State of Utah

GARY R. HERBERT
Governor

SPENCER J. COX
Lieutenant Governor

Department of
Environmental Quality

Amanda Smith
Executive Director

DIVISION OF SOLID AND
HAZARDOUS WASTE
Scott T. Anderson
Director

October 28, 2013

Sean McCandless
Director of Permitting and Compliance
EnergySolutions, LLC
423 South 300 West, Suite 200
Salt Lake City, UT 84101

RE: Depleted Uranium Performance Assessment for the Clive Facility
Preliminary Completeness Review
UTD982598898

Dear Mr. McCandless:

The Department of Environmental Quality has completed the Preliminary Completeness Review of the Depleted Uranium Performance Assessment. Comments are enclosed. Please provide a written response by November 8, 2013 if possible.

We appreciate you cooperation. If you have any questions, please call me at (801) 536-0215.

Sincerely,

Helge Gabert, Project Manager DU Contract
Division of Solid and Hazardous Waste

HG/STA/tjm

Enclosure

c: Myron Bateman, EHS, MPA, Health Officer, Tooele County Health Department
Jeff Coombs, EHS, Environmental Health Director, Tooele County Health Department

FINAL REPORT

Task 1
Preliminary Completeness Review
Clive Depleted Uranium Performance Assessment

Prepared for
State of Utah
Division of Radiation Control
Contract No. 146061

Prepared by
SC&A Inc.

October 25, 2013

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
bgs	below ground surface
BLM	Bureau of Land Management
CFR	*Code of Federal Regulations*
CR	Compliance Report
CSM	Conceptual site model
DCF	dose conversion factor
DEQ	Department of Environmental Quality (Utah)
DRC	Division of Radiation Control (Utah)
DU	depleted uranium
DUO_2	depleted uranium dioxide
DUO_3	depleted uranium trioxide
DU_3O_8	depleted triuranium octoxide
EPA	(U.S.) Environmental Protection Agency
EPRI	Electric Power Research Institute
ES	Executive Summary
ETTP	East Tennessee Technology Park
FEPs	features, events, and processes
FGR	Federal Guidance Report
GDP	gaseous diffusion plant
GWPL	groundwater protection limit
HQ	hazard quotient
ICRP	International Commission on Radiological Protection
IHI	inadvertent human intruder
km	kilometers
ky	thousand years
LANL	Los Alamos National Laboratory
m	meter
Mg	megagrams
MOP	member of the public
mrem/year	millirem per year

My	million years
NEPA	National Environmental Policy Act
nCi/g	nanocuries per gram
NNSS	Nevada National Security Site
NRC	(U.S.) Nuclear Regulatory Commission
OMB	Office of Management and Budget
PA	performance assessment
PAWG	(NRC’s) Performance Assessment Working Group
pCi/g	picocuries per gram
RfC	reference concentration
RfD	reference dose
SA	sensitivity analysis
SI	sensitivity index
SRS	Savannah River Site
SRTC	Savannah River Technology Center
TEDE	total effective dose equivalent
UAC	Utah Administrative Code
UDRC	Utah Division of Radiation Control
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978
UZ	unsaturated zone

1.0 INTRODUCTION

Energy*Solutions* is considering the disposal of large quantities of depleted uranium (DU) at its waste disposal facility in Clive, Utah. In accordance with the regulations of the State of Utah, Department of Environmental Quality (DEQ), and radioactive materials license #UT2300249, issued by the Division of Radiation Control (DRC), Energy*Solutions* has submitted to the State a Compliance Report and a Performance Assessment (PA):

- Energy*Solutions*, "Utah Low-Level Radioactive Waste Disposal License – Condition 35 (RML UT2300249) Compliance Report," June 1, 2011 (hereafter Compliance Report or CR)
- Neptune and Company, Inc., "Final Report for the Clive DU PA Model version 1.0," June 1, 2011 (including Appendices 1 through 17) (hereafter Appendix A to the Compliance Report; also referred to as "Final Report")

The State of Utah has undertaken a contract with SC&A, Inc., to provide technical support to the DEQ in reviewing these submissions. This report addresses the first contractual task – performing a completeness review of the cited documents and supporting appendices.

SC&A's review report provides general and specific comments on completeness for each of the relevant documents. It should be emphasized that this report does not address the technical merits of the Energy*Solutions* documents, but only whether the submission is complete when tested against the cited Utah regulations and guidance documents. In addition, comments on completeness are provided when the text is lacking in clarity, where statements are not supported by adequate references, where key literature sources are not cited, or where sufficient detail is not presented to support statements in the text. Although all appendices were given a preliminary review for completeness, some appendices to the Clive DU PA are not discussed here because SC&A had no completeness comments on those appendices. However, during the subsequent technical review, it is possible that technical comments will be developed even though there were no completeness comments.

In some instances, the distinction between completeness and technical comments is not distinct. It is possible that some of the comments included here may be judged to be technical comments by some reviewers. Rather than making judgments as to whether particular comments speak to completeness or are technical in nature, it will facilitate the review of the DU proposal to resolve all comments presented here as soon as possible. Early resolution of the comments presented here will ensure that the technical review can proceed expeditiously.

2.0 REVIEW OF ENERGY*SOLUTIONS* "UTAH LOW-LEVEL RADIOACTIVE WASTE DISPOSAL LICENSE – CONDITION 35 (RML UT2300249) COMPLIANCE REPORT," JUNE 1, 2011

2.1 GENERAL COMMENTS

Comment 1, Inadequate References

In general, the Compliance Report refers to the 2008 Energy*Solutions* license renewal application as justification for limiting further consideration of numerous issues addressed in the plans and manuals provided as part of the license renewal application. When addressing a specific issue, without review of the relevant plan or manual in the Compliance Report, sufficient reasons have not been provided by Energy*Solutions* to conclude that revisions are not necessary. Individual review of each technical issue should be documented and provided as necessary. At a minimum, specific citations (chapter, section, page, etc) to past license renewal applications with descriptions and justification need to be added. Examples of this problem include, but are not limited to: Section 2-2,page 2-4, refers "Occupation Dose Limits for Adults," where the licensee states there is a plan or manual that addresses exposures but does not provide a name, chapter or page number or Section 2-7, page 2-6, "Posting Requirements" where the licensee refers to the Radiation Safety Manual but does not provide chapter or page number.

Comment 2. Over-reliance on Past Licensing Activities

In addition to the primary function as the site-specific PA, the Compliance Report and its Appendix A also serve as a license amendment application request. As such, the Compliance Report is expected to have sufficient detail to provide a complete picture of the large-quantity DU disposal proposal. However, sufficient detail is lacking. Too much reliance is placed on past licensing activities without showing how past work embraces DU disposal. See comment for Paragraph 4 of page 4 for examples of the deficiencies.

Comment 3. Erroneous Rule References

Multiple errors have been made in citations to the Utah Radiation Control Regulations. Please re-examine all references and correct them as needed.

Comment 4. Failure to Consider Multiple Rules in R313-15 and R313-25.

On multiple locations in the Compliance Report, Energy*Solutions* fails to identify key rule requirements applicable to a major license amendment such as the DU waste proposal. In other locations, key phrases from existing rules have been omitted without explanation or justification. These are identified in the discussion below, and must be corrected.

Comment 5. Assumption that CAS Cell Design was Acceptable

At multiple locations in the June 1, 2011 DU submittal, the licensee assumes that the CAS Cell design was acceptable to DEQ. This assumption is unwarranted because DRC review of this proposal was never completed. The DEQ acknowledges two Energy*Solutions* submittals that included engineering design information, dated January 4, 2008[1] and June 9, 2009.[2] Between these submissions, DRC provided Energy*Solutions* a November 26, 2008, Completeness Review.[3] Based on our records, no other interrogatory was prepared by DRC or delivered to Energy*Solutions*. In fact, on May 2, 2011, Energy*Solutions* submitted a request to retract its January 4, 2008, CAS Cell license amendment request.[4] As a result, after the Energy*Solutions* response to this Completeness Review, DEQ will re-open the project and begin a detailed review of both the January 4, 2008, and June 9, 2009, Energy*Solutions* submittals. In the event that Energy*Solutions* decides to alter or modify these design submittals, and to expedite review of the DU proposal, any design changes made by Energy*Solutions* will need to be provided upon submittal of your response to this DEQ Completeness Review.

<u>Comment 6. Clive Facility Definition</u>

The PA uses the term "Clive facility" or sometimes just the term "the facility" throughout. Please define the term "Clive Facility" and describe what that entails, in particular, distinguishing it from its component parts.

2.2 SPECIFIC COMMENTS

Section 1.3. This section lists the expected mass of DU waste, in the form of U_3O_8, from the DOE de-conversion facilities at Paducah, Kentucky, and Portsmouth, Ohio (projected for a 20–25-year operating period). Please provide an estimate of the total mass of DU waste that has been and will be received from the Savannah River Site (SRS), and identify its chemical and physical form. If any other source or generator of DU waste is considered for Clive disposal, please indicate its specific source (by generator), chemical/physical form(s), estmates of total mass, and volume.

Section 1.4, Basis for Performance Assessment. This section makes reference to parts of R313-25-8(5). On page 1-8, the applicant proposes to use an intruder dose of 500 millirem per year (mrem/year). However, Utah Radiation Control Rule R313-15-401 states, in part, that the License Termination Rule applies only to ancillary surface facilities that support radioactive waste disposal activities. Therefore, it appears the 500 mrem/yr dose standard does not apply to the disposal embankment; and instead the 25/75/25 mrem/yr dose requirements of UAC R313-25-19 should apply instead. Additional detail on DEQ findings in this matter are found below. In addition, the NRC had not considered large quantities of DU as radioactive waste when it promulgated 10 CFR Part 61 in 1982.

---

[1] Entitled "Energy*Solutions* Amendment Request Class A South / 11e.(2) Embankment," 38 pages and 5 attachments.

[2] Entiled "Energy*Solutions* Class A South / 11e.(2) Embankment Revised Application and Response to Completeness Review UT2300249 and UGW450005," 49 pages and 8 attachments.

[3] DRC Completeness Review was prepared by the URS Corporation, and entitled "Completeness Review; Energy*Solutions*, LLC Amendment Request; Class A South / 11e.(2) Embankment," 15 pages.

[4] May 2, 2011 Energy*Solutions* letter from Sean McCandless to Rusty Lundberg, "Radioactive Materials License # UT2300249 and Ground Water Quality Discharge Permit No. UGW450005. Amendment and Modification Request – Class A West Embankment; Retraction of the Class A South/11e.(2) Embankment Design Change Request," CD11-0123, 2 pages.

DRC staff acknowledge that NRC staff have proposed to the Commission consideration of a 500 mrem/yr dose standard for the inadvertent intruder. However, this federal rulemaking effort will not be complete for a year or more. In the meantime, the DEQ licensing action is based on current DRC rule requirements. Therefore, if Energy*Solutions* is intent on using a 500 mrem/year for the intruder dose, please explain and justify why this would protect human health and the environment. Also, be advised that Energy*Solutions* will need to request a variance from the Utah Radiation Control Board.

Table 2-1, Applicable Requirements Potentially Impacted by the Disposal of Depleted Uranium (pp. 2-2 and 3). Please make the following modifications to the table:

1. R313-15-402 – please delete this reference, it is not applicable to the CAS Cell. For more information, see discussion below.
2. R317-6 – description on how this rule applies has been omitted. Please revise the table.

Sections 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, and 2.11. These sections each broadly mention various plans or manuals submitted to the Division of Radiation Control as part of previous licensing activities. However, they should make more specific reference to the relevant discussion in the appropriate plan or manual; e.g., by chapter and page. For example, Section 2.2 states that the 2008 license renewal application includes models demonstrating that atmospheric pathway doses to the general public during operations will remain below required regulatory levels. The text should cite the specific place(s) in the documents that discusses the models to confirm that they included the handling of large quantities of DU.

Section 2.8, R313-15-906; Procedures for Receiving and Opening Packages. This section discusses receipt and opening of waste packages at Clive. In Section 1.3, Energy*Solutions* also describes how DOE has identified corroded 55-gallon drums of DU waste at the SRS that have been overpacked (p. 1-6); and discovery of corroded DUF_6 Storage Cylinders (DUF_6 Cylinders) at their Paducah, Kentucky, and Portsmouth, Ohio, facilities (p. 1-6). Please disclose: (1) the range of weight (tare, net, and gross) expected for each type of DU waste package, for each physical/ chemical form of DU waste, be it UO_3 or U_3O_8; and (2) if the Paducah and Portsmouth DU waste will be shipped to Clive in existing DUF_6 Cylinders. Please explain how currently approved Energy*Solutions* waste handling procedures (in various plans), designed for management of solid LLRW materials, will apply to DUF_6 Cylinders, designed by DOE for storage of gaseous DUF_6.

Section 2.9, R313-15-1002; Method for Obtaining Approval of Proposed Disposal Procedures (p. 2-7). Regarding the 55-gallon (~7.35 ft^3) drums from SRS (in UO_3 form) and DUF_6 Cylinders mentioned in Section 1.3, it appears the latter will be significantly larger (~151 ft^3). Please verify whether or not the same DUF_6 cylinders will be re-used for DU waste transport to Clive, and if they will be directly disposed in the embankment. If any other types of DU waste containers are to be used for transport and disposal, please indicate their size, volume, type, and weight, etc. Please justify how existing waste disposal procedures at Clive, designed for disposal of containers of LLRW solid materials, will apply to disposal of the recycled DUF_6 Cylinders filled with DU oxides.

Section 2.10, R313-15-1009; Waste Classification (p. 2-7). Table 2-2 provides concentrations of radioactive elements, including U-235, found in some of the DU waste streams. However, the Compliance Report has not addressed the applicability of License Condition 13 to the disposal of large quantities of DU containing U-235. Further review of License Condition 13 should be documented and submitted.

Additionally, Utah Radiation Control Rule R313-15-1009 provides a concentration limit for Ra-226 as a Class A waste. Because of the very long half-life of DU (principally U-238), the concentration of Ra-226 in the waste will continue to increase for thousands of years beyond the 10,000-year period assessed in the PA and will eventually exceed the Class A concentration limit. A discussion of the matter should be provided.

R313-25-6; General Information Omitted. Review of the CR shows this section of the rule has been omitted. Please modify it to ensure, at a minimum, the requirements of R313-25-6(3) and (4) are included and adequately addressed.

R313-25-2 defines "inadvertent intruder" with regard to activities that might occur after site closure. However, the first paragraph on page 2-15 refers to the "protection of inadvertent intruders from radiation exposures during facility operations," which is inconsistent with this definition. The paragraph should be revised to address this apparent inconsistency.

R313-25-9(1) and (2), Institutional Information - Omission. No discussion is provided in the Energy*Solutions* CR about how and when Energy*Solutions* will comply with the requirements of this rule. In that the Clive facility is not located "… on land not owned by the federal or state government …", please demonstrate that binding legal provisions are in place "… for assumption of ownership in fee by the federal or a state agency." Alternatively, explain how Energy*Solutions* will provide other institutional controls to enable long-term site control and maintenance for a minimum period of 10,000 years or more after site closure.

Section 2.15, R313-25-10; Financial Qualifications to Carry Out Activities (p. 2-23). It appears this section addresses the requirements of R313-25-10. In light of the fact that 2.5 of the 3 different DU waste depths considered in the CR are above native ground elevation, please explain and justify why the Director should not revise the surety to address the need for long-term disposal site maintenance should future pluvial lakes cause wave-cut erosion.

R313-25-16; Transfer of License – Omission. No description is found in the CR to explain and justify how the DU waste proposal will comply with this requirement. Specific attention must be given to R313-25-16(5).

Section 2.17; R313-25-18, Individual Exposure Assurance (p. 2-27) – In the last paragraph of this section, please disclose where the Requirements 2508-1 through 4 can be found, or alternatively, provide those references as an attachment to the revised CR. Also, because the DU waste and progeny in-growth will pose higher risks to human health and the environment with time, please describe and justify how future adverse exposures to individuals can be controlled and prevented in light of the fact that there are no provisions currently in place for the Clive disposal site "… for assumption of ownership in fee by the federal or state agency" [see R313-25-9(2)]. Please describe in detail how the DU waste proposal will allow Energy*Solutions* to comply with the requirements of R313-25-19 (protection of general public) and R313-25-22 (inadvertent intruder protection). Alternatively, Energy*Solutions* may cross-reference those sections of the CR that resolve these requirements.

