended to physically represent the edges of the cover design and is designed to evaluate lateral flow, and to not underestimate infiltration.

Again, the 2-D HYDRUS model is not intended to physically represent the cover design but rather to evaluate lateral flow. The intention is to evaluate lateral flow, and to ensure that infiltration is not underestimated. If lateral flow actually occurs with the evapotranspiration cover design, then the 1-D HYDRUS results are not underestimating infiltration.

The approach used in the PA of using a 2-D HYDRUS model to test lateral flow was followed by the use of 1-D HYDRUS with RESRAD to ensure that infiltration is not underestimated and that the PA results are therefore, conservative.

13.5 **INTERROGATORY STATEMENT(S):** The proposed model cross-sectional schematics on Pages 31 and 32 of Neptune and Company, Inc. (2012) show that a no-flow boundary, in addition to the no-flow boundaries at the ends of the surface layer, exists over approximately the downslope 23% (2.1 meters, or 7 feet) of the top of the modeled 9.1 meter-long (30-foot-long) surface layer.

This no-flow boundary along the surface does not correspond with physical conditions to be realized in the field once construction plans are implemented. Re-do the model to remove the artifice of imposing a no-flow boundary over the lower 2.1 meters, or seven feet, of the top of the surface layer. Also, fix other problems with the way the model is set up. Alternatively, provide justification for imposing this boundary.

**ENERGY*SOLUTIONS'* RESPONSE:** Also refer to the response to comment 13.4.

The 2-D HYDRUS test models were set up as a truncated portion of the actual cover, only for the purposes of evaluating lateral flow and not intended to physically represent the edges of the cover design. The existing geometry and boundaries are set up only for an evaluation of lateral flow as a justification for using 1-D HYDRUS for the simulations used with RESRAD.

The 2-D HYDRUS test model geometry is set up specifically to evaluate whether lateral flow occurs. The no-flow boundary at the downslope end of the top of the model domain precludes infiltration from occurring beneath this boundary. Therefore, increases in water contents at the observation node beneath this boundary, and outflow observed at the seepage face can only occur as a result of lateral flow.

The 2-D HYDRUS test model is a 2-D model with sloped layers, a no-flow portion of the top boundary, an observation node, and seepage face, all of which are used to evaluate whether lateral flow occurs in this cover design. If in fact this model setup causes infiltration to be over-estimated, then the model results are conservative. If some lateral flow is occurring, and not accounted for, then this also ensures that infiltration is not underestimated.

The comment is made that water must travel at an angle of 74 degrees to be observed by the observation node and that this flow angle is not reasonable. Flow in a straight line from the soil surface to the observation node in these cover designs is not physically possible. Flow occurs in response to a gradient in total potential. The total potential is the sum of the matric and the gravitational potentials. In the cover system the total potential will be greatest in the direction of gravity (i.e., vertically downward). Flow in the upper layers will be downward at an angle slightly different from 90 degrees to the surface expected for a horizontal surface since the cover has a 20% slope. Flow continues downward into the frost protection layer in Design 1 and into the filter zone in Design 2. These layers are both constructed above lower permeability clay layers. If the flow of water into the frost protection layer in Design 1 or into the filter zone in Design 2 is greater than the flow possible vertically downward through the clay layers, water can accumulate on the top of the clay layers and begin to flow laterally.

Yes, we agree that lateral flow could be missed by the observation node, so the seepage face is also included to calculate any lateral flow leaving the system via the frost protection or filter layers.

Again, the 2-D HYDRUS model is not intended to physically represent the cover design but rather to evaluate lateral flow. Other boundaries may indeed be more appropriate for a model that is intended to physically represent the cover design. But the intention is to evaluate lateral flow, and to not underestimate infiltration. If lateral flow actually occurs with the evapotranspiration cover design, the 1-D HYDRUS results are not underestimating infiltration.

As previously discussed, the no-flow boundary at the lower 2.1 meters of the surface layer, the observation node, and seepage face, are all used to evaluate whether lateral flow occurs in this cover design. If in fact this model setup causes infiltration to be over-estimated, then the model results are conservative.

