OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

2. ☒ Analysis — Check all that apply

Type of Analysis:
- ☐ Engineering
- ☒ Performance Assessment
- ☐ Scientific

Intended Use of Analysis:
- ☐ Input to Calculation
- ☒ Input to another Analysis or Model
- ☐ Input to Technical Document
- ☐ Input to other Technical Products

Describe Use:

The inventory abstraction feeds TSPA-SR. It determines