Section 2.18, R313-25-19, Protection of the General Population from Releases of Radioactivity (starting on p. 2-27) – Several concerns were found in this section during our review, as follows:

1. Energy*Solutions* Requirements Section (pp. 2-27 and 28) – This section omits the 4 mrem/yr dose limit for the groundwater pathway mandated by R313-25-19. Please correct this omission and revise the section accordingly. In order to comply with the provisions of R313-25-8(5)(a), please demonstrate how dose to an individual via the groundwater pathway will remain below this limit for 10,000 years or more after site closure.
2. Basis for Dose Conversion – We appreciate the argument that dose limits in R313-25-19 are based on whole body dose, and that more modern means are available to determine dose to an individual, namely a total effective dose equivalent (TEDE) methodology. Please disclose what internationally recognized publication (and dose conversion factors) was used by Neptune to calculate the TEDE doses quoted in Table 2-3 and the Ground Water Protection Levels found in Table 2-4. We recognize that this information is in the DU PA but should be included here as well or appropriately cross-referenced
3. Unidentified Exposure Scenarios – Neither the Energy*Solutions* CR text nor the tables themselves identify the exposure scenario(s) represented by the predictions listed in Tables 2-3 and Table 2-4. Please identify all exposure scenarios used in these tables. Please confirm how much of the DU waste was exposed at the surface for each of the waste depths listed in these tables. Please identify the percentage of the embankment area where DU waste was exposed by erosion in each exposure scenario.
4. Peak Doses in Table 2-3 – Please identify the DU waste isotopes and exposure pathways behind each receptor scenario listed in this table. Please also explain how the doses may vary, should certain fundamental assumptions change in the Neptune predictions, including, but not limited to, DU waste nuclides, source term activity, cover system erosion rates, relative area of cover system eroded (or area of DU waste exposed) in the model, etc.
5. Groundwater Pathway, 500-Year Groundwater Prediction Timeframe, Table 2-4 – Please explain and justify how a 500-year simulation of concentrations in the groundwater pathway can demonstrate Energy*Solutions* compliance with the minimum 10,000 year quantitative predictions required by R313-25-8(5)(a) for each exposure pathway. Alternatively, provide results of groundwater fate and transport modeling for a minimum 10,000-year period after site closure.
6. Groundwater Protection Levels, Table 2-4 – Please disclose if any differences exist in the dosimetry and/or dose conversion methods used to derive the Ground Water Protection Levels listed, versus those doses methods used for Table 2-3. If there are differences, please explain and justify why they should be acceptable, i.e., why they represent the most modern dosimetry methodology.

7. Groundwater Point of Compliance, Table 2-4 – Please identify the relative horizontal location and distance of the compliance monitoring well from the CAS Cell, as used in the groundwater transport model.

R313-25-23; Disposal Site Suitability Requirements for Land Disposal – Near-Surface Disposal - Omission. No text is provided in the Energy*Solutions* CR to address how the DU proposal will meet the requirements of this section of state rule. Please amend the CR to address and resolve each of the 11 requirements found in this rule. In all cases, site suitability must be considered in light of the "deep time" aspects for DU disposal and progeny in-growth. Where engineered features are not sufficient to control and contain the proposed DU waste, please explain and justify how site characteristics will come to bear to sequester and control DU contaminants, and protect public health and the environment.

One key omission that must be carefully addressed is driven by the above-grade disposal planned for the DU waste. Any demonstration of compliance with R313-25-23 must include pluvial lake formation and wave-cut erosion. In your resolution of this requirement, Energy*Solutions* may be able to draw on discussions submitted to demonstrate compliance with R313-25-7 (see Division comments above).

Section 2.22, R313-25-24: Disposal Site Design for Near-Surface Land Disposal (p. 2-38). The state rule lists 6 requirements that must be met. Unfortunately, Energy*Solutions* has only addressed the first one (site design features). Please revise the CR to address facility compliance with the missing five requirements; i.e., R313-25-24(2) thru (6). In this process, please ensure that both the engineered disposal embankment and site characteristics together can provide protection of public health and the environment, pursuant to R313-25, for at least 10,000 years post-closure.

R313-25-25 thru 30: Multiple Rule Omissions. These requirements in the DRC rule have been omitted from the CR, and must be included with justification for how the DU proposal will comply with the respective rules. In total, there are 20 regulatory items needing consideration and resolution, as follows:

Rule	Title	No. of Items Missing or Unaddressed
R313-25-25	Near Surface Land Disposal Facility Operation and Disposal Site Closure	12
R313-25-26	Environmental Monitoring	4
R313-25-27	Alternative Requirements for Design and Operations	1
R313-25-28	Institutional Requirements	2
R313-25-30	Applicant Qualifications and Assurances	1

Please revise the CR to resolve this omission, so that the DEQ review can move forward.

Section 2.25, R313-25-32; Financial Assurance for Institutional Control (pp. 2-38 and 2-39). The requirements text in the first two paragraphs of this section is from R313-25-31(1)(a) and (b), and not from R313-25-32. Please remove. Because significant quantities of DU disposal were not considered by the NRC in its original 10 CFR 61 rulemaking (circa early 1980s), please explain and justify why a 100-year Institutional Control period, as required by R313-25-28(2), is adequate for shallow land disposal of DU waste where progeny in-growth creates a greater future risk to human health and the environment.

3.0 REVIEW OF NEPTUNE AND COMPANY, INC., APPENDIX A, "FINAL REPORT FOR THE CLIVE DU PA MODEL VERSION 1.0," JUNE 1, 2011

3.1 GENERAL COMMENTS

Comment 1. Intergenerational Consequences

The ALARA analysis presented in Section 6.4 of the Final Report implies that either an undiscounted value of $1,000 per person-rem or a discounted value of $2,000 per person-rem may be used, and it includes discount factors of 3% and 7%. Two issues with these values needs to be considered.

First, as stated in NUREG-1530 and included in revisions of NUREG/BR-0058, it is the policy of the NRC to use a value of $2,000 per person-rem for ALARA determinations.

Second, as stated in NUREG/BR-0058, Revision 4, when intergenerational consequences are involved, lower discount rates (including potentially no present worth, or 0%) should be used:

> *For certain regulatory actions, such as those involving decommissioning and waste disposal issues, the regulatory analysis may have to consider consequences that can occur over hundreds, or even thousands, of years. The OMB recognizes that special considerations arise when comparing benefits and costs across generations. Under these circumstances, OMB continues to see value in applying discount rates of 3 and 7 percent. However, ethical and technical arguments can also support the use of lower discount rates. Thus, if a rule will have important intergenerational consequences, one should consider supplementing the analysis with an explicit discussion of the intergenerational concerns such as how future generations will be affected by the regulatory decision. Additionally, supplemental information could include a presentation of the values and impacts at the time in which they are incurred with no present worth conversion. In this case, no calculation of the resulting net value or value-impact ratio should be made. Also, one should consider a sensitivity analysis using a lower, but positive discount rate.*

Comment 2. Inadvertent Intruder

The definition of "inadvertent intruder" in 10 CFR 61.2 is:

> *…a person who might* ***occupy the disposal site*** *after closure and engage in normal activities, such as agriculture, dwelling construction, or other pursuits in which the person might be unknowingly exposed to radiation from the waste.*

Utah Administrative Code (UAC) R313-25-2 defines "inadvertent intruder" as:

> *…a person who may* ***enter the disposal site*** *after closure and engage in activities unrelated to post closure management, such as agriculture, dwelling construction, or other pursuits which could, by disturbing the site, expose individuals to radiation.* (Emphasis added.)

Both definitions are similar, in that they suggest agriculture and dwelling construction as activities that an inadvertent intruder might take. However, they differ in that the NRC's definition requires the inadvertent intruder to "occupy the disposal site," while the UAC's definition only requires the inadvertent intruder to "enter the disposal site." Synonyms for "occupy" include "live in," "dwell in," "reside in," and "inhabit;" thus, a hunter or off-highway vehicle enthusiast who occasionally "enters" the site would not meet the NRC's definition of inadvertent intruder but would meet the UAC's definition. On the one hand, the UAC's definition means that many more individuals can be classified as inadvertent intruders; on the other hand, it does not require that the inadvertent intruder be someone who inhabits the site and who would likely receive the largest exposure.

UAC R313-25-20 provides a different perspective on inadvertent intruders than does UAC R313-25-2:

> *Design, operation, and closure of the land disposal facility shall ensure protection of any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed.*

UAC R313-25-20 requires protection of individuals occupying the site (or contacting the waste) rather than those who are simply entering the site and, therefore, is more akin to the definition in 10 CFR 61.2.

As documented in NRC 2012, the NRC is proposing to amend 10 CFR 61.13 to specifically require licensees under 10 CFR Part 61 to conduct an inadvertent intruder analysis. The proposed language states, in part:

> *An intruder assessment shall: (1) Assume that an inadvertent intruder occupies the disposal site at any time during the compliance period after the period of institutional controls ends, and engages in normal activities including agriculture, dwelling construction, resource exploration or exploitation (e.g., well drilling), or other reasonably foreseeable pursuits that unknowingly expose the intruder to radiation from the waste.*

Note that the proposed language specifies occupancy.

Given the apparently dissimilar definitions, the Final Report should explain why the selected approach, which does not consider site occupancy, was selected.

Comment 3. Compliance Period

UAC R313-25-8(5)(a) includes the statement:

> *For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years.*

The Final Report performs all of its analyses (except the deep time) at 10,000 years, the minimum allowed under UAC R313-25-8(5)(a). Furthermore, the Final Report does not discuss the rationale behind the selection of 10,000 years as the period of performance.

The NRC (2011b) and the Utah Division of Radiation Control (UDRC 2012) have both expressed concerns regarding limiting the compliance period (or period of performance) to 10,000 years. The applicant should provide the basis for using the minimum compliance period and justify why a longer period of analysis should not be required in light of R313-25-8(1)(b).

Comment 4. Deep Time – Time

In defining the length of the deep time assessment, the Executive Summary (ES) (page 5) states:

> *Peak activity of the waste occurs when the principal parent ^{238}U (with a half-life that is approximately the age of the earth—over 4 billion years), reaches secular equilibrium with its decay products. This occurs at roughly 2.1 My from the time of isotopic separation, …*

In order to determine whether 2.1 million years (My) is the appropriate time for deep time assessment, the applicant should clarify the above statement. First, decay products usually reach secular equilibrium with their principal parent, rather than the other way around. Second, the text should discuss how the value of 2.1 My was determined based on a half-life of 4.49×10^9 years for U-238 and the half-lives of its decay products (e.g., 244,500 years for U-234).

Comment 5. Deep Time – Sediment Concentration

Section 6.5.2 of the Final Report provides U-238 lake sediment concentrations derived from successive lake events.[5] Section 7.2 (page 84) then states, "Despite these possible conservatisms in the deep-time model, the lake water and lake sediment concentrations are small." The report should give the basis for presenting only the U-238 sediment concentrations (rather than the full U-238 decay series), as well as the basis for concluding that these concentrations are "small."

For example, 40 CFR 192.12(a) states:

> *The concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than—*

[5] We note that the concentration values given in Table 14 do not appear to agree with the concentrations shown in Figure 13. For example, the mean concentration in Table 14 is 1,500 picocuries per gram (pCi/g), but Figure 13 shows the mean concentration as always less than 1,000 pCi/g.

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and

(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.

Although 40 CFR 192.12 was developed specifically for the cleanup of uranium mill tailings sites under Title 1 of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), the U.S. Environmental Protection Agency (EPA) has used the criteria in 40 CFR Part 192 when setting remediation goals at Comprehensive Environmental Response, Compensation, and Liability Act sites with radioactive contamination. The applicant should indicate why the 40 CFR Part 192 soil criteria should not apply to the deep time assessment.

Comment 6. Ra-226 Class A Concentration Limit

Table 1 of UAC R313-15-1009 includes a 10 nanocuries per gram (nCi/g) limit on the concentration of Ra-226 that can be included as Class A waste. The specific activity of U-238 in DU_3O_8 is about 285 nCi/g. As the U-238 decays, the activities of its daughter products build towards the U-238 activity. After 10,000 years, the Ra-226 activity would be about 0.2 nCi/g, but after about 61,000 years, it would exceed the Class A limit in Table 1 of R313-15-1009. After about 266,000 years, it would exceed the Class C limit of 100 nCi/g. The applicant should provide justification for disposing of material that will exceed the regulatory limits. A qualitative analysis of estimated temporal changes in Ra-226 activity concentration should be provided as part of the associated deep-time analysis.

Comment 7. Other Wastes

Section 2.2 (page 25) of the Final Report states:

> *…this Clive DU PA Model considers only to the long-term performance of DU disposed in this waste cell [the Class A South].*

UAC R313-25-8(5)(a) requires:

> *…a performance assessment…for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of….*

The applicant should indicate the basis for not including in the PA "other wastes" and waste already disposed of. This is of particular concern because the applicant has proposed that the 11e.(2) wastes share the same Federal Cell as the DU (Appendix 3, "Embankment Modeling for the Clive DU PA Model," May 28, 2011, Figure 2). Additionally, during the October 10, 2011, meeting, Neptune (on behalf of Energy*Sloutions*) indicated that low-level radioactive waste (LLW) would be disposed of in the CAS cell along with the DU.

The applicant should indicate the basis and justification for not including in the PA "other wastes", including 11e.(2) waste disposed of in the Federal Cell, and LLW disposed of within the CAS. Alternatively, the applicant needs to modify the PA to account for all DU, LLW, and 11e.(2) wastes to be disposed of in the Federal Cell. Thirdly, the applicant needs to evaluate the impact of alternative disposal cell designs on the PA results, including 1) two separate disposal cells one for DU and LLW and the other for 11e.(2) waste and 2) three separate disposal cells one for DU, a second for LLW, and a third for 11e.(2) waste.

Comment 8. PA Intent

Section 2.1, page 21, states:

> *…the intent of a PA is not necessarily to estimate actual long-term human health impacts or risks from a closed facility. Rather, the purpose of the Model is to provide a robust analysis that can examine and identify the key elements and components of the site, the engineered system, and the environmental setting that could contribute to potential long-term impacts.*

This statement should be revised to indicate that the intent of the PA is to demonstrate that disposal of DU at the Clive facility would meet the requirements of UAC R313-25-8 and the performance standards of 10 CFR Part 61, Subpart C.

Comment 9. Critical Group

Section 4.1.2.10.1 describes the dose receptors and exposure pathways that are evaluated in the PA. The PA includes ranchers and recreationists (e.g., hunters, off-highway vehicle enthusiasts), but no residents. Resident receptors seem to have been excluded because there are currently no individuals living in close proximity to the site [i.e., the nearest resident is a caretaker at the eastbound Interstate 80 Grassy Mountain Rest Area at Aragonite, approximately 12 kilometers (km) (7.5 miles) northeast of the site]. In NUREG-1573, in response to public comments, the NRC's Performance Assessment Working Group (PAWG) recommended an approach to defining a critical group when there are currently no residents living nearby the disposal facility. Because there are no justifiable methods or procedures for forecasting human habits or lifestyles in the future (i.e., the very long term), the PAWG recommends that an analogue site, of comparable geology and climate, be identified and that the critical group be defined in terms of the analogue site. For example, for the Clive facility, the caretaker at the Interstate 80 Aragonite rest area [approximately 12 km (7.5 miles) to the northeast] might be used as an analogue site. The Final Report should document why it did not use the approach established by the PAWG.

Comment 10. Analysis of Routine Operations and Likely Accidents

Utah Radiation Control Rule R313-25-8(4)(c) states:

> *Analysis of the protection of individuals during operations shall include assessments of expected exposures due to routine operations and likely accidents during handling, storage, and disposal of waste. The analysis shall provide reasonable assurance that exposures will be controlled to meet the requirements of R313-15.*

The Final Report should explain why these analyses were not included in the DU PA.

Comment 11. Inconsistent Definitions

The Final Report frequently cites “peak mean” values. In some cases, identified in specific examples in Section 3.2, this terminology may not be correct. The document should be carefully reviewed to determine if the terms “peak,” “mean,” “peak of the mean,” and “mean peak” are correctly and consistently used.

Comment 12. Incomplete Figures

Many of the graphs, including those identified in specific examples in Section 3.2, lack proper notation as to metrics for the x and y axes.

Comment 13. Incomplete Discussion of Sensitivity Plots

As indicated in the specific examples in Section 3.2, the various sensitivity and partial dependence plots are complex and should be discussed in greater detail in the text to ensure that the information they contain is sufficiently transparent.