We agree that lateral flow could be missed by the observation node, so the seepage face is also included to calculate any lateral flow leaving the system via the frost protection or filter layers.

The modeling strategy described in the PA ensures that infiltration (and ultimately dose), are not underestimated.

**13.6 INTERROGATORY STATEMENT(S):** The conceptual model for the proposed cover system as described on Pages 30 through 32 of the Neptune and Company, Inc. (2012) report appears to assume isotropic conditions for soils, wherein values of components of hydraulic conductivity in the x, y and z directions in the model are equivalent to each other. No mention is made in the text of any anisotropy having been modeled.

Please re-run the model without the assumption of isotropicity. Assume reasonable ratios of horizontal to vertical conductivity ($K_x/K_z$) ranges. Please also perform sensitivity and uncertainty analyses.

**ENERGY*SOLUTIONS'* RESPONSE:** The 2-D HYDRUS simulations demonstrated no lateral flow in the cover systems. The 2-D models results were used to justify 1-D HYDRUS modeling. Because multi-dimensional analysis using HYDRUS-2D revealed unidirectional flow, all performance evaluation simulations were run using HYDRUS-1D which being one dimensional does not represent anisotropy. The engineering specifications for the saturated hydraulic conductivity correspond to the conductivity in the vertical direction.

As the Summary of Basis for Interrogatory concluded, "...the failure to account for anisotropy will tend to make flow in the model appear to be more vertically oriented than it actually is." With the flow vertically oriented, net infiltration through the waste is not underestimated (thereby conservatively bounding) since any lateral flow would not pass through the waste. Even with the model constructed to force infiltration to flow vertically, essentially zero transport is demonstrated. A more complex model accounting for horizontal as well as vertical flow would predict comparable or improved performance. Thus, there is limited value in more complex modeling, as protection of human health and the environment is already demonstrated. Given these modeling results, the 1-D HYDRUS models are considered realistic for this PA model, but note that any other form of modeling that admits some lateral flow would result in less overall infiltration.

**13.7 INTERROGATORY STATEMENT(S):** Figure 8 (which purports to represent "daily precipitation") on Page 35 of the Neptune and Company, Inc. (2012) report shows many data points over a 100-year period with precipitation varying between 1.0 and 2.0 centimeters (0.4 to 0.8 inches). The average value, although not easily decipherable from the figure, appears to be in the range of 0.5 centimeters (0.2 inches).

Please explain, justify, or fix the data provided. If the model is affected, then please fix the model.

**ENERGY*SOLUTIONS'* RESPONSE:** The 100-year daily record of precipitation for the site was generated using HELP's synthetic methodology. Determining daily average values visually from a plot of 36,500 precipitation values is not practicable. The mean annual value from the record generated by HELP is 21.4 cm and is consistent with the value suggested by DRC in the Basis for Interrogatory.

**13.8** **INTERROGATORY STATEMENT(S):** Page 39 of Neptune and Company, Inc. (2012) states, "The saturated hydraulic conductivity of the filter layer had to be reduced to a value of 864 cm/day for the 2-D model in order to reach model convergence."

Please re-do the model using the Meyer et al. (1996) hydraulic conductivity of 86,400 cm/day. It is not acceptable to the DRC for the Licensee to artificially reduce modeled hydraulic conductivity for the filter layer 100-fold without first attempting other model modifications; the performance of the filter layer is critical to making decisions about the performance of cover system design. What other approaches can be taken to attain model convergence (e.g., changing time steps, changing spatial discretization, etc.) without artificially reducing hydraulic conductivity of an important component of the model?

**ENERGY*SOLUTIONS'* RESPONSE:** As stated in the text extremely large values of hydraulic conductivity result in nearly instantaneous desaturation of the layer and make the simulations unstable. The value of saturated hydraulic conductivity used is large enough to allow any lateral flow for the 2-D numerical experiment models to be simulated. For saturated gravity-driven flow a saturated hydraulic conductivity of 864 cm/day corresponds to a pore water velocity of 109 ft/day.

The value of saturated hydraulic conductivity was reset to 86,400 cm/day for the 1-D performance evaluation simulations where a more highly discretized finite element mesh could be used.

**13.9** **INTERROGATORY STATEMENT(S):** Page 43 of Neptune and Company, Inc. (2012) says that "zero water flux was recorded through the seepage faces."

Page 45 says, "The results of these 2-D simulations demonstrate that water flow in the cover system for both designs is predominantly vertical with no significant horizontal component."

These conclusions are not justified. Please re-do the modeling with more appropriate boundary conditions and model assumptions. Alternatively, justify the existing modeling results.

**ENERGY*SOLUTIONS'* RESPONSE:** Please refer to the responses to comments 13.4, 13.5, and 13.6.

The 2-D HYDRUS model was set up as a truncated portion of the actual cover, only for the purposes of evaluating lateral flow and not intended to physically represent the evapotranspiration cover design.

The modeling strategy described in the PA ensures that infiltration (and ultimately dose), are not underestimated..

**13.10 INTERROGATORY STATEMENT(S):** On Page 50 of Neptune and Company, Inc. (2012), it is said in regard to RESRAD-OFFSITE that "the runoff coefficient was set at a value of 0.99."

The value for Cr, the runoff coefficient, used in the model and described in the text appears to be high. Please change it so that it appropriately represents physical processes at the site. This will, of necessity, also force change of the evapotranspiration coefficient value used in the model.

**ENERGY*SOLUTIONS'* RESPONSE:** This is the same issue as Interrogatory 4.8. The DRC comment is concerned with the value of the runoff coefficient used in RESRAD-OFFSITE. However, the runoff coefficient is simply a fitting parameter used to match the steady-state infiltration value provided from the HYDRUS code and not meant to accurally represent the fraction of precipitation expected to run-off the cover system (see the RESRAD-OFFSITE infiltration equation and discussion of equation parameters on page 50 of Appendix B).

**13.11 INTERROGATORY STATEMENT(S):** Page 60 provides results of current modeling efforts. It states, "Iodine-129 did not reach the groundwater well within the 10,000- -year time frame." Since iodine-129 is assumed to be conservative, it is concluded in the text that no radionuclide breaks through to a point of compliance within the 10,000-year time frame.

For protection of human health and the environment, and to comply with the rules and regulations listed below, please revise model input for long-term cover-system clay soil hydraulic conductivity in accordance with NRC guidance in Benson et al. (2011), re-run the model, and re-design the cover system for the site in order to provide for needed reductions in risk to human health and the environment. Please describe the changes in the text.

**ENERGY*SOLUTIONS'* RESPONSE:** This comment is substantially similar to previous comments, particularly interrogatory statements 11.1 and 13.3 (see the responses to those comments) with an increased focus on changes in cover properties that could affect travel time through the vadose zone.

As stated in response to previous comments, the objective of the revised modeling described in Appendix B is to update model simulations of fate and transport of LLW contaminants from the disposal facility. These simulations were developed for two cover designs and provide steady state infiltration rates to the RESRAD-OFFSITE transport model. Bounding transport assumptions are used to demonstrate that the Clive disposal site meets regulatory requirements for radionuclide concentrations at Class A limits.

The DRC comment treats the recommendations of the Benson et al. (2011) as "rules and regulations" and "NRC guidance;" the applicable regulations are the performance objectives of 10 CFR 61. The Benson et al. (2011) reference is a credible report that emphasizes cover properties in general, not the specific cover types and materials proposed for the Clive site and the local climatic setting. The recommendations from the report, by itself, are not sufficient justification to require redesigning the cover system nor is it contradictory with the steady state infiltration rates developed from the HYDRUS modeling.

The comment does identify potential concerns from the effects of cover performance associated with combined freezing temperatures, frost heave, desiccation from wetting and drying cycles, and biotic intrusion that could over time effect the properties of the cover, particularly the upper parts of the cover. It is not clear whether these combined effects would significantly change the steady state infiltration rates. An assessment of these processes would require probabilistic modeling of cover performance and evaluation of their impact on uncertainty in steady state infiltration rates.