Comment 14. Links to References

The file Report References AtoZ.zip (available from the Utah Division of Radiation Control’s website: http://www.radiationcontrol.utah.gov/EnSolutions/performassess/duperfass.htm) contains the references used in the Final Report. Many of the references are given as Internet shortcuts, especially those that are copyrighted and/or must be purchased. To check the availability of these references, SC&A tested each Internet shortcut. With six exceptions, we successfully accessed the websites from which each reference could be obtained, although we did not actually purchase the references. The six Internet shortcuts that did not function as expected are shown below.

Internet Shortcut	Problem Encountered
Burnham and Anderson 2002	Instead, link opens to Casella and Berger 2002.
Efron and Tibshirani 1994	Displays a blank screen, with URL: http://www.crcpress.com/product/isbn/0412042312
Link et al. 1999	Displays: The page cannot be found
Linsalata and Cohen 1980	Link opens to NYU Medical Center, biosketch page.
MSUE 2011	Displays “server not found” or “This page can’t be displayed,” for URL: http://waterresources.msue.msu.edu
NCRP 1988	NCRP website displays: “We’re not able to complete your request”

Additionally, website links are embedded within the Final Report document itself. SC&A checked each of those links and found them to be active, except for those on pages 883 and 887 that link to the Neptune, Inc., website (i.e., neptuneinc.org), most of which require a usercode and password.

Comment 15. Federal vs. Agreement-State Regulations

In various sections of the appendices, e.g., Appendix A, Section 1.3, reference is made to Federal rules as though they have primacy for the Clive Facility. However, Utah is an agreement state under the Atomic Energy Act of 1954, as amended. Section 274 of the Act provides a statutory basis under which NRC has relinquished to Utah portions of its regulatory authority to license and regulate byproduct materials (radioisotopes), source materials (uranium and thorium), and certain quantities of special nuclear materials.

As an agreement state, Utah has developed its own rules, and it has primacy for administering the NRC agreement state regulatory program. It is the Utah rules, not Federal rules, that specifically govern regulated activities related to radioactive materials at the Clive Facility. Accordingly, all relevant appendices in the PA should be revised to discuss regulation primarily relative to Utah rule, rather than primarily Federal rule. Where Federal rules are referred to, the corresponding Utah rule should also be cited, and any differences in wording between the two should be described.

3.2 SPECIFIC COMMENTS

In the following comments, the acronym ES generally denotes Executive Summary.

ES, page 2. The third paragraph states, "The model does not consider the effects of enhanced infiltration or radon diffusion from a compromised radon barrier." The Final Report should explain why the effects of a compromised radon barrier are not considered, since the durability of the radon barrier over time is problematic and as described in the Final Report, plant roots and burrowing animals are active at the Clive site and could compromise the radon barrier by creating "short-circuit" pathways.

ES, page 2. The last paragraph states, "The potentially significant cover degradation process of gully formation is evaluated using a simple modeling construct, in order to determine whether it warrants more sophisticated modeling approaches." The text should reference the section within the Final Report that contains the determination as to whether a more sophisticated modeling approach is warranted.

ES, page 3. The last two sentences of the first paragraph state:

> *No associated effects, such as biotic processes, effects on radon dispersion, or local changes in infiltration are considered. When gullies encounter DU waste, doses and uranium hazards are increased, but when wastes are buried sufficiently deep the gullies have essentially no effect on human exposures*.

The Final Report should provide the justification for not assuming that gully erosion will lead to increased infiltration.

ES, page 3. The second paragraph states that typical NRC intrusion scenarios do not adequately describe likely human activities in the arid west and will usually underestimate the performance of the disposal system. The Final Report should explain why an underestimation is usual and under what unusual circumstances the performance will not be underestimated.

ES, page 4. The second-to-last paragraph states:

> *In accordance with UAC Rule R313-25-8, doses are calculated within a 10,000-year compliance period and may be compared to a performance criterion of 25 mrem in a year for a MOP, and 500 mrem in a year for an inadvertent intruder.*

The Final Report should confirm that concentrations of radionuclides in the groundwater are only compared to the groundwater protection limits (GWPLs) and are not factored into the dose assessment. It should also provide the rationale for assuming that the groundwater will never have beneficial uses and that potential exposure routes and receptors will not exist over the minimum 10,000-year compliance period.

ES, page 5. The first sentence on the page states:

> *These doses and the supporting contaminant transport modeling that provides the dose model with radionuclide concentrations in exposure media, are evaluated for 10,000 yr, in accordance with UAC R313-25-8(2).*

This statement might at first appear to be inconsistent with the discussion in Section 6.1, where the groundwater concentrations are only evaluated for 500 years. Please discuss the basis for these apparently conflicting assumptions.

ES, page 6. The first paragraph states, "Consequently, six different models are considered for the dose and groundwater concentration endpoints." Since the erosion scenarios are claimed to not affect the groundwater modeling results, it seems that there would be only three groundwater concentration endpoints representing the three emplacement depths.

Table ES-7. Footnotes 1, 2, and 3 are missing.

Section 1.3, page 15. The last paragraph states that 10 CFR 61.42 defines ALARA; rather, the definition is given in 10 CFR 61.41.

Section 1.3, page 16, paragraph 1; Section 4.1.2.11, page 39; Section 6.4, page 77, paragraph 1. When discussing the NRC's "options for discounting costs of human exposures over time," the Final Report should describe the NRC's position on intergenerational impacts, as defined in NUREG/BR-0058, Section 4.3.5.

Section 1.3, page 16. The text should include a reference (NUREG-1530) for the NRC cost of $2,000 per person-rem.

Section 2.1, page 23. The second sentence on the page states:

Note that there are 5,000 estimates of the peak of the mean for each receptor from the 5,000 simulations that are run. This is usually enough simulations to stabilize an estimate of the mean.

The Final Report should reference the work that was performed to demonstrate that additional simulations will not significantly change the statistics.

Section 4.1.2.5, page 30. This section provides a number of assumptions regarding total dissolved solids, pH, solubilities, and other parameters. These assumptions should be supported with appropriate references.

Section 4.1.2.6, page 31. The Final Report should provide the basis for establishing a point of compliance for groundwater at 27 meters (90 feet) from the edge of the embankment interior.

Section 4.1.2.7, page 32. The Final Report should provide support for the statement in the third paragraph that "Accumulation on-site seems more likely."

Section 4.1.2.8, page 32. The Final Report should provide support for the statement that the "…effect on radionuclides transport might be small" (emphasis added).

Section 4.1.2.8.2, page 34. The specific literature meant in the statement "Correlations reported in the literature" should be referenced.

Section 4.1.2.8.3, pages 34 and 35. This section discusses burrowing mammals and generally concludes that "…the burrows are sufficiently shallow that it is unlikely that they will have a significant impact on radionuclide transport." The Final Report should provide literature- and/or field-based support or justification for this statement and clarify whether this conclusion includes the "short-circuiting" effect that burrows would have for radon transport.

Section 4.1.2.10.1, page 37. In the first paragraph of the section, the text states "…the IHI [inadvertent human intruder] is someone who intrudes onto the facility and may directly contact the waste (e.g., by well drilling, or basement construction)." This statement requires revision or additional justification. Contrary to what is expressed here, UAC R313-25-20 does not restrict inadvertent intrusion scenarios to someone who directly contacts the waste. The rule speaks rather of "any individuals inadvertently intruding into the disposal site ***and occupying the site*** or contacting the waste after active institutional controls over the disposal site are removed" [emphasis added]. It is noted that an inadvertent intruder (1) inadvertently intrudes into the site, and EITHER (2a) occupies the site, OR (2b) contacts the waste, or both, after active institutional controls over the disposal site are removed. The Final Report should clarify whether there is ever any exposure assumed for obtaining water from a well (e.g., for dust suppression, cleaning, etc.).

Section 4.1.2.10.1, page 27, addresses only a ranching scenario and a recreational scenario. While each of these scenarios is likely, neither one is a scenario in which the greatest radioactive doses would likely occur, should the scenario come to pass. The PA should consider other likely scenarios in which the doses would likely be far greater. This will be more protective of inadvertent intruders and members of the public. These scenarios include an industrial scenario, in which industrial activities, such as industrial waste disposal, are conducted on site. This may involve construction and use of buildings with basements, as well as use of groundwater from onsite wells for dust suppression, etc. The scenario may also involve digging of materials for onsite cover use. Another scenario that should be considered is mining for sand and clay onsite, e.g., for road construction. Both types of activities have historically taken place on and/or near the site.

Section 4.1.2.12, page 39. The correct, updated reference for the groundwater discharge permit is missing. It should be Ground Water Quality Discharge Permit No. UGW450005 (UWQB 2012), not (UWQB 2010) as given in the body of the text on page 39, and not UWQB (State of Utah, Division of Water Quality, Utah Water Quality Board), 2009. Ground Water Quality Discharge Permit No. 450005, 23 Dec 2009, as listed in the PA References, and found on page 90.

Section 4.1.2.12, page 40. The text says, "The main concern for the PA model is the potential for transport of ^{99}Tc, a contaminant in the DU waste, to the point of compliance." The text should provide a reference to a section in the PA that fully discusses transport of technetium in groundwater at the site and tells what steps will be taken to mitigate its presence in groundwater at concentrations in excess of Utah limits.

Section 4.1.2.12, page 40. The text says, "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."

The text claims that "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." This statement is missing important context relative to use of the groundwater following suitable treatment. That context should be provided in the text and accommodated in the model. A number of countries throughout the world regularly treat saline water of approximately the same or even greater average TDS content than at Clive (i.e., about 40,500 mg/L) to make the water potable for their citizens to drink or employ for other "human uses." Desalination of Mediterranean sea water (e.g., with TDS at about 37,000–39,000 mg/L) is currently expected to provide up to 80% of the needs of Israel as of next year (Sales 2013). Desalination along the Persian Gulf (with TDS content commonly ranging between 41,000 and 48,000 mg/L) provides potable water for citizens of a number of countries. Kennecott Utah currently desalinates saline groundwater in nearby Jordan Valley and provides the treated, potable water via a distributor to about 14,000 people each year. Regionally, Arizona and California either use or plan to use reverse osmosis to provide potable water from saline or brackish water sources. As population soars over hundreds, thousands, tens of thousands, hundreds of thousands, or millions of years, as the need for drinkable water rises, and as water treatment technology continues to advance, treatment of saline water via desalination is expected to increase over time. Groundwater at Clive is found at depth as well as in the shallow aquifer, and such groundwater can potentially be produced at rates sufficient to provide, after desalination, potable water for a small community. Whether that is done depends on whether there is sufficient economic incentive to do so. The water, from a technology standpoint, can be made potable. The PA should discuss the potential to treat uncontaminated groundwater and mention the logistical, economic and regulatory difficulties of attempting to treat groundwater contaminated by radionuclides.

Section 4.1.2.13, page 40. The Final Report should provide a reference for the statement, "Given that long-term climatic cycles of 100 ky are considered very likely…."

Section 4.1.2.13, page 42. The text indicates that "…an assumption that the sediments completely mix is expedient, and probably leads to conservative results" (emphasis added). The Final Report should indicate under what conditions mixing of the sediments does not lead to conservative results.

Section 5.1.1, page 43. The text says, "For the deep-time model, there are no receptors that are considered, and doses are not calculated. Instead, concentrations of radionuclides are estimated in lake water and in lake sediment in the general vicinity of the CAS embankment."

Please provide additional discussion of how the PA accounts for radionuclide concentrations in lake water and lake sediment as a function of time. Also please provide further explanation as to why the PA does not perform a quantitative analysis of doses to persons exposed to radioactivity from the wastes in the embankment as a function of time as the embankment erodes.

In addition, please provide the rationale for not performing a qualitative assessment of the time to peak dose, since this determination is required by UAC R313-25-8(5)(a)."

Section 5.1.1, page 43. This section identifies compliance points for the dose assessment and the GWPLs, but not for uranium chemical toxicity.

Section 5.1.3, page 44. This section describes three potential disposal configurations. In each configuration, there are 27 layers within the disposal cell. In the first configuration, DU waste is disposed of in 21 layers; in the second configuration, DU waste is disposed of in 17 layers; and in the third configuration, DU waste is disposed of in 7 layers. The Final Report should describe the type of material that will be used to fill the layers and spaces not filled with DU waste.

Section 5.1.7, page 45. The text provides well drilling and basement construction as examples of inadvertent intrusion, but then states that "such direct activities are unlikely at this site," implying that there was no need to analyze them. Such activities would be unlikely at any well-sited disposal site; therefore, the fact that these activities are unlikely is not a reason to preclude their analysis, and an analysis of these activities thus should be included in the PA. Please provide additional rationale for excluding these activities since they would be unlikely at any well-sited disposal site but are typically included as part of the analysis.

Section 5.2, page 45. In discussing distribution averaging, the Final Report states:

In addition, these types of models are characterized by differential equations and multiplicative terms. Averaging is a linear construct that does not translate directly in non-linear systems. Again, care needs to be taken to capture the appropriate systems-level effect when dealing with differential equations and multiplicative terms.

SC&A agrees with this statement. The Final Report should clarify what "cares" were taken in this PA "to capture the appropriate systems-level effect."

Section 5.4.4, page 49. The text at the end of the first paragraph states:

As the model progresses through time, these radionuclides migrate into other parts of the physical system, and eventually are found in environmental media (air, water, soils) that receptors will encounter.

The Final Report should provide additional information on how the water pathway is considered in the dose assessment.

Section 6.1.1, page 55. The caption in Figure 5 appears to be incorrect. These are plots of calculated Tc-99 concentrations as a function of time for each realization and are not "mean peak" values.

Section 6.1.1, page 57. Similarly, the caption for Figure 6 should be "Statistical Summary of Tc-99 Concentrations as a Function of Time."[6]

Section 6.1.2, page 58. The x and y axes on the right-hand graph in Figure 7 should be labeled. The corresponding text should explain the development and interpretation of partial dependence plots, an example of which for ^{99}Tc is shown on the right-hand side of Figure 7.

Section 6.1.2, page 58. The Final Report should list which parameters were varied in the sensitivity analysis.

Section 6.2.1, page 60. The document states that "other [waste configuration] options could also be considered." The Final Report should identify which waste configuration Energy*Solutions* intends to use.

Section 6.2.2, page 63. The x and y axes in Figure 8 should be labeled.

Section 6.2.2, page 64. The x and y axes in Figure 9 should be labeled. The text should provide more discussion on how to interpret Figures 7, 8, and 9.

Section 6.2.2, page 65. The term "sensitivity index (SI)" on line 8 should be defined.

[6] "Peak mean" indicates the peak value of the time-dependent mean dose rate. "Mean peak" refers to the average value of the peak dose rate from each realization, while the "median peak" is the median value of the peak dose rate from each realization (Morris et al. 2006, page 5).

Section 6.2.2, page 67. The relationship between burrowing animals and the radon escape/ production ratio, if any, should be discussed.

Section 6.3, page 67. The term “hazard quotient” should be defined.

Section 6.3, page 67. The Final Report should identify which exposure pathways were evaluated when determining the uranium hazard quotients.

Section 6.3.1, page 68. The text and Table 7 appear to be inconsistent. The text (line 1) refers to “mean…hazard quotient,” while the title of Table 7 refers to “peak mean” and the body of Table 7 refers to “peak.”

Section 6.3.1, page 68-69. By definition, Hazard Quotient (HQ) is the ratio of exposure dose (mg/kg-day or mg/m^3) divided by RfD mg/kg-day or RfC mg/m^3 for the various exposure route. Since there are multiple exposure routes (ingestion, inhalation, dermal contact), their respective HQ must be summed to produce a Hazard Index (HI). It appears that Tables 7 and 8 present HIs rather than HQs, as they are labeled. Please clarify what the HQs (or HIs) in Tables 7 and 8 signify, for each receptor indicated, which exposure pathways were included in the HI and which pathways were excluded, and why.

Section 6.3.2, page 70. The x and y axes in Figure 10 should be labeled. The text should provide more discussion of how the partial dependence plots are interpreted and the type of information that can be abstracted from them.

Section 6.3.2, page 71. The document should discuss the significance of the reference to “uranium parents” in the second paragraph. Does this refer to the parents of uranium or the uranium parents of the decay products?

Section 6.3.2, page 72. The x and y axes in Figure 11 should be labeled.

Section 6.4, Table 11, page 76. Both the table title and the right-hand column title identify the dose as the “peak” population dose. Since population doses are summed over all years, the document should clarify what is meant by “peak.”