**13.12 INTERROGATORY STATEMENT(S):** Page 60 of Neptune and Company, Inc. (2012) provides results of current modeling efforts. It states, "Iodine-129 did not reach the groundwater well within the 10,000-year time frame." Since iodine-129 is assumed to be conservative, it is concluded in the text of the PA that no radionuclide breaks through to a point of compliance within the 10,000-year time frame.

However, iodine-129 does not appear to be the most conservative radionuclide with respect to transport in groundwater (i.e., it does not appear to have the lowest distribution coefficient, or $K_d$, value). After upgrading the groundwater transport model to reflect more accurate assumptions and data, please change the model to follow, at a minimum, the most conservative radionuclide solute. If that solute is found to break through to the above mentioned groundwater well within 10,000 years, then examine all other radionuclide solutes that may break through within 10,000 years. Alternatively, justify the current model approach.

**ENERGY*SOLUTIONS'* RESPONSE:** The $K_d$ value used for iodine-129 in the RESRAD-OFFSITE modeling is zero (see page 49 and page 60 of appendix B).

The combination of a zero $K_d$ and the long-half-life of Iodine-129 (15.7 million years) provides an acceptably bounding condition for the radionuclide transport studies described in Appendix B. Iodine-129 does not sorb and because of its long half-life, there is no significant reduction in the concentration of iodine-129 from radioactive decay during 10,000 years. The $K_d$ values from the Whetstone Associates (2011) Table 27 and in Table C-4 were not used in and are not applicable to the modeling studies described in Appendix B.

**13.13 INTERROGATORY STATEMENT(S):** Page 61 of Neptune and Company, Inc. (2012) refers to www.conservationphysic.org/atmcalc/atmoclc2.pdf, from which several equations used in the model are obtained. Please find another reference for the equations, as the current reference contains errors that reduce its credibility. Please also correct the equation for saturation vapor pressure in the PA so that its units are equivalent on both sides of the equation. (The numerical value of the equation is correct; the units provided in the equation are incorrect.)

**ENERGY*SOLUTIONS'* RESPONSE:** DRC noted that the numerical value of the saturation vapor pressure is correct. There are no errors in the Appendix B calculations used to convert the annual relative humidity values cited in Whetstone, 2011; Table 2, for the Clive, UT site to the annual average absolute humidity value in air required by the RESRAD-OFFSITE program.

This response covers two items that are requested in the DRC interrogatory statement and basis: 1) an updated reference for the humidity conversions, and 2) correction of units in the $C_{sat}$ equation of Appendix B.

Humidity Conversions. This is a standard humidity conversion and there are multiple humidity conversion programs and online converters that can be used for the calculations (for example http://www.humcal.com/ used by metrology institutions). The conversions/converters all give similar values dependent only on the number of significant figures used in the conversions. An updated reference for the equations in the humidity conversions is the HumCon.pdf provided through the Biometeorology program at the University of California, Davis.

Corrected Equation. The equation for $C_{sat}$, the concentration of water in air at the saturation water vapor pressure is revised as follows:

$$C_{sat} = (2165* \text{VPsat})/ (T + 273.16)$$

Where $C_{sat}$ is in gm-3, VPsat is in kPa and T is in degrees centigrade.

13.14 **INTERROGATORY STATEMENT(S):** Sensitivity analyses in Neptune and Company, Inc. (2012) are limited in number, in the range of variables examined, and in quality. A sensitivity analysis is the evaluation of how changes in input parameter values affect model output. Uncertainty analysis is not carried out in the document.

**ENERGY*SOLUTIONS'* RESPONSE:** The approach and structure of a sensitivity and uncertainty analysis (SA) are greatly dependent on the modeling approaches used for a performance assessment. The Neptune and Company, Inc. (2012) modeling study is a bounding deterministic performance assessment. Modeling parameters and modeling assumptions in the PA were all designed to maximize the potential for radionuclide transport from the disposal site (or conversely underestimate the performance of the disposal site). Additional sensitivity and uncertainty analyses would provide limited information to enhance understanding of the bounding modeling results. Moreover, modeling results using this approach show that the Clive site easily meets the regulatory requirements for disposal of Class A radioactive waste.