Section 6.5, page 77. The document indicates that 2.1 My was selected as the time for the deep time assessment based on the half-life of the U-238 decay products; however, the U-238 decay products are not included in the deep time assessment. The text should resolve this discrepancy by providing the rationale for the selected approach.

Section 6.5, page 78. The second paragraph states that sediment accumulates at about 17 meters (m) per 100 thousand years (ky). According to the Deep Time Assessment (Appendix 13, Section 6.3, page 24), the sedimentation rate for large lakes has a log-normal distribution with a geometric mean of 120 millimeters (mm)/ky and a geometric standard deviation of 1.2. This geometric mean is equivalent to 12 m per 100 ky. The differing values cited in the Final Report and Appendix 13 should be reconciled.

Section 6.5, page 78. The statement, "Sediment core records show significant mixing of sediments," in the third paragraph should be referenced.

Section 6.5.1, page 79. The document should clarify the number meant by a "handful" in the statement in the first paragraph: "Intermediate lakes only occur a handful of times."

Section 6.5.1, page 80. It might provide a useful perspective to compare the concentrations in Table 13 with the current GWPL for uranium.

Section 7.1, page 83. The beginning of the fourth paragraph in the section states, "Once gullies are involved, the doses increase (groundwater concentrations do not change noticeably)." If groundwater concentrations are not identical with and without the gullies, then the text should explain why not.

Section 7.2, page 85. The Final Report should provide justification for a 500-year compliance period for Tc-99. According to R313-25-8(5)(a), "for the purposes of this performance assessment," which applies to "the total quantities of concentrated depleted uranium and *other wastes*," "the compliance period shall be a minimum of 10,000 years," and "additional simulations shall be performed for the period where the peak dose occurs and the results shall be analyzed qualitatively." The first paragraph states that, "Because the groundwater concentration of ^{99}Tc increases with time, the peak of the mean concentration occurs at 500 yrs." However, Figures 5 and 6 show the concentration of Tc-99 as still increasing at 500 years. The paragraph further states that "The 5,000 simulations provide 5,000 estimates of the peak of the mean concentrations." However, the 5,000 simulations provide 5,000 estimates of the Tc-99 concentration as a function of time from 0 to 500 years. From these 5,000 realizations, one can calculate the mean dose at any time. The highest mean dose will occur at 500 years, since the analysis was truncated at that time. SC&A does not believe that this is the generally accepted understanding of the peak of the mean concentration.

Section 7.2, page 85. The second sentence in the second paragraph states, "Infiltration rates might be overestimated." The text should discuss why the estimates for infiltration may be too high.

Section 7.2, page 85. The last paragraph states that "the MOP performance objectives are not exceeded in all cases." However, Table 17 shows that the 95th percentile ranch worker dose is 72.3 mrem/yr, which is greater than the 25 mrem/yr performance objective. The text should address this discrepancy.

4.0 REVIEW OF APPENDIX 1 – "FEP ANALYSIS FOR DISPOSAL OF DEPLETED URANIUM AT THE CLIVE FACILITY," MAY 28, 2011

4.1 GENERAL COMMENTS

Comment 1. Definition of Features, Events, and Processes (FEPs)

For document clarity, the text should include some discussion as to how FEPs are defined.

4.2 SPECIFIC COMMENTS

Section 4.1.1, page 5. The discussion lists FEPs said to be mentioned in 10 CFR Part 61; however, it is not clear that the items listed are FEPs. Section 4.1.2 refers to similar items as "technical performance objectives." A clear distinction should be made between FEPs and technical performance objectives.

Section 4.2, page 7. The discussion states that the PA reflects post-closure conditions, and FEPs related to operations are not considered relevant. It is not clear that this approach is consistent with UAC R315-25-8(4)(c), which states:

> *Analysis of the protection of individuals during operations shall include assessments of expected exposures due to routine operations and likely accidents during handling, storage, and disposal of waste.*

In light of this requirement, the document needs to explain, in greater detail, why the protection of individuals during operations was not considered.

Section 6.0, page 9. The text should provide a specific cross-reference to the evaluation of canister degradation and corrosion in the conceptual site model.

5.0 REVIEW OF APPENDIX 2 – "CONCEPTUAL SITE MODEL FOR DISPOSAL OF DEPLETED URANIUM AT THE CLIVE FACILITY," MAY 28, 2011

5.1 GENERAL COMMENTS

There are no general comments.

5.2 SPECIFIC COMMENTS

Pages vi and vii. Some of the page references for the figures and the table in the table of contents are incorrectly stated.

Section 1, page 1. The second paragraph mentions a Federal rule (10 CFR 61) relative to radiological performance assessment, but it does not mention the controlling Utah rule(s), created and administered by Utah as an NRC agreement state. The text should frame the discussion within the context of governing Utah rule.

Section 1, page 1. The third paragraph states that the "PA model is intended to…support environmental decision making in light of inherent uncertainties." The text should clarify whether the PA is a National Environmental Policy Act (i.e., NEPA) document or a nuclear licensing document.

Section 1, page 2. The third paragraph states that the quantitative probabilistic PA model is based on projecting current societal conditions "up to 10,000 years." Utah rule UAC R313-25-8(5)(a) requires quantitative modeling for a minimum of 10,000 years, not a maximum of 10,000 years. Please provide text and modeling, as needed, to address this discrepancy.

Section 2, page 3. The third paragraph states that the "…focus of the uncertainty analysis in the PA model will be parameter uncertainty." The paragraph should also state how parameter variability was addressed.

Section 2, page 5. The first paragraph on the page says, "However, it is very important to capture correlations between variables in a multiplicative model. Otherwise, system uncertainty is not adequately constrained. GoldSim provides some limited capability to introduce correlation into a PA model, but steps will be taken to evaluate the correlation effects of some variables." The text should provide a reference to the section in the PA where these steps are discussed.

Section 3, page 5. The second paragraph states that, "Pending the findings of the PA, DU waste will be stored in a permanent above-ground engineered disposal embankment that is clay-lined with a composite clay and rock cap." The term "pending," as a preposition, means "while awaiting," or "during." The quoted statement is not correct, since DU waste will not be stored as described while awaiting or during "findings of the PA." Assuming that the PA is approved, DU waste may then potentially be disposed, perhaps as described above. However, before DU is disposed of at the Clive facility, a license amendment (of which the PA is a part) must be approved by the Utah Division of Radiation Control.

Section 3.4.2.2, page 11. The last paragraph of this section states that the groundwater "is not potable for humans." The text should clarify whether there are any non-humans for which the groundwater may be potable.

Section 4.1.2, page 15. Discussions between the DRC and EnergySolutions have resulted in verbal agreements to limit doses to the general public to 25 mrem/yr TEDE. A discussion of these TEDE limits should be added to the information contained in this section.

Section 4.1.4, page 16, of the PA says, "In addition to protecting any member of the public, 10 CFR 61 requires additional assurance of protecting individuals from the consequences of inadvertent intrusion. An inadvertent intruder is someone who is exposed to waste without meaning to, and without realizing it is there (after loss of institutional control). This is distinct from the 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."

This discussion should be framed in the context of applicable Utah rule, not 10 CFR 61. Utah rule UAC R313-25-20, entitled "Protection of Individuals from Inadvertent Intrusion" says, "Design, operation, and closure of the land disposal facility shall ensure protection of any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed." While not directly applicable, 10 CFR 61 says essentially the same thing. Therefore, it is not correct to define an inadvertent intruder as someone who is exposed to waste, per se. An inadvertent intruder may "inadvertently" intrude "into the disposal site and" occupy "the site" and be exposed to radiation without direct contact with the waste. In addition to inadvertently intruding into the disposal site, an inadvertent intruder, under Utah rule, is one who is "occupying the site" OR "contacting the waste."

While the intentional intruder, relative to the site, may be interested in "extracting materials from it, or who might be driven by curiosity or scientific interest," so might an inadvertent intruder. In fact, resource exploitation is one of the common classes of actions considered by the federal government in developing inadvertent intruder scenarios. The discussion in the PA should account for the possibility of inadvertent intruders engaging in resource exploitation (e.g., mining of clay, sand or aragonite materials).

Section 4.1.4, page 16. The last paragraph of this section asserts that, "because the definition of inadvertent intruders encompasses exposure of individuals who engage in normal activities without knowing that they are receiving radiation exposure, there is no practical distinction made here between a member of the public (MOP) and inadvertent intruders with regard to exposure/ dose assessment."

A review of UAC R313-25-19 and UAC R313-25-20 enables making such a practical distinction. Under UAC R313-25-19, entitled "Protection of the General Population from Releases of Radioactivity," reference is made to releases of "radioactive material" "to the general environment in ground water, surface water, air, soil, plants or animals." And under UAC R313-25-20, protection is extended to "any individuals inadvertently intruding into the disposal site and occupying the site or contacting the waste." In the former, radioactive materials or radioactivity is released to the general environment, which in many cases could be offsite, whereas in the latter, individuals must come into the disposal site itself and either occupy it or contact the waste, and it would be there that they could receive a dose of radioactivity. MOPs, unlike inadvertent intruders, do not need to enter the site. MOPs, unlike inadvertent intruders, may be aware of the potential for radioactive exposure, but still receive it. Inadvertent intruders do not have to be exposed to releases of radioactive materials to the environment, but, unlike members of the public, they may expose themselves directly to unreleased sources or shine from unreleased sources as well as releases of radioactive materials to the environment. The text should clarify these significant differences.

Section 4.2.1, page 17. The last paragraph claims to reproduce the new section for R313-25-8 as follows:

> *(2)(a) Any facility that proposes to land dispose of significant quantities of depleted uranium, more than one metric ton in total accumulation, after June 1, 2010, shall submit for the Executive Secretary's review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period will be a minimum of 10,000 years. Additional simulations will be performed for an analysis for the period where peak dose occurs and the results shall be analyzed qualitatively.*

This is not correct. The correct new section in R313-25-8 is designated as R313-25-8(5)(a), not as R313-25-8(2)(a). The correct new section is also reproduced properly as follows:

> *(5)(a) Notwithstanding R313-25-8(1), 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, shall submit for the Director's review and approval a performance assessment that demonstrates that the performance standards specified in 10 CFR Part 61 and corresponding provisions of Utah rules will be met for the total quantities of concentrated depleted uranium and other wastes, including wastes already disposed of and the quantities of concentrated depleted uranium the facility now proposes to dispose. Any such performance assessment shall be revised as needed to reflect ongoing guidance and rulemaking from NRC. For purposes of this performance assessment, the compliance period shall be a minimum of 10,000 years. Additional simulations shall be performed for the period where peak dose occurs and the results shall be analyzed qualitatively.*

The main difference between the two versions, other than the numbering, is that the correct, up-to-date version refers to "significant quantities of concentrated depleted uranium" (adding the word concentrated). Note that this rule applies to the facility as a whole, not simply to a particular embankment. The text should include the correct reproduction of the rule as well as the correct numbering.

Section 4.2.2, page 18. This section refers to Utah rule R313-15-1008 as being "Classification and Characteristics of Low-Level Radioactive Waste." Figure 5 refers also to R313-15-1008. The rule numbers are not correct. The correct rule that should be referenced is UAC R313-15-1009.

The PA says that "Ra-226, a decay product of uranium-238, the principal component of DU," is of direct interest to the disposal of DU waste." However, Ra-226 is also one of the many "other wastes" mentioned in UAC R313-25-8(5)(a) for which modeling must be performed during not only the compliance period of a minimum of 10,000 years, but also during an extended period of time beyond that, i.e., for a time sufficient for the peak dose to be evaluated through the model, with the results then being analyzed and discussed qualitatively. The text should discuss ramifications for modeling associated with the Utah rule that includes ingrowth of Ra-226 in determining LLW classification and characteristics.

Classification for most radioactive substances involves those whose activity concentrations are maximums at the time of initial classification, and decline via radioactive decay thereafter. However, activity concentrations for Ra-226 are not maximum at the time of LLW classification, but they continue to grow through time until secular equilibrium is attained with the uranium parent(s). This is a situation not analyzed for in the original development of the classification tables. This is a point of importance in considering whether the Director of the DRC should allow for DU disposal at Clive in Utah, where radioactive materials having a classification above Class A are not permitted to be disposed of by law. This factor needs to be discussed in depth. The text should accordingly reference the section of the PA that provides modeling results for Ra-226 and that indicates the point at which the activity concentrations of Ra-226, through radioactive ingrowth associated with depleted DU, exceed Class A concentrations, and also the point, if any, at which activity concentrations of Ra-226 exceed Class C concentrations. The text should also provide justification as to why Utah should permit disposal of materials producing substances that, even though initially passing Class A limits, will ultimately lead to the anomalous condition of Ra-226 activity concentrations exceeding Class A limits, and possibly even Class C limits, over time.

Section 4.2.2, page 18. The second paragraph states, "…some radionuclides listed in the tables shown in Figure 7 in addition to the Ra-226 added by Utah (Figure 5)." However, there are no tables in Figure 7; Figure 5 includes a single table. The text should be revised to clarify.

Section 4.2.3, page 19, says, "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. As noted in Section 3.4.2.2 , 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."

It is true that the Permit states that groundwater at Clive is classified as Class IV groundwater, which is saline. However, it is not true that "according to the Permit, groundwater at Clive . . . is highly unlikely to serve as a future water source." The permit does not appear to speak to that speculation. The Licensee should provide appropriate justification for this claim, or make modifications as needed.

The claims that groundwater at Clive, because of its natural high salinity, "…is not suitable for most human uses, and is not potable for humans" are simply not correct. Water of comparable salinity is currently being used, after appropriate treatment, in many Middle Eastern countries as potable water, and it is employed there for many human uses. Saline water is also currently used to provide potable water for people in other parts of the world, including the local region. Saline water is currently being used, for example, here in Utah by Kennecott and a local water distributor to provide potable water for people in the Jordan Valley. Regionally, it is being used in Arizona and California. The text should provide more appropriate, extended discussion of this issue, or it should justify the original statements.

Section 5, page 20, first paragraph. Information in the meteorology section appears to be incomplete and in error. Numerous tornados have been reported in Utah; one web site lists 120 tornados between 1953 and 2012 (http://www.tornadohistoryproject.com/tornado/Utah/table). Please provide complete and accurate information.

Section 5, page 20, last paragraph. Information about seismic activity section appears to be incomplete and in error. (See also Section 4.2.) Please provide complete and accurate information.

Section 5, page 21, Containerization. The text states that canister degradation and corrosion are evaluated in the conceptual model. The document should provide a specific cross-reference to this discussion.

Section 5, page 22, Human Processes. The text states that anthropogenic climate change is among the human process FEPs identified for assessment. The text should provide a specific cross-reference to this assessment.

Section 6, page 22. The text states that the "scope of this CSM is limited to the disposal of DU wastes…." This statement appears to conflict with UAC R313-25-8(5)(a), which requires the PA to demonstrate that performance standards will be met for "depleted uranium and other wastes, including wastes already disposed of…." Please reconcile this apparent inconsistency.

Section 6, page 22. The first paragraph describes DU oxides to be produced from GDPs, but the information is not complete on this matter. Please provide it.

Section 6, page 22. The text should provide a reference for the statement in the third paragraph, "If uranium hexafluoride derived from irradiated reactor returns is introduced to the cascade, the associated fission products and actinides migrate to the depleted end of the cascade, with the U-238."

Section 6.3, page 24. This section refers to depleted uranium oxide from gaseous diffusion plants. The section, however, does not describe the types and quantities of uranium oxide(s) produced or expected to be produced from de-conversion of DUF_6 at these plants. This section needs to reference one or more other section(s) in the PA where detailed information about these oxides are presented in the PA, since chemical properties and environmental behavior differ depending on the type of oxide and its relative fractional contribution to the DU waste.

Section 6.4, page 25. Depleted uranium already disposed of at the Clive Facility is not accounted for in the DU PA Model. However, Utah code requires demonstration within the PA that performance standards will be met for "depleted uranium and other wastes, including wastes already disposed of…." [UAC R313-25-8(5)(a)]. Reference should be made here to that section of the PA where depleted uranium already disposed of at the Clive Facility is discussed and evaluated. If such a section does not currently exist, then it needs to be created.

Section 6.6, page 26. The second paragraph states that, "The transport of radon in both the saturated and unsaturated zones will be included in the PA model." However, radon is not mentioned in the saturated zone modeling appendix (Appendix 7); the text should provide a specific cross-reference to the discussion of radon transport under saturated conditions.

Section 7.1.1.1, page 27. The third paragraph states that "Diffusion in the air phase within the UZ below the facility will not be modeled, since the only diffusive species would be radon...." However, Section 6.6 states that "The transport of radon in both the saturated and unsaturated zones will be included in the PA model." The text should resolve these apparently contradictory statements.

Section 7.1.1.2, page 27. The second paragraph states that "A range of values will allow the sensitivity analysis (SA) to determine if this is a sensitive parameter...." The text should provide a specific cross-reference to the discussion of this sensitivity analysis.

Section 7.1.3.1, page 28. The first paragraph states that "Over time, cracks, fissures, animal burrows, and plant roots can also provide preferential diffusion pathways that reduce the effectiveness of the engineered barrier." The document should indicate how this was accounted for in the PA model, particularly with respect to the potential release of radon to the surface.

Section 7.1.4, page 31, says, "However, in areas where precipitation does not infiltrate to groundwater, black greasewood will not form taproots and will maintain a more shallowly rooted growth form. Excavations of several greasewood plants at the Clive site by SWCA (2011) found roots that did not exceed one meter in depth."

SWCA (2011) explains that these greasewood roots went down to a compressed clay layer located at that shallow depth, and then spread out laterally. Where there locally is a perching layer such as this clay layer appears to be, one that traps moisture at a shallow level and makes it available for roots, such shallow plant rooting behavior is expected. However, where such a perching layer does not exist, it is expected that greasewood roots may extend to great depths in search of groundwater or capillary-fringe water. As Neptune and Associates (2011) says of the site, "The vegetative survey of the Clive site found that the majority of greasewood plants are less than one meter tall . . . 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."

As the PA implies, greasewood is a phreatophyte. Its scientific name is *Sarcobatus vermiculatus*. Maxwell et al. (2007) state that greasewood is an obligate phreatophyte, whose roots almost always grow into groundwater. Waugh (1998) states of greasewood that it "is an obligate phreatophyte requiring a permanent ground-water supply, and can transpire water from aquifers as deep as 18 meters below the land surface (Nichols 1993)." Nichols (1993) reports greasewood taproots growing to depths equivalent to about 60 feet. Meinzer (1927) states that "Near Grandview, Idaho, H. T. Stearns observed roots of greasewood penetrating the roof of a tunnel 57 feet below the surface." White (1932) reports greasewood growing at localities where the depth to groundwater is 50 to 60 feet. WSDNR (2011) states that "Sarcobatus vermiculatus is an obligate phreatophyte and is able to tap into groundwater at great depth (>10 meters)." Chimner and Cooper (2004) report that xylem water from greasewood plants overlying a groundwater table at a depth of about 13 meters (43 feet) was isotopically similar to xylem water from greasewood at other sites where depth to groundwater ranged from 2 to 13 meters (6 to 43 feet). Harr and Price (1972) report maximum greasewood rooting depths of at least 12.7 m (42 feet).

When natural soils in the area are disturbed during excavation to procure cover-system materials, these cover-system materials will no longer possess an intact compressed natural clay layer at a depth of 1 meter that acts to pond infiltrating water and limit deeper greasewood rooting. While the radon barrier may provide some local resistance, the radon barrier is susceptible to damage over time via plant rooting, animal burrowing, water-based and wind-based erosion, and violent meteorological events, such as tornados and microbursts. This section should discuss the potential for deeper rooting by greasewood.

Section 7.1.5, page 32. The first paragraph states that "site-specific information about the utilization of the site by specific animal species is likewise limited." The PA does not include much information relative to burrowing mammals. Such information, however, can be found specifically for the site in SWCA (2011; 2012). SWCA in particular describes burrowing mammals on site, or very near the site, such as coyotes, badgers, kit foxes, burrowing owls, ground squirrels, and deer mice. Additional generic and case-study information is available in the literature. Much more analysis on the potential for burrowing mammals to impact site rock and soil materials is needed, since burrowing mammals may play an important role in cover-system degradation over time. The PA should include extensive analysis about this important topic, including additions to modeling to show effects of burrowing on site conditions.

Dwyer et al. (2007) state that, "…biointrusion can lead to increased infiltration and preferential flow of surface water through the cover system as well as contribute to the change in the soil layer's hydraulic properties." Hakonson (1999; 2002) and Hakonson et al. (1982) indicate that biointrusion by mammals can be problematic at disposal sites and that pocket gophers, for example, can increase rates of infiltration by 200% to 300%. Breshears et al. (2005) report that burrows made by pocket gophers in simulated landfills dramatically increased infiltration rates, i.e., by about one order of magnitude. Badger burrows at the Hanford site are reported to have captured much runoff and allowed the runoff to infiltrate into soils deeper than elsewhere on site. Measurements by researchers of moisture in soils under the burrows after artificial rainfall events demonstrated this impact. "These measurements confirmed that larger mammal burrows can and do cause the deep penetration of precipitation-generated runoff at Hanford" (Link et al. 1995). Hakonson (2002) says, "Erosion and percolation increase dramatically when the vegetation cover is absent in the presence of burrowing." According to SWCA Environmental Consultants (2012), "A bioturbation barrier will likely be needed that is designed to exclude large and small burrowing mammals (i.e., mice, rats, hares, badgers)." The text should clarify whether additional site-specific information about use of the site by animals and also biointrusion is going to be collected, and if not, document why the limited available site-specific information is sufficient for the PA and the license amendment.

Section 7.1.5, page 32. The PA does not mention coyotes inhabiting the site. SWCA (2012) noted that, while coyote burrows or dens were not observed directly on the several plots used for their limited sampling events, evidence of coyotes was noted nearby. The presence of coyotes on or near the site indicates the potential for cover damage by the coyotes.

Coyotes are capable of deep burrowing. In one study, it is reported that minimum depth of 17 dens ranged from 2 to over 5 meters (6 to 16 feet), with an average depth of 2.5 m (8 feet) (Way et al. 2001). This depth is much greater than the depth of the proposed cover system (6.5 feet), so a risk from biointrusion into radon barriers and bulk waste exists.

Biointrusion by coyotes can badly damage cover systems, possibly allowing a direct path for water to percolate into waste, and permitting the release of radon into the atmosphere, increasing risk to people and the environment. If coyotes get into waste, they may become surficially contaminated by radioactive particles and may spread these radioactive particles to other parts of the environment. Additionally, radioactive materials within the coyotes (e.g., from eating other fossorial mammals) may subsequently adversely impact the environment via excretion of coyotes' urine, feces or other bodily fluids, or, when the coyotes die, through decomposition of their flesh. The cover system needs to provide a high level of protection from intrusion by burrowing animals, including coyotes. The PA should account for this and also document the potential for deep burrowing by coyotes.

Section 7.1.5, page 32. The PA does not mention badgers inhabiting the site. SWCA (2012) shows photos documenting that badgers live at the site, and this reference also reports badger burrows at the site. McKenzie et al. (1982) is said to give a burrowing depth for badgers that is greater than 2.0 meters, or 6.6 feet (Hampton 2006). Based on a study of a couple of badgers in Utah and Idaho, Lindzey (1976) reports that one badger observed in the study burrowed to a depth of 2.3 meters (7.5 feet). Reported burrowing depths of 6.6 to 7.5 feet are significantly greater than the depth of the proposed DU cover system soil and rip rap. It is estimated in Eldridge (2004) that each badger creates or enlarges up to 1,000 to 1,700 burrows or pits each year. Badgers do this primarily while searching for fossorial mammals (e.g., ground squirrels, kangaroo rats or deer mice) to eat. Since each pit lasts, on average, about 4 years (see Eldridge 2004), one badger may be responsible for the presence of 4,000 to 6,800 relatively large pits being in existence each year.

Biointrusion by badgers can potentially cause a number of problems. Biointrusion can potentially damage cover systems, allow too much water to percolate into LLW, and permit release of radon into the atmosphere, increasing radioactive doses to humans and the environment. If badgers get into LLW, they may become contaminated by radioactive particles and may spread them throughout the environment. Badgers may also ingest radioactive materials by eating other fossorial mammals impacted by waste. They may then spread radioactivity through the environment via urine, feces, and other bodily fluids, and, when the badgers die, via decomposing flesh.

Rock armor cover may by itself provide minimal biointrusion protection. Many plants and burrowing mammals may be able to penetrate a rock armor cover by migrating through the large interstices or voids existing between its cobbles. Larger fossorial mammals, such as badgers, may be able to remove some or all of the smaller cobbles by digging or burrowing. The PA should account for this and also document the potential for deep burrowing by badgers.

Section 7.1.5, page 32. The PA does not mention kit foxes inhabiting the site. Kit foxes, which are found in western Utah, among other places, either create or use (in some cases) dens as deep as 2.5 meters (8.2 feet; Tannerfeldt et al. 2003, referencing O'Neal et al. 1987). This depth is considerably deeper than the design depth of the top of radon barrier, and even considerably deeper than the design depth of the top of the bulk waste. Foxes are mentioned on page 3-4 of Section 3.1.6 of the Energy*Solutions* PA for blended and processed resin LLW, which states, "Other burrowing animals at the site include jackrabbits, mice, and foxes." Jackrabbits do not burrow. The PA, however, should account for fox burrowing into bulk waste.

Section 7.1.5, page 32. The PA does not mention burrowing owls. The Energy*Solutions* PA for blended waste says, "Furthermore, the presence of badgers and a large family of burrowing owls indicates that the biota can potentially move large volumes of soil." SWCA (2012) also mentions them, and shows a photograph. The PA should document the potential for deeper burrowing by burrowing owls.

Section 7.1.5, page 32. SWCA Environmental Consultants (SWCA 2012) reports on the species of ground squirrels observed onsite: *Spermophilus* spp. Suter (1993) and Suter et al. (1993) report ground squirrel burrowing to depths of at least 1.4 meters (4.6 feet), but do not mention species. HERD (1998) reports that ground squirrels in California burrow to depths of at least 66 inches (1.7 meters, or 5.5 feet). These data indicate that the potential depth to which ground squirrels may burrow may be nearly as deep as the proposed cover system soil thickness and deeper than the top of the radon barrier. These data indicate the potential for ground squirrels to biointrude through at least some of the cover-system soils at the site.

Biointrusion by ground squirrels can badly damage cover systems, possibly allowing for more water to percolate into waste, and facilitating the release of radon into the atmosphere, increasing risk to people and the environment. The cover system needs to provide a high level of protection from intrusion by burrowing animals, including ground squirrels. The PA should account for this.

Section 7.1.5, page 32. The PA does not talk extensively about deer mice. Yet, according to the SWCA (SWCA 2011; 2012), 83 deer mice and 1 kangaroo rat were trapped during a single biological survey on site.

Kenagy (1973) reports on the depth of nests of the kangaroo rat, *Dipodomys merriami*, at a site in Owens Valley between the Mohave Desert and the Great Basin. Maximum depth of kangaroo rats that could be located by tracking devices used at this site is reported to have been 1.75 m (5.7 feet). However, many of the kangaroo rats are reported to have stayed in their burrows during the study at considerably greater depths than this maximum depth to which the tracking devices used in the study could read a signal and track them. Different species of kangaroo rats may burrow more deeply or less deeply. The species of kangaroo rat found at the site is not mentioned in the PA. The kangaroo rat captured by SWCA Environmental Consultants (2012) is thought to have been an Ord's Kangaroo rat (see page 23 of SWCA 2012b).

Arthur and Markham (1986, 1987; see also Bowerman and Redente 1998) note that deer mice penetrated an Idaho National Environmental Laboratory (INEL) cover system having a thickness of 2.4 meters. Many of the mice are reported to have received relatively high radiation doses, some of which are said to have been lethal.

Landeen and Mitchell (1981) found that other types of mice (i.e., pocket mice) at the Hanford site burrowed about 79% deeper in disturbed soils than in native soils. This indicates that, for combinations of some mammals and some soils, biointrusion may be deeper in disturbed soils than in non-disturbed soils.

Based on the foregoing, it appears that the potential for biointrusion exists for both kangaroo rats and deer mice at the site. Kangaroo rats are noted in field observations to have burrowed down to soil depths of at least 1.75 meters (5.7 feet). It is not known how species variation affects burrowing depth. Deer mice can burrow down to at least 2.4 meters (7.9 feet). These are depths for which actual field samples are relatively few. Therefore, greater depths of burrowing could be expected if an entire population were to be evaluated. Furthermore, as reported for one species in one soil by Landeen and Mitchell (1981), burrowing depths may possibly tend to be greater in disturbed soil.

For the Licensee-preferred cover design at the site (see pages 12 and 15), the proposed cover-system soil thickness is several feet. Both kangaroo rats and deer mice have been reported to burrow down into soil fairly deeply. This indicates the potential for biointrusion at the site. The PA should include discussion of the potential for this from mice and kangaroo rats, and the effects of biointrusion by mice and kangaroo rats, and all other potential biointrusions, should be accounted for in the PA model.

Section 7.2, page 35. Even though predictions of dose in deep time involve much uncertainty, doses can be discussed qualitatively under certain assumptions. This approach has value in assisting regulators and the general public in understanding how radioactivity values of DU's daughter products (and therefore their potential contribution to dose) tend to increase over time. A simple bounding assumption that could be used would be to assume that site conditions do not deteriorate at all. Annual dose could then be estimated, for example, for an inadvertent intruder working 8 hours per day, 5 days per week, in a basement of a building located over the embankment. The results, though based on quantitative numbers, would need to be assessed qualitatively, because there would be, in fact, dramatic uncertainty associated with the result, and this set of criteria can be communicated to the reader of the PA. Determination of dose at the time of peak dose and qualitative discussion of the results is mandated by Utah rule, and it should be included as one of the PA results.

Section 7.2.1.4, page 39. This section discusses the indirect effects of volcanism in diverting the Bear River from Idaho to the Bonneville basin. The effects of volcanism on the Clive area should be included, or the text should document that there is no possibility for impacts of volcanism on the Clive area over the next 10,000 years.

Figure 7.2.1.5, page 40. The X on the Whittaker biome diagram (which is supposed to represent site conditions) appears to be too high. As it currently is depicted, the scaled precipitation value for the X appears to be in the range of 27–30 cm/yr. Yet average precipitation at Clive is 8.62 in/yr (about 21.9 cm/yr). This appears to change the biome depicted for the site conditions. The placement of the data point for site conditions as presented by the X on the diagram should be modified in the PA.

Section 7.2.2, page 42. The document says, "When the first lake returns at or above the elevation of Clive, the waste embankment will be treated as destroyed." This interpretation of results may, under many circumstances, be reasonable. However, if all waste and cover-system materials are located below natural grade level, then it is not likely that the waste would be redistributed into the environment nearly as readily, if at all. The PA model should be re-run under this scenario, with the top of the cover at natural grade level, and the results presented in the text.

Section 8.1, page 44. The last sentence of the section states that, "All wastes are assumed to have the characteristics of local Unit 3 sandy soil." The text should provide the basis for making this assumption, rather than assuming that the DU waste would have the characteristics of DUO_3 from SRS and DU_3O_8 and DUO_2 associated with de-conversion of UF_6.

Sections 8.2 and 8.3, page 44. The text should provide a brief description of the liners and cap or provide a specific cross-reference to where descriptions may be found.

Section 8.2, page 45. Paragraph three of the first bulleted item says, "The measured moisture content in the Cover Test Cell at the site provides evidence for an evaporative zone depth greater than 18 in (Envirocare 2005)." However, the DRC in its 2012 report on the covered test cell, clearly demonstrated a lack of substantive evidence for an evaporative zone depth greater than 18 in exists. Substantial evidence, in fact, exists to show that in many studies, coarse-grained material (such as rip rap) placed at the surface of a soil layer acts as an inorganic mulch and greatly reduces or, in some instances, nearly eliminates evaporation. The PA should be modified to account for this.

Section 8.3, page 45. The suppositions in the second bullet about the behavior of smaller mammals and ants should be supported by appropriate references.

Section 8.2, page 45. The third bulleted item says, "On balance, the evidence suggests that bioturbation and homogenization of the radon barriers will probably occur very slowly relative to the 10,000-year time frame for the PA." No justification is provided for this claim. Moreover, homogenization of the radon barriers is not the only result of biointrusion and bioturbation. This bulleted item should be expanded, and any assertions made should be justified.

Section 8.2, page 46, says, "Freeze/thaw cycles will also tend to degrade performance of the cap. This process is anticipated in the design, however, which includes a sacrificial layer to accommodate it (Whetstone, 2000)." However, the sacrificial layer is not necessarily of sufficient thickness in its current design to withstand sustained cold winter temperatures.