The PA emphasized the important components controlling the Clive disposal system: cover performance and its effect on the steady state infiltration rate, the radionuclide source term release and transport modeling and intruder dose calculations. The modeling approach for cover performance and infiltration justified and used a 1-D modeling approach and conservative modeling parameters that maximize the potential for higher rates of steady state infiltration. The source term release and transport model assumed an Iodine-129 source, no sorption of iodine-129 and radionuclide concentration limits equal to Class A waste limits. The dose calculations assumed standard NRC exposure scenarios despite non-potable groundwater at the disposal site and compliance points. The transport and intruder dose calculations are bounding and there is no justification for running additional sensitivity cases. Interrogatory 11.1 discusses issues with and the limited value in running additional simulations with HYDRUS using non-systematic changes in cover properties.

## 14.0 INADVERTENT INTRUDER ANALYSIS

**14.10 INTERROGATORY STATEMENT(S):** Appendix A of the PA is entitled “Regulatory Basis for Selecting Reasonable Inadvertent Intruder Scenarios”. Page A-2 of this appendix notes that the NRC associates the meaning of "reasonable assurance" with the meaning of “reasonable expectation.” Page A-2 states that the NRC defined the term “reasonable” in the fourth point of 10 CFR 63.304, as “discouraging the modeling of unreasonably-extreme physical situations in the performance assessments”.

The Licensee applies this line of thinking on Page A-5 of the appendix, where it says,

> “*The intruder-construction scenario involves direct intrusion into disposed wastes for activities associated with the construction of a house {(e.g., installing utilities, excavating basements, and similar activities [as described in Section 4.2.2 of NRC (1986)]). However, because there is no historic evidence of prior residential construction at the Clive site, the extreme salinity of Clive's soils, the unpotable groundwater, the severe lack of irrigation sources, and the inadequacy of precipitation to support agriculture, the inadvertent intruder-construction scenario is not considered 'reasonable' for the Clive site nor included in this Report's site-specific Performance Assessment.*”

Please correct the foregoing statements to make them accurate, or else defend and justify them.

**ENERGY*SOLUTIONS'* RESPONSE:** Pages A-2 through A-4 of the appendix provide a summary of NRC discussions on identifying inadvertent intrusion scenarios in regulation, methodology, and guidance. The essence of this summarization in relation to identifying relevant scenarios is that assumptions be consistent with regional practices (NRC, 2007), and that current land-use and behaviors may be assumed to apply throughout the duration of the analysis (NRC, 1986; NRC, 2000). Archaeological surveys of the Clive area (AERC, 1981; Sagebrush, 2001) were cited as evidence that permanent human habitation has not occurred near the Clive facility, and the absence of potable water (NRC, 1993) and high soil salinity noted as supporting reasons to conclude the site is unsuited for human habitation.

Page A-5 of the appendix provides rationale for evaluating the intruder-drilling scenario described in NRC (1986), and for determining that the remaining inadvertent human intruder scenarios (intruder-discovery, intruder-construction, and intruder-agriculture) described in NRC (1986) are unreasonable at the Clive facility. The main argument supporting this determination is that discovery of the waste during excavation for a building, and exposures related to building construction and inhabitation, are precluded by the fact that exploratory drilling for potable water will be unsuccessful. This argument is defined in Section 4.1.1.1 of NRC (1986) and quoted on page A-4 of the appendix:

> *"It would be unreasonable to expect the inadvertent intruder to initiate housing construction at a comparatively isolated location before assuring that water for home and garden use will be available. Thus, this scenario (intruder-driller) is assumed to precede the following three scenarios."*

The text of Appendix A is fully consistent with NRC guidance for the inadvertent human intruder and no changes are required.

**14.11 INTERROGATORY STATEMENT(S):** Page A-3 of the PA lists five bulleted quotations from NRC (2007) that refer to scenarios that are physically reasonable and appropriate for a site, as well as consistent with regional practices and characteristics. Several bulleted items refer to regional practices. These are mentioned in the PA in providing a rationale for not performing an inadvertent intruder-resident analysis. The DRC requires that the Licensee conduct inadvertent intruder-resident analyses for this site.