At the Cover Test Cell previously built and tested on site, freezing temperatures occurred at a depth of 30 inches for January 2004, which was not an exceptionally cold month. Neither was the month before an exceptionally cold month. In very cold winters, it stands to reason that the zone of freezing may extend even deeper than 30 inches, and this may necessitate even greater design soil layer thickness above the radon barrier to protect it.

In the Cover Test Cell that month, while freezing occurred at a depth of about 30 inches, temperatures only slightly above freezing (e.g., 2°C, or about 36°F) were noted even at a depth of 42 inches, at or near the top of the radon barrier. During that month, mean monthly low air temperatures are reported as having been 11.35°F (see http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?utdugw). However, meteorological records show that, in the 56 years between 1951 and 2006, inclusive, there were 13 years (23%) in which mean monthly low air temperatures for January dropped to values lower than 11.35°F (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?utdugw), and sometimes much lower. Likewise, about 25% of December monthly low air temperatures between 1951 and 2006 were colder than those in December 2003, and sometimes much colder. It follows that test results for freezing of the Cover Test Cell in 2004 are not conservatively representative of all freezing temperatures experienced over time.

In January, 1989, monthly low air temperatures plummeted to 0.39°F, which is nearly 11 degrees cooler than in January 2004. With a similar drop of 11 degrees in monthly low air temperature in the future compared to January 2004, it is possible that a radon barrier at the DU embankment could be subjected to below-freezing temperatures, with consequent severe damage.

The PA should discuss the potential for freezing of the radon barrier, which could cause it to undergo severe damage through frost heave.

Section 8.2, page 46. As stated in the document, "Subsidence is not expected to be an important process at the Clive facility, since the waste is aggressively compacted in order to prevent this occurrence (Energy*Solutions*, 2009c). However, the subsidence described in the Energy*Solutions* reference does not refer to compaction of DU in its drums or canisters, which may behave very differently in the embankment from, for example, compacted bulk waste. Drums of DU-related LLW from SRS or canisters of DU-related LLW from GDPs may have headspace within the associated containers that may not respond to compaction efforts at Clive. However, this headspace may become important as the containers deteriorate over long periods of time, perhaps decades or hundreds of years, and as the headspace is filled in by overlying waste, resulting in differential subsidence. What is missing from the PA is an analysis of stability conditions as this compaction occurs. The analysis is required under UAC R313-25-22 and analysis should be part of the PA.

Section 9.1.1, page 47. The document states, "Based on laboratory analysis of the contents of DU waste (including all radionuclides in the containers), the species in the disposed inventory include (Beals et al. 2002; Energy*Solutions* 2009b; Johnson 2010): . . " This statement is unclear as to which waste it is referring. Does it refer to all DU waste expected to be disposed of including that in the future, or to currently disposed of DU waste, or to DU waste from SRS, or to DU waste from GDPs? Each of these will have different DU-waste species compositions. How is this accounted for in the model? This section needs clarification.

Section 9.1.2, page 47. The text should describe how "spontaneous fission" is modeled in the PA such that it is "accounted for in terms of [its] dose effects on humans."

Section 9.2, page 51. It is stated that, "The disposed DU waste is assumed to be uncontainerized, since standard operations at the site include significant compaction of disposed waste." This appears to be an incorrect assumption. Planned disposal practices at the site include disposal of SRS drums and GDP canisters as well as the DU waste that each type of container holds. Correct information about containers needs to be supplied for the model and for the text in this section. This information is important in considering physical stability of the waste, since any headspace in the containers will eventually allow for partial collapse of the waste and cover above it.

Section 9.3, page 52. This section discusses use of partition coefficients in the model. However, the text, and presumably the model, either openly or implicitly assume that sorption and exchange processes occur:

(1) Under equilibrium conditions, rather than non-equilibrium or time-dependent conditions
(2) Linearly, rather than nonlinearly
(3) Reversibly, rather than irreversibly
(4) Independently of pH, Eh, temperature, and other physical and chemical characteristics of the external environment, rather than dependently

While choosing such an approach to sorption and exchange processes may be considered by the modeler(s) to be necessary to keep the model sufficiently simple and workable, and data acquisition minimal, it is well known that there are some rather severe limitations to the accuracy of such an approach with respect to radionuclides. For example, as stated by Cygan et al. (2001), "linear and reversible sorption (i.e., K_D approach) is rarely observed in soils and groundwaters because of complex geochemical factors that can significantly affect radionuclide transport mechanisms and kinetics (e.g., pH, fluid composition, ionic strength, mineral substrate structure and composition, organic complexation)."

There is thus a great deal of uncertainty involved in model results based on an application of the partition coefficient approach, such as occurs in the PA model. This section should either provide a discussion of this inherent uncertainty, or provide a reference to a relevant discussion found elsewhere in the PA. The discussion of uncertainty should attempt to quantify it. Another section of the PA should address model sensitivity to the value of the partition coefficient used.

Section 9.3, page 52. The text provides the partition coefficient concept. It should also provide details on how the retardation factor was calculated and specifically whether moisture content or porosity is used in the unsaturated zone transport calculation.

Section 10.3, page 56. The text states that "Potential activities of interest…are based on the predominant present day uses of the general area…." As we described in Section 3.1, General Comment 9, the PAWG (see NRC 2000a) expects that an analogue site would be used when there are currently no nearby residents. The applicant should provide the basis for not using an analogue site.

Section 10.3.1, page 57. The second paragraph states that "Inputs for developing exposure parameter values under the ranching scenario include…restrictions related to BLM leases…." The document should explain why it is appropriate to include Bureau of Land Management (BLM) restrictions, given the potential for BLM policies to change in the future over the next 10,000 years.

Section 11, page 62. The first paragraph states that "…process-level models may be developed." The text should clarify whether process-level models were, in fact, developed and integrated fully into the overall model; it should describe how the conceptual site model was actually implemented.

6.0 REVIEW OF APPENDIX 4 – "RADIOACTIVE WASTE INVENTORY FOR THE CLIVE DU PA," MAY 28, 2011.

6.1 GENERAL COMMENTS

Comment 1. Clarification of Metrics

When the appendix cites a material mass, the material comprising the mass should be stated. For example, on page 6 (line 2), the text states, "…weight (total of 7,886,738 pounds corresponding to a mass of 3,577 Mg)." The document should indicate whether this is 3,577 Mg of DU, DUO_3, or DUO_2.

Comment 2. Overlooked Reference

The list of references does not include the following document (DOE 2003):

> *Recycled Uranium, United States Production, Enrichment and Utilization*. DOE/SO-0003. U.S. Department of Energy. May 2003.

This document and its supporting references may contain useful information on the levels of actinides and fission product contaminants in materials at the three gaseous diffusion plants.

6.2 SPECIFIC COMMENTS

Section 2.2.2, page 5. The first paragraph mentions samples analyzed by the Savannah River Technology Center (SRTC) and by BWXT Services, Inc., for uranium, fission, and transuranic radionuclides. The last sentence of the paragraph provides the references for the results from SRTC, but not for BWXT Services, Inc.; the document should also provide a specific cross-reference to the results of the BWXT analysis.

Section 2.2.2, page 6. The document states that "In January of 2010 Energy*Solutions* collected 15 samples that were analyzed for uranium isotopes (Table 14, in the Appendix). In April 2010 Energy*Solutions* collected 11 samples that were analyzed for uranium isotopes and ^{99}Tc (Table 15, in the Appendix)." The number of samples should be reversed; Table 14 shows 11 samples for January 2010, and Table 15 shows 15 samples for April 2010.

Section 2.3.2, page 7. The document states that "Little information is available at this time regarding the exact nature and extent of the contamination within the contaminated DU population." Based on Comment 2 above (see DOE 2003), SC&A believes that this statement is not accurate. Additional information is available to augment the analysis.

Section 3.1.2, page 10. The text states, "However, different sampling events for ^{99}Tc and U indicate potentially different measurement types between sampling events." The meaning of this statement is not clear. What are different measurement types? How is this judgment made?

Section 3.2.1, page 12. We believe that the subscripts in the denominator of equation 1 should be i (eye).

Section 3.2.2, page 14. The document states:

> *In general, the differences this causes in uranium activity concentrations are fairly small relative to the likely effect on the PA model results, however, this will be tested in the model evaluation and sensitivity analysis*.

The text should provide a specific cross-reference to the sensitivity analyses.

Section 3.2.3, page 16. The text states:

> *If, given these relatively broad distributions, the uranium isotopes are not sensitive to any PA model endpoint, then the need to refine these distributions will be less.*

The text should indicate whether any analyses were conducted to determine if the uranium isotope distributions significantly affected the PA results.

Section 3.3, page 17. The text states:

> *The effect of the inclusion of these data has been tested during model evaluation and is reported as part of the sensitivity analysis.*

The text should provide a specific cross-reference indicating where the results are reported.

Section 3.3, page 18. The text should describe how the information contained in the box plots in Figure 3 (and later in Figure 5) should be interpreted. What statistical parameters do the boxes display?

Section 3.3, page 19. The document states:

> *Given the mobility of ^{99}Tc and the width of the input distribution defined above, it is reasonable to expect that concentration of ^{99}Tc will be a sensitive parameter*.

The text should indicate whether this expectation was tested and, if so, where the results are reported.

Section 3.3, page 20. The intent of the dashed lines in Figure 4 should be defined.

Section 3.4, page 20. The introductory paragraph in this section states:

> *As noted in Section 2.1, there are other potential contaminants in the SRS DU, including decay, activation and fission products (see Table 3). Given the only source of data for these radionuclides in SRS-2002, the concentrations are very*

low, and are unlikely to significantly contribute to the PA, however, input distributions for the mean concentrations of each of these radionuclides are developed and included in the PA to confirm that this is the case.

To test the supposition that the contaminant radionuclides are unlikely to significantly contribute to PA, one might suppose that doses were assessed with and without these contaminants. The text does not indicate whether such a comparison was made. The document should state how the PA confirmed that the contaminants did not contribute significantly to the PA.

Section 3.5, page 21. It is stated here:

The exact nature of the DU oxides that will be generated by the deconversion plants at Portsmouth and Paducah will not be known until their production, so this PA relies on the best information available to develop estimates. What is known is that the oxides will be primarily U_3O_8, and that they will be shipped and disposed in used DUF_6 cylinders, some of which will contain residual contamination from reactor returns.

It is assumed by the Licensee within the PA that the radioactive waste from GDPs will primarily be U_3O_8. However, the exact nature of the oxides produced at the GDPs, as stated, is not known. A number of sources suggest that the deconverted DU material may also contain UO_2. At an NRC Website (NRC 2012), it says, "What will happen to the waste products from the de-conversion process? De-conversion permits the recovery of fluoride compounds . . . as the fluorine is extracted, the uranium is converted to an oxide (either U_3O_8 or UO_2)." Even the PA (2011), on page 21 of Appendix 4, says, "Note that UO_2 . . . may make up a small amount of the GDP DU."

UO_2 formed by some processes is known to be pyrophoric when finely divided. Finely divided uranium oxide materials may be created during processing, or they may form as a result of movement and abrasion during shipping and waste emplacement.

Pyrophoric wastes, of course, may present some hazards. Disposal of pyrophoric wastes, unless they are treated, prepared and packaged to be nonflammable, is forbidden by rule in Utah [R313-15-1009(2)(a)(vii)].

An ORNL document (Thein and Bereolos 2000) says, "UO_2 may even be pyrophoric when the particle size is very fine." A U.S. Air Force translation of Budnikov et al. (1963) says, "Finely dispersed UO_2 has pyrophoric properties, it burns to U_3O_8." Clayton and Aronson (1958) indicate that whether or not UO_2 is pyrophoric depends on the process used in chemically preparing it. Eidson and Beals (2010) state, "Finely divided UO_2 is pyrophoric, oxidizing in air to a variety of oxide phases including U_3O_8 as the most stable phase."

Gupta and Singh (2003) warn, "When dealing with uranium powder or some other powder in a finely divided form, it should be borne in mind that one is handling pyrophoric materials and that it is absolutely necessary to exercise the corresponding control and implement precautions in every stage of production and processing . . ."

Either the Licensee must make provisions for exclusion of UO_2 from the waste, or the PA should justify disposal of waste containing UO_2 at the site. Factors to consider include development of finely divided particles and possible pyrophorism during physical transport by rail or road, placement in an embankment, or geochemical modification subsequent to burial.

Section 3.5.2.3, page 23. Please provide a complete reference for "(personal communication, Tammy Stapleton, April 2011)."

7.0 REVIEW OF APPENDIX 5 – "UNSATURATED ZONE MODELING FOR THE CLIVE PA," MAY 28, 2011

7.1 GENERAL COMMENTS

There are no general comments.

7.2 SPECIFIC COMMENTS

Section 2, page 7. The Final Report (first paragraph, page 55) states that "the waste is more concentrated [when placed lower in the embankment] since it is arranged into a smaller volume, thereby decreasing the duration of breakthrough at the well, and increasing its amplitude." Appendix 5 should provide a schematic similar to Appendix 7, Figure 1, for the saturated zone modeling that shows the different arrangements of the wastes as a function of the three burial depths.

Section 3.1, page 11. The text indicates that the distribution of recharge rates is based on 18 years of historical data. The text should explain the rationale for not adjusting the distribution to include potential climatic changes (wetter) and subsequent impacts to precipitation. Studies at Yucca Mountain have suggested significant climate changes over the next 10,000 years (e.g., BSC 2004).

Section 3.2, page 15. The text at the end of the fourth paragraph states, "Since the upper filter layer is assumed to have been silted up and is therefore ineffective at diverting infiltrating water, it is assigned a lateral flow of 0 cm/yr (0 in/yr)." The document should clarify why, after the upper flow barriers are compromised, water will not collect above the clay liner ("bathtub effect") and provide a driving force to increase the infiltration rates above those predicted by HELP and UNSAT-H.

Section 5.1.5 and 5.1.6, page 27. Please provide additional justification for the modeled post-installation upper and lower radon barriers since the values used are orders of magnitude lower than that indicated as being appropriate in NUREG guidance (see Benson et al., 2011).

Section 8.0, page 30. The document should provide the mass-balance information for both the flow and contaminant transport from the model simulations.

Section 8.3, page 37. The last sentence in the section states, "Numerical testing demonstrated that the geometric zoning produces stable solutions for the top slope and side slope models with the Runge-Kutta method up to flow rates of 5 cm/year." The text should provide a specific reference to where this work is presented.

Section 9.2.1, page 49. The text states, "Air-phase advection is not included in the Clive DU PA Model. It is assumed that the advective flux of gases is negligible compared to the diffusive gas flux." The document should provide additional justification for this statement, since it is a major assumption in predicting radon flux back to the surface. If a total pressure gradient exists in a soil as a result of external forces, such as atmospheric pumping or diurnal temperature changes, gases, especially when considering dispersion, will experience net flow, e.g., from points of higher to lower pressure. Furthermore, it has been shown that relatively small gradients in total pressure can result in advective gas fluxes that are much larger than diffusive gas fluxes (Thorstenson and Pollock 1989; Massmann and Farrier 1992; Weisbrod et al. 2009; Ganot et al. 2012).

8.0 REVIEW OF APPENDIX 6 – "RADIONUCLIDE GEOCHEMICAL MODELING FOR THE CLIVE DU PA," MAY 28, 2011

8.1 GENERAL COMMENTS

Comment 1. Up-to-Date References

Appendix 6 uses data developed for the Yucca Mountain Site Characterization Project's Total System Performance Assessment to define solubilities for several species. The source document is LANL 1997. There are more recent Yucca Mountain studies that should be considered to be sure that the most current sources are considered. This includes "Dissolved Concentration Limits of Radioactive Elements," ANL-WIS-MD-000010, Revision 05, July 2005 (Bechtel SAIC 2005).

Comment 2. Reactions with Water

This appendix does not consider reactions of depleted uranium oxides with water. Please provide justification for not considering reactions of depleted uranium oxides with water. Particularly due to the potential to create flammable, explosive or pressurizing gases, such as hydrogen DUO_3 is an example of depleted uranium oxide that is potentially prone to production of pressurizing gases, even at ambient temperatures. As stated by Thein and Bereolos (2000):

> *There has been a continuing concern that moisture and other volatiles theoretically can produce pressurizing gases during long-term, sealed storage via radiolysis. Reduction of this potential source of pressurization is a primary reason for treating the uranium oxides. Heating uranium oxide will reduce moisture content to less than 0.5 wt % and similarly reduce equivalent quantities of residual species (e.g., hydrates), which might produce pressurizing gases. The 0.5 wt % specification is a generally accepted limit that is reasonable to achieve and for which no negative affects have been identified. Reducing the amount of moisture present also reduces the potential for and rate of container corrosion.*
>
> *Free water is eliminated during heating at temperatures above 100°C (i.e., simple evaporation in a vented vessel). The three principal uranium oxides (UO_2, UO_3, and U_3O_8) all form hydrates. However, UO_2 and U_3O_8 form hydrates only when prepared via a precipitation reaction. On the other hand, UO_3 can form hydrates directly through reaction with H_2O between temperatures of 5 and 75°C (Vdovenko 1960).*

It is not presently known if DUO_2 and DU_3O_8 present in the proposed LLW will be formed during de-conversion at the GDPs via a precipitation reaction and therefore be susceptible to hydrate formation and gas production if buried in containers at Clive. However, it is known that the SRS depleted uranium LLW is in the form of UO_3. It can therefore presumably "form hydrates directly through reaction with H_2O between temperatures of 5 and 75°C (Vdovenko 1960)." Subsurface temperatures at Clive are expected to be between temperatures of 5°C and 75°C. If UO_3 is buried at Clive, it will ultimately be exposed to soil moisture. This could occur in the unsaturated portion of the vadose zone, the saturated portion of the vadose zone (i.e., the capillary fringe, which, in fine-grained materials such as fine silts or clays, may be as high as 5–10 feet above the water table), or the saturated zone (located beneath the water table). During prolonged inundation, as during a large-scale intermontane lake level rise, the porous media surrounding buried UO_3 would ultimately be saturated. This would occur even in the initially unsaturated portion of the vadose zone, which would become saturated over time. Since exposure to moisture leads to hydrate formation, and hydrate formation is associated with production of potentially hazardous gases via radiolysis, it follows that the PA should discuss how this problem can be obviated.

<u>Comment 3. DU Solubility in Water and SRS Waste</u>

The DU oxide DUO_3, under oxidizing conditions, is moderately soluble in water (Weiner 2008). DUO_3 dissolved in groundwater will move offsite given enough time. Complexes of uranium with water and some other minerals such as sulfate and carbonate can also be fairly mobile in groundwater. The Utah limit on uranium in groundwater is 30 ug/L, comparable to about 27 pCi/L. The uranium in a plume that has moved downgradient from the embankment over time will decay to form radon-222 in areas where no cover-system exists to protect the general public or inadvertent intruders from exposure. As such, DUO_3 in general, and SRS waste specifically, does not appear to be suitable for long-term subsurface burial at Clive. The PA should discuss this issue and justify why UO_3 should be allowed to be disposed of at the Clive LLW Disposal Facility.

8.2 SPECIFIC COMMENTS

Section 1.0, Table 3, page 2. The notation "U" should be defined. SC&A presumes it refers to a uniform distribution with the indicated minimum and maximum.

Section 2.0, page 2. Please provide clarification as to whether the fill placed between the waste containers before the cell is closed would be radioactive bulk LLW or non-radioactive earthen material.

Section 4.1.11, page 15. Please provide a reference to the section of the PA that covers transport of technetium in groundwater at the site. Please also provide additional information on the role that waste acceptance criteria may play to exclude sources of DU having elevated concentrations of technetium-99.

Section 5.0, page 17. The first sentence of the last paragraph states, "The potential for colloidal transport of actinides at the Clive facility is not incorporated into the PA model." The text then refers to actinide intrinsic colloids, which comprise one type of colloid. The text should discuss the potential for other types of colloids and colloidal-forming constituents in the waste (e.g., ligands).

Section 5.0, page 18. The last two sentences of the first paragraph state:

> *Retention of colloids is favored at high ionic strength, low pH and in impermeable rock. The high ionic strength conditions in the saturated zone at Clive are counter to conditions considered favorable for colloid transport*.

The text should provide citations for the statement that retention of colloids is favored in high ionic strength solutions.

Section 5.0, page 18. The first sentence in the second paragraph states:

> *In many cases the solubility of radionuclide species used in the transport model was based to some extent on the data provided in the proposed Yucca Mountain Project (LANL 1997) and the Nevada National Security Site (NNSS, formerly the Nevada Test Site) (Sandia 2001) modeling*.

The discussion should also include the solubility and speciation work with radionuclides in high ionic strength brines that has been performed (and is currently ongoing) to support the Waste Isolation Pilot Plant.

9.0 REVIEW OF APPENDIX 7 – "SATURATED ZONE MODELING FOR THE CLIVE DU PA," MAY 28, 2011

9.1 GENERAL COMMENTS

Comment 1. Vertical Hydraulic Conductivity and Gradient

Please provide additional discussion on how vertical components of hydraulic conductivity and vertical gradients are considered in the PA.

9.2 SPECIFIC COMMENTS

Section 3.1, page 3. Typically, hydraulic conductivity has a log-normal distribution, as opposed to the normal distribution assigned in the model. The applicant should provide the Excel® spreadsheet prepared by R. Sobocinski, the random-effects analysis, and any other information that supports the derivation of normal distribution for the hydraulic conductivity.

Section 3.3, page 4. The applicant should provide any factors taken into consideration when developing the distribution of hydraulic gradients from off-normal conditions (e.g., impacts by increased infiltration due to climatic changes, or gully erosion/plant or animal penetration of the liner).

Section 4.1, page 7. The text in the last paragraph on the page states:

> *An aquifer thickness for each of the four locations was calculated as the difference between the recorded elevation of the water table and the elevation of the bottom of the shallow aquifer. Since the four locations do not quite form a square, triangulation was used to calculate an average thickness across the region*.

The document should explain the rationale for this approach and provide any information that supports the assumption that uniform mixing is likely to occur over the "aquifer thickness" described, i.e., to a depth of 16 or more feet beneath the waste unit. This assumption is important since there is a direct linear relationship between the thickness of the aquifer (vertical extent of plume) and the concentrations arriving at the monitoring well.

Section 4.2, page 11. The text in the second paragraph states, "Only longitudinal dispersion will be considered for this discussion because of the geometry of the transport pathway." The applicant should provide the longitudinal dispersivity value used in the model, as well as any studies (e.g., grid convergence) or calculations that demonstrate the grid spacings are sufficiently small.

The applicant should also provide the mass-balance information for both the flow and contaminant transport from the model simulations.

10.0 REVIEW OF APPENDIX 10 – "EROSION MODELING FOR THE CLIVE PA," MAY 28, 2011

10.1 GENERAL COMMENTS

Comment 1. Below-Grade Disposal

Please provide a discussion of how the performance of the system may change if the top of the cover system was set at or below natural grade, particularly with respect to gulley formation, radon releases, and the ability to meet groundwater GWPL's.

Comment 2. Gully Screening Model

As stated in Section 4.0, "The purpose of the initial gully model in the Clive PA model is to determine whether gullies and fans are significant contributors to dose and whether a more sophisticated erosion model is needed. A simple screening-type gully model was developed with the advice of Dr. Willgoose." Similarly, the Final Report on the Clive DU PA states in Section 4.1.2.9, "The gully model is a simplistic model of gully erosion and landscape evolution. For example, the model assumes that 1) a gully forms instantly and doesn 't change with time, 2) that between 1 and 20 gullies only are allowed to form, and 3) that gullies do not interact with other model processes such as biotic transport (e.g., no plants grow in a gully). This stylized model was used to provide a basis for discussion of whether or not gully formation is an important consideration in this waste disposal system, and to evaluate the consequences of human activities that inadvertently cause doses to future humans." In Section 6.2.1 of the Final Report, it is shown that the presence of gullies increases the peak mean dose to a rancher from 4.37 to 20.9 mrem/y TEDE, and is due to thinning of the cover layers (cap and fill materials) and possible direct exposure of the DU waste. Based on this information, it would appear that gully formation is an important consideration in evaluating the waste disposal system. The report should explain why a more sophisticated erosion model is not needed, including how the assumed 1 to 20 gullies can be reconciled with the actual number of gullies expected to form during a minimum of 10,000 years. If a more sophisticated erosion model is developed, the report needs to describe the new model, including how it will be implemented in the PA and its effect on the peak mean dose to a rancher or other relevant scenarios.

10.2 SPECIFIC COMMENTS

Section 4, page 5. The text in the first bullet states, "Gullies are assumed to form instantaneously, from the time of loss of institutional control." In Section 5.1.2 of the Final Report (page 43), the text indicates that the institutional control period of 100 years is assumed for the dose calculations. The document should indicate when gullies are instantaneously formed for the PA.

Section 4, page 5. Please provide additional rationale for excluding potentially important biological processes in considering gully formation. For instance, burrowing of animals within gullies since presumably the gullys could be penetrated more readily in areas of rip rap erosion.

Section 6.2, page 17. The second sentence in the first paragraph states, "In the current Clive PA model, waste is buried only under the top slope, so the quantity of concern is the distance from the ridge that the gully gets into the waste." The text should clarify whether this is the case for all three burial scenarios.

11.0 REVIEW OF APPENDIX 11 – "DOSE ASSESSMENT FOR THE CLIVE DU PA," MAY 28, 2011

11.1 GENERAL COMMENTS

There were no general comments.

11.2 SPECIFIC COMMENTS

Section 3.1, page 10. To be consistent with other sections of the PA, "2.5 million years" should be changed to "2.1 million years."

Section 3.1, page 11. The document should provide a basis for the statement that "the assumption that future land use and receptors will be similar to today's is likely conservative (i.e., protective)."

Section 3.2, pages 12 and 13. The text states that "screening-level" calculations will be performed to determine what quantity of plant material and volume of water would need to be consumed to exceed the radiation dose performance objective. Provide a specific cross-reference to the results of these "screening-level" calculations.

Section 3.3.1, page 16; Section 3.3.3, page 18. A *de minimis* dose value is developed based on EPA's *de minimis* risk level and dose equivalence. Given that the Energy Policy Act of 1992 contained provisions revoking the NRC's 1986 and 1990 Below Regulatory Concern Policy Statements, the applicant should provide the justification for proposing a *de minimis* (i.e., below regulatory concern) dose value.

Section 3.4.3, page 22. With regard to the dose conversion factors (DCFs), the text should clarify what is meant by the phrase "proof-of-principle uncertainty distributions."

Section 3.4.5, page 25. With regard to the uranium toxicity analysis, the text should clarify what is meant by the phrase "a proof-of-principle exercise."

Section 3.4.5, page 25. Instead of simply referencing EPA documents, the PA needs to provide a brief description of the Superfund and drinking water uranium RfDs. For example, are the RfDs for soluble or insoluble uranium salts, or both? This appendix states that there is a five-fold difference between the two RfDs; a brief description of why there is this difference would be helpful. Also, what was the basis for assigning a 50/50 probability to each RfD? Why not simply assign 100% probability to the Superfund RfD, since it is the more recent, or 100% probability to the drinking water RfD, since it is the more limiting?

Section 4.5, page 30. The text does not describe how "non-standard" receptors (e.g., teenagers, children, infants, pregnant women, Native Americans) were addressed. The text should address such non-standard receptors or explain why they do not need to be addressed.

12.0 REVIEW OF APPENDIX 12 – "DECISION ANALYSIS METHODOLOGY FOR ASSESSING ALARA COLLECTIVE RADIATION DOSES AND RISKS," MAY 30, 2011

12.1 GENERAL COMMENTS

There are no general comments.

12.2 SPECIFIC COMMENTS

Section 1, page 1. The third and fourth paragraphs refer to the "Exposure and Dose Documentation" white paper. The applicant should clarify which reference is meant; we assume it is the "Dose Assessment for the Clive DU PA" (May 28, 2011) white paper (Appendix 11). Please confirm or clarify.

Section 1, page 1. The fourth paragraph refers to the ALARA regulation as "a second decision rule;" however, a first decision rule has not been identified.

Section 1, page 1; Section 2, page 2. In addition to the DOE and NRC documents listed in Section 1 and ICRP Publication 26 (ICRP 1977) discussed in Section 2, ICRP Publication 101b (ICRP 2006) provides a good description of the ALARA concept, including a history of its evolution. ICRP 101b describes ALARA as an "optimisation" process. It should be ascertained that the information contained in this appendix is consistent with ICRP 2006.

Section 2, page 3. As discussed in Section 3.1, General Comment 1 for the Final Report, the government has indicated that the use of discount factors other than the 3% and 7% may be necessary when intergenerational consequences are involved [see NUREG/BR-0058 (NRC 2004) and OMB Circular A-4 (OMB 2003)]. In addition, NUREG-1757 (NRC 2006) replaces NUREG-1727 (NRC 2000b), as stated in the abstract for NUREG-1757.

13.0 REVIEW OF APPENDIX 15 – SENSITIVITY ANALYSIS METHODS ("MACHINE LEARNING FOR SENSITIVITY ANALYSIS OF PROBABILISTIC ENVIRONMENTAL MODELS," MAY 29, 2011)

13.1 GENERAL COMMENTS

Comment 1. Relevance to PA

The document, *Machine Learning for Sensitivity Analysis of Probabilistic Environmental Models* (May 29, 2011), is a generic presentation describing various approaches to sensitivity analyses. As such, it is not a useful document by itself to support the sensitivity analyses described in Section 6.0 of the Final Report. The sensitivity analysis methods report should be expanded to discuss the sensitivity index and the partial dependence plots for specific parameters modeled in the DU PA.

13.2 SPECIFIC COMMENTS

There are no specific comments.

14.0 REVIEW OF APPENDIX 16 – "MODEL PARAMETERS FOR THE CLIVE DU PA MODEL VERSION 1.0," MAY 28, 2011

14.1 GENERAL COMMENTS

There are no general comments.

14.2 SPECIFIC COMMENTS

Section 3.2, Table 5, page 5. The comment associated with Dose _Simulation _Duration states, "User can set this value, up to 10,000 yr, per UAC R313-28-8." UAC R313-25-8(5)(a) states that "the compliance period shall be a <u>minimum</u> of 10,000 years" (emphasis added), not a <u>maximum</u> of 10,000 years.

15.0 SECTION 4.1, FIGURE 1, PAGE 7. THE TEXT OF FIGURE 1 INDICATES THAT THE BRANCHING FRACTIONS WERE OBTAINED FROM "THE NUCLEAR WALLET CARDS (TULI, 2005)." THE REPORT SHOULD INCLUDE A REFERENCE SECTION, WITH A COMPLETE REFERENCE FOR TULI 2005.APPENDIX 17 – QUALITY ASSURANCE PROJECT PLAN

15.1 GENERAL COMMENTS

Comment 1. Missing Approvals

The signature page of Document No. 06245-001 available on the web is incomplete in that the indicated signatures are not provided and the signature page does not include approval by the State of Utah. The document should indicate that all necessary approvals have been obtained. This comment also applies to Appendices A, B, and C.

Comment 2. Lack of Page Numbers

There no page numbers in the document. Page numbers should be added.

Comment 3. GoldSim Model Calibration

The only GoldSim model calibration appears to be that done to counteract numerical dispersion on air diffusion (Appendix 5, Section 9.4.3). Please provide a discussion of the role that model calibration has taken in substantiating that GoldSim adequately simulates the physical, chemical and biological site processes.

15.2 SPECIFIC COMMENTS

Section 5.0, Table 2. Several scheduled completion dates are listed as TBD. Please indicate when the tasks with TBD dates were completed and that other scheduled tasks with specific completion dates have been completed.

Appendix B. Section 2.6. Please provide the verification and benchmarking exercises that were designed to test the GoldSim abstractions against results obtained from process-level analytical and/or numerical models, including (but not limited to) all of the simulated fate and transport pathways, input/output links to external models (e.g., HELP, atmospheric modeling), probabilistic components and dose assessments.

16.0 REFERENCES

AMEC Earth & Environmental, Inc., 2005. Geotechnical Report, Combined Embankment Study, Envirocare, Clive, Utah. AMEC Job No. 4-817-004769. December 13, 2005.

AMEC Earth & Environmental, Inc., 2011a. Geotechnical Update Report, Class A West Embankment Study, Energy Solutions Clive Facility, Clive, Tooele County, Utah. AMEC Job No. 10-817-05290. February 15, 2011.

AMEC, Earth & Environmental, Inc., 2011b. "Response to Interrogatory CAW R313-25-8(4)-16/1: Seismic Hazard Analysis," Job Number 10-817-05290. October 25, 2011.

AMEC, Earth & Environmental, Inc., 2011c. "Response to Interrogatory CAW R313-25-8(4)-16/2: Seismic Hazard Analysis", EnergySolutions Clive Facility, Class A West Embankment, Clive, Tooele County, Utah. Job Number 10-817-05290. December 23, 2011.