**ENERGY*SOLUTIONS*' RESPONSE:** The bulleted list of items referenced to NRC (2007) is a summary of guidance for NRC reviewers of performance assessments specific to identifying reasonable exposure pathways and land use scenarios. These items, and similar summaries or quotations from other NRC regulation, methodology, and guidance on pages A-2 through A-4 of the appendix, are cited as rationale for focusing the inadvertent intrusion analysis on activities that are physically reasonable and consistent with regional practices and past/current land-use and behaviors.

The logic for the intruder analysis presented in Appendix A is fully consistent with NRC guidance and requirements. No changes are required without an established regulatory basis for the changes.

**14.12 INTERROGATORY STATEMENT(S):** On Page 21 of Neptune and Company, Inc. (2012), it says, "The intruder drilling scenario is highly unlikely due to the nature of the embankment design, which as a raised mound covered with rip' rap would be a very difficult place to site a drilling rig."

Please correct the statement above, or justify it.

**ENERGY*SOLUTIONS*' RESPONSE**: The quoted statement is in an introductory paragraph of Section 3.3 (Inadvertent Human Intruder exposure Scenarios) that provides a brief summary of applicability of the generic exposure scenarios described in NRC reports (NRC 1981; NRC, 1986) to the Clive facility. This statement is based on the low joint probability that a future well driller would be unaware of the non-potable nature of regional groundwater AND that the driller would attempt to locate a drill rig on the relatively inaccessible top of the embankment rather than on surrounding level ground. This is discussed on page 23:

> *"The intruder-drilling scenario is assumed to be an initiating event for the intruder-discovery, intruder-construction, and intruder-agriculture scenarios (NRC 1986, Section 4.1.1.1). That potable groundwater is not present below the floor of the Great Salt Lake Desert where the disposal site is located is common knowledge today. However, there is a very remote but finite chance that someone in the future might drill a well to determine whether potable groundwater exists at the Clive, UT site. Even if this were to occur, it is also highly unlikely that a drilling rig would be sited upon the rip rap cap of the embankment, rather than on the flat-lying landscape surrounding the disposal facility. Nevertheless, the initiating scenario of intruder-drilling suggested as an example in NRC (1986) is evaluated in the IHI dose assessment."*

No changes are required in Appendix A for this topic.

**14.13 INTERROGATORY STATEMENT(S):** It says on Page 23 of Neptune and Company, Inc. (2012) that "Consistent with Section 4.1.1.1 of NRC (1986), the three subsequent IHI scenarios are not assessed in this report because the prospective resident will be unable to secure potable water and therefore will not initiate construction of a home."

Please assess the three subsequent IHI scenarios.

**ENERGY*SOLUTIONS'* RESPONSE:** Section 3.3 of Appendix B (Neptune and Company, Inc. (2012)) presents an assessment of the applicability of the generic exposure scenarios described in NRC (1986) to the Clive facility. This assessment concludes that only the initiating intrusion event (drilling) is physically plausible because the remaining intrusion scenarios are predicated on the successful completion of a drinking water well and potable groundwater is unavailable at the site. A broader discussion of the basis for identifying reasonable inadvertent intruder scenarios that are consistent with site history and regional practices and behaviors is provided in Appendix A.

The logic for the intruder analysis presented in Appendix A is fully consistent with NRC guidance and requirements. No changes are required without an established regulatory basis for the changes.

**14.14 INTERROGATORY STATEMENT(S):** Please revise the following statement found on Page 23 of Neptune and Company, Inc. (2012). It says, "Because groundwater at the site is not potable, the groundwater exposure scenario is incomplete."

**ENERGY*SOLUTIONS'* RESPONSE:** The quotation from Appendix B (Neptune and Company (2012)) is correct as stated because there is no reasonable exposure pathway for the non-potable groundwater at the site. Despite the non-potable condition of the groundwater, radionuclide concentrations in groundwater were compared with groundwater protection limits, derived from standards published in UAC R317-6-2, based on requirements of the Ground Water Quality Discharge Permit (EnergySolutions, 2010).