Arthur, W. J. III and Markham, O.D., 1983. "Small mammal soil burrowing as a radionuclide transport vector at a radioactive waste disposal area in southeastern Idaho," Journal of Environmental Quality, v. 12, pp. 117–122.

Arthur, W.J. III, Markham, O.D., Groves, C.R. and Halford, D.K. 1986. "Radiation dose to small mammals inhabiting a solid-radioactive-waste disposal area." Journal of Applied Ecology, v. 23, p. 13-26.

Arthur, W.J. III, Markham, O.D., and Groves, C.R. 1987. "Radionuclide export by deer mice at a solid radioactive waste disposal area in southeastern Idaho," Health Physics, v. 52, pp. 45–53.

Bechtel SAIC 2005. "Dissolved Concentration Limits of Radioactive Elements," ANL-WIS-MD-000010, Revision 05, Bechtel SAIC Company, LLC, for U.S. Department of Energy, July 2005, retrieved September 2013 at http://www.osti.gov/scitech/servlets/purl/883412.

Benson, C.H., Albright, W.H., Fratta, D.O., Tinjum, J.M., Kucukkirca, E., Lee, S.H., Scalia, J., Schlicht, P.D., and Wang, X. 2011. *NUREG/CR-7028, Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment*, Volume 1, Office of Nuclear Regulatory Research, NRC. December 2011.

Black, B.D., Solomon, B.J. and Harty, K.M. 1999. Geology and Geologic Hazards of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah, Utah Geological Survey Special Study 96, retrieved 20 Mar 2012 from http://www.ugs.state.ut.us/geology/online/ss/ss-96.pdf.

BNL 2007. Nuclear Data Sheets, Volume 108, Issue 10, Pages 2173–2318, E. Browne, J.K. Tuli, October 2007, accessed through the National Nuclear Data Center, Brookhaven National Laboratory, September 27, 2013.
http://www.nndc.bnl.gov/chart/decaysearchdirect.jsp?nuc=137CS&unc=nds

Bowerman, A.G. and Redente, E.F., 1998. "Biointrusion of protective barriers at hazardous waste sites," Journal of Environmental Quality, v. 27, pp. 625–632.

Breshears, D.D., Nyhan, J.W. and Davenport, D.W., 2005. "Ecohydrology monitoring and excavation of semiarid landfill covers a decade after installation," Vadose Zone Journal, v.4, pp. 798–810.

Brodeur, J. R., 2006. "Mixed Low-Level Radioactive and Hazardous Waste Disposal Facilities," Energy Sciences and Engineering, Kennewick, Washington.

BSC 2004. *Technical Basis Document No. 1: Climate and Infiltration*. Revision 1. Las Vegas, NV:BSC. http://pbadupws.nrc.gov/docs/ML0413/ML041390007.pdf.

Chimner, R.A., and Cooper, D.J., 2004. "Using stable oxygen isotopes to quantify the water source used for transpiration by native shrubs in the San Luis valley, Colorado, U.S.A.," Plant and Soil, v. 260, p. 225-236.

Cloyton, J.C., and Aronson, S., 1958. "Some preparation methods and physical characteristics of UO_2 powders, Contract AT-11-l-GEN-14, WAPD-178, UC-25: Metallurgy and Ceramics, TID-4500 (14th Ed.).

Connell 2013. "Radon – a brief discussion," Caoimhín P. Connell, Forensic Applications Consulting Technologies, inc., retrieved September 2013 at http://www.forensic-applications.com/radon/radon.html.

Cygan, R.T., Anderson, H.L., Arthur, S.E., Brady, P.V., Jová Colón, C.F., Liang, J.-J., Lindgren, E.R., Siegel, M.D., Teter, D.M., Westrich, H.R., and Zhang, P. 2001. Toward an accurate model of metal sorption in soils. In M.E. Wacks, Ed. Proceedings of the Waste Management Conference, WM'01, p. 43-30.

DOE 2003. *Recycled Uranium, United States Production, Enrichment and Utilization*. DOE/SO-0003. U.S. Department of Energy. May 2003.

Drago, J.A. 1998. "Critical Assessment of Radon Removal Systems for Drinking Water Supplies." American Water Works Association.

Dwyer, S.F., Rager, R.E. and Hopkins, J., 2007. "Cover System Design Guidance and Requirements Document,: LA-UR-06-4715, April 2007, EP2006-0667, Environmental Programs-Environmental Restoration Support Services, Los Alamos National Laboratory, New Mexico, 170 pp. plus appendices.

Eidson, A.F. and Beals, D.M. 2010. *Environmental Forensics: Contaminant Specific Guide*, Radioactive materials, pp. 111–141, in Morrison, R.D. and Murphy, B.L., eds., Academic Press, Elsevier Science, 576 pp.

Energy*Solutions* 2011. "Utah Low-Level Radioactive Waste Disposal License – Condition 35 (RML UT2300249) Compliance Report," Energy*Solutions*, June 1, 2011.

EPA 1999. "Technologies and Costs for the Removal of Radon from Drinking Water," U.S. Environmental Protection Agency, Office of Water, EPA 815-D-99-004. May 1999.

EPRI 1985. "Radionuclide Correlations in Low-Level Radwaste," Electric Power Research Institute NP-4037, June 1985.

FR 2012. Proposed Rules, Docket ID NRC-2011-0012, Federal Register 72997, Vol. 77, No. 236, published Friday, December 7, 2012.

Ganot, Y., Dragila, M.I. and Weisbrod, N., 2012. Impact of thermal convection on air circulation in a mammalian burrow under arid conditions, Journal of Arid Environments, v. 84, p. 51-62.

Gupta, C. and Singh, H. 2003. Uranium Resource Processing: Secondary Resources, Springer, 542 pp.

Hakonson, T. E. 1999. The effects of pocket gopher burrowing on water balance and erosion form landfill covers. J. Environ. Qual. v. 28, p. 659–665.

Hakonson, T.E. 2002. Review of Sandia National Laboratories/New Mexico Evapotranspiration Cap Closure Plans for the Mixed Waste Landfill, Prepared for Citizen Action 2/15/02.

Hakonson, T.E., Martinez, J.L. and White, G.G. 1982. Disturbance of a low-level waste burial site cover by pocket gophers, Health Physics, v. 42, pp. 868–871.

Hampton, N.L. 2006. Biological Data to Support Operable Unit 7-13/14: Modeling of Plant and Animal Intrusion at Buried Waste Sites, INEEL/EXT-01-00273 Revision 1 Project No. 23378, Idaho Cleanup Project, January 2006.

Harr, R.D. and Price, K.R. 1972. Evapotranspiration from a Greasewood-Cheatgrass Community, Water Resources Research, v.8, p. 1199-1203.

ICRP 1977. "Recommendations of the International Commission on Radiological Protection," International Commission on Radiological Protection, Publication 26. Ann. ICRP 1 (3).

ICRP 2006. "The Optimisation of Radiological Protection – Broadening the Process," International Commission on Radiological Protection, Publication 101b. Ann. ICRP 36 (3).

ICRP 2010. "Lung Cancer Risk from Radon and Progeny and Statement on Radon," International Commission on Radiological Protection, Publication 115, Ann. ICRP 40(1).

Kenagy, G.J. 1973. Daily and seasonal patterns of activity and energetics in a heteromyid rodent community, Ecology, v. 54, p. 1201-1219.

Kennecott Utah Copper | Environmental Restoration Group, 2012. South Facilities Groundwater 2011 Remedial Progress Report, April 2012, 136 pp.

Landeen, D.S. and Mitchell, R.M. 1981. Invasion of radioactive waste burial sites by the Great Basin Pocket Mouse (Perognathus parvus), 13 pp., in International symposium on migration in the terrestrial environment of long-lived radionuclides from the nuclear fuel cycle, Knoxville, TN, USA, 27 Jul 1981.

Landeen, D.S. 1994. The influence of small mammal burrowing activity on soil water storage at the Hanford Site, WHC-EP-0730, Westinghouse Hanford Company, Richland, Washington.

LANL 1997. "Summary and Synthesis Report on Radionuclide Retardation for the Yucca Mountain Site Characterization Project," Los Alamos National Laboratory, LA-13262-MS, 1997.

Lee, K.Y., Yoon, Y.Y., Cho, S.Y., Ko, K.S., Yum, B-W, 2012. Determination of radon partitioning between groundwater and atmosphere by liquid scintillation counter, Journal of Radioanalytical and Nuclear Chemistry, v. 294, p. 27-30.

Lenntech (2012) Composition of Seawater. Retrieved October 2012 from http://www.lenntech.com/composition-seawater.htm.

Lindzey, F.G. 1976. Characteristics of the natal den of the badger, Northwest Science, v. 50, p. 178–180.

Link, S.O., Cadwell, L.L., Petersen, K.L., Sackshewsky, M.R., and Landeen, D.S. 1995. Role of Plants and Animals in Isolation Barriers at Hanford, Washington. Battelle.

McKenzie, D.H., Cadwell, L.L., Eberhardt, L.E., Kennedy, W.E.. Jr., Peloquin, R.A. and Simmons, M.A., 1982. Relevance of biotic pathways to the long-term regulation of nuclear waste disposal, NUREG/CR-2675, Pacific Northwest Laboratory, Richland, Washington.

Massmann, J. and D.F. Farrier, 1992. "Effects of atmospheric pressures on gas transport in the vadose zone." *Water Resour. Res.*, 28:777–791.

Maxwell, B., Carroll, M., Waugh, J., Jordan, F. and Glenn, E. 2007. Remediation of soil and ground water using native desert phreatophytes, USA Water Quality Conference, work performed under DOE contract DE-AC01-02GJ79491.

Meinzer, O.E. 1927. Plants as Indicators of Ground Water. U. S. Geological Survey, Water Supply Paper 577, 95 p.

Morris, E.E., W.M. Nutt, and R.A. Wigeland, 2006. "Effect of Reprocessing and Recycling on the Geologic Repository Dose Rate: Status," ANL-AFCI-179, Argonne National Laboratory, September 2006.

Neptune and Company, Inc., 2012. 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, prepared for Energy*Solutions*.

Neptune and Company, Inc., 2011. "Final Report for the Clive DU PA Model version 1.0," Neptune and Company, Inc., June 1, 2011.

Nichols, W. D. 1993. Estimating discharge of shallow groundwater by transpiration from greasewood in the Northern Great Basin, Water Resources Research, v. 29, p. 2771–2778.

NRC 1995. "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy," U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, NUREG-1530, December 1995.

NRC 2000a. "A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities: Recommendations of NRC's Performance Assessment Working Group," U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, NUREG-1573, October 2000.

NRC 2000b. "NMSS Decommissioning Standard Review Plan," U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, NUREG-1727, Appendix D, "ALARA Analyses," September 2000.

NRC 2004. "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, NUREG/BR-0058, Revision 4, September 2004.

NRC 2006. "Consolidated Decommissioning Guidance: Decommissioning Process for Materials Licensees," U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, NUREG-1757, Volume 1, Revision 2, September 2006.

NRC 2011a. "Technical Basis for Proposed Rule to Amend 10 CFR Part 61 to Specify Requirements for the Disposal of Unique Waste Streams, Including Large Quantities of Depleted Uranium," U.S. Nuclear Regulatory Commission, NRC-2011-0012-0002, May 2011.

NRC 2011b. "Technical Analysis Supporting Definition of Period of Performance for Low-Level Waste Disposal," U.S. Nuclear Regulatory Commission, May 3, 2011, ADAMS Accession No. ML111030586.

NRC 2012. "November 2012 Preliminary Rule Language for Proposed Revisions to Low-Level Waste Disposal Requirements (10 CFR Part 61)," U.S. Nuclear Regulatory Commission, NRC-2011-0012, November 2012.

OMB 2003. "Regulatory Analysis," Office of Management and Budget, Circular A-4, September 17, 2003.

O'Neal, G.T., Flinders, J.T. and Clary, W.P. 1987. Behavioral ecology of the Nevada kit fox (Vulpes macrotis nevadensis) on a managed desert rangeland, p. 443–481 in H.H. Genoways, ed., Current Mammalogy, Volume 1. Plenum Press, New York, New York.

Oviatt, C.G., Currey, D.R. and Sack, D. 1992. Radiocarbon chronology of Lake Bonneville, Eastern Great Basin, USA, Palaeogeography, Palaeoclimatology, Palaeoecology v. 99, p.225–241.

Pawel, D.J., R.W. Leggett, K.F. Eckerman, and C.B. Nelson, 2007. "Uncertainties in Cancer Risk Coefficients for Environmental Exposure to Radionuclides: An Uncertainty Analysis for Risk Coefficients Reported in Federal Guidance Report No. 13," U.S. Environmental Protection Agency and Oak Ridge National Laboratory, ORNL/TM-2006/583, January 2007.

Sales, B. 2013. Water surplus in Israel? With desalination, once unthinkable is possible, JTA, May 28, 2013 3:46pm, Retrieved September, 2013 from http://www.jta.org/2013/05/28/news-opinion/israel-middle-east/water-surplus-in-israel-with-desalination-once-unthinkable-is-possible#ixzz2fRo3XR7J

Suter, G.W. 1993. Ecological Risk Assessment, 2nd Edition, CRC Press, Boca Raton, Florida, 655 pp.

Suter, G.W., Luxmoore, R.J., and Smith, E.D. 1993. Compacted soil barriers at abandoned landfill sites are likely to fail in the long term. J. Environ. Qual., v. 22, p. 217-226.

SWCA Environmental Consultants, 2011. Field Sampling of Biotic Turbation of Soils at the Clive Site, Tooele County, Utah, Prepared for Energy*Solutions*, January 2011.

SWCA Environmental Consultants, 2012. Vegetated Cover System for the Energy*Solutions* Clive Site: Literature Review, Evaluation of Existing Data, and Field Studies, Summary Report, Prepared for Energy*Solutions*, August 2012.

Tannerfeldt, M., A. Moehrenschlager, and A. Angerbjörn, 2003. Den ecology of swift, kit and Arctic foxes: a review, in Sovada, M. and Carbyn, L., eds., The swift fox: ecology and conservation of swift foxes in a changing world. Canadian Plains Research Centre, University of Regina, Regina, Saskatoon, p. 167–181.

Thorstenson, D.C. and D.W. Pollock, 1989. "Gas transport in unsaturated porous media: The adequacy of Fick's law." *Rev. Geophys.*, 27:61–78.

USGS, Undated. ShakeMap Scientific Background, retrieved October 2013 from http://earthquake.usgs.gov/earthquakes/shakemap/background.php

UDRC 2012. "Comments on NRC 10 CFR 61 Rulemaking Initiative," Docket ID NRC-2011-012, Utah Division of Radiation Control, July 31, 2012.

UWQB (State of Utah, Division of Water Quality, Utah Water Quality Board), 2009. Ground Water Quality Discharge Permit No. 450005, 23 Dec 2009.

Budnikov, P.P. and Berezhnov, A.S. et al. 1963. Translation of: Objects from uranium dioxide, Foreign Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base CQ, Ohio.

Vdovenko, V. M., 1960. Chemistry of Uranium and Transuranium Elements, trans. from the Russian, AEC-tr-6421, U.S. Atomic Energy Commission, Division of Technical Information, Oak Ridge, Tennessee

Waugh, W.J. and Smith, G.M. 1998. Root intrusion of the Burrell, Pennsylvania, Uranium Mill tailings cover, pp. 89–108, in Proceedings: Long-Term Stewardship Workshop, CONF–980652, U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado (invited paper).

Way, J.G., Auger, P.J., Ortega, I.M. and Strauss, E.G. 2001. Eastern coyote denning behavior in an anthropogenic environment, Northeast Wildlife, v. 56, p. 18-30.

Weiner, E.R. (2008) Applications of Environmental Aquatic Chemistry: A Practical Guide, CRC Press, 456 pp.

Weisbrod, N., Dragila, M. I., Nachshon, U. and M. Pillersdorf, 2009. Falling through the cracks: The role of fractures in Earth-atmosphere gas exchange, Geophys. Res. Lett., 36, L02401, doi:10.1029/2008GL036096.

White, W.N. 1932. A method of estimating groundwater supplies based on discharge by plants and evaporation from soil, U.S. Geol. Surv. Water Supply Pap. 659, 1-105, 1932.

WSDNR 2011. Ecological Integrity Assessments: Inter-Mountain Basins Greasewood Flat, Natural Heritage Program, Washington State Department of Natural Resources, Version: 2.22.201, 11 pp.