No changes are required in Appendix A in response to this comment.

## 15.0 MISCELLANEOUS

**15.11 INTERROGATORY STATEMENT(S):** The PA application includes as Appendix B a document entitled, "Modeling report: fate and transport of contaminants from the Class A West Embankment and exposure to a post-closure traditional inadvertent human intruder at the Energy*Solutions* Clive, Utah facility" by Neptune and Company, Inc. (2012). Page 7 of that document states that "To the east and southeast, the site is bounded by the north-south trending Lone Mountains, which rise to a height of 5,362 ft amsl."

Please provide references for the name of the mountains and also the elevation that is provided. "Lone Mountain" is familiar to the DRC, but not "Lone Mountains."

**ENERGY*SOLUTIONS'* RESPONSE:** The description referred to in the Interrogatory Statement is from Bingham Environmental 1994. Hydrogeologic Report Mixed Waste Disposal Area Envirocare Waste Disposal Facility South Clive, Utah.

This site description has been updated by Energy*Solutions* in the License renewal application. Since the site description has no impact on the modeling approach or results, there is no need to revise the Neptune report.

**15.12 INTERROGATORY STATEMENT(S):** Page 7 of Neptune and Company, Inc. (2012) states "Alluvial and lacustrine sediments that fill the valley floor are estimated to extend to depths of greater than 500 ft with unconsolidated sediments ranging from 300 to over 500 ft."

Please review this text and revise it as needed.

**ENERGY*SOLUTIONS'* RESPONSE:** Sediments above 300 ft are described in the paragraphs following the text cited by DRC.

**15.13 INTERROGATORY STATEMENT(S):** On Page 8 of Neptune and Company, Inc. (2012), it says, "The site aquifer system consists of a shallow unconfined aquifer that extends through the upper 40 ft of lacustrine deposits."

Please review this text and revise it as needed to indicate that the aquifer only exists from the top of the water table (which, on average, exists at a depth of about 15 feet below normal ground surface) down to about 40 feet below normal ground surface.

**ENERGY*SOLUTIONS'* RESPONSE:** The clarification is noted. This site description has been updated by Energy*Solutions* in the License renewal application. Since the site description has no impact on the modeling approach or results, there is no need to revise the Neptune report.

15.14 **INTERROGATORY STATEMENT(S):** Page 29 of Neptune and Company, Inc. (2012) speaks of a "capacity flow rate of a drainage layer ... " as

$$Q^{cap} = K_s * T * i$$

Please fix the description of this equation, or justify its inclusion in the PA as is.

**ENERGY*SOLUTIONS'* RESPONSE** In the PA report instead of stating:

> *"The capacity flow rate of a drainage layer sloping at an angle β is given by Meyer et al. (1996)..."*

It would be more accurately presented as:

The capacity flow rate for a 2-D cross-section of a drainage layer sloping at an angle β is given by Meyer et al. (1996)...

Unit dimensions are provided below:

| | |
|---|---|
| $Q^{cap}$ | $[L^2 T^{-1}]$ |
| Ks | $[L T^{-1}]$ |
| T | [L] |
| i | [dimensionless] |

15.15 **INTERROGATORY STATEMENT(S):** Page 48 of the Neptune and Company, Inc. (2012) report refers to four tested cores having "slightly less than 50 percent clay and 50 percent silt and a small percentage of clay."

Please correct the statement on Page 48 quoted above by changing the last word to "sand". Please also address the mineralogical composition of on-site silts and clays since the use of these terms in the report as quoted above does not refer to mineralogical composition but only to grain size.

**ENERGY*SOLUTIONS'* RESPONSE:** The clarification is noted. The text "*... small percentage of clay" should read "...small percentage of sand."*

The paragraph cited by DRC describes a simulation conducted to examine the effect of using soil hydraulic properties associated with a coarser-grained soil than Unit 4. A coarser-grained soil was examined because the saturated hydraulic conductivity is significantly influenced by grain and aggregate size. Soil mineralogy is not an important factor influencing soil hydraulic conductivity so it was not included in the discussion.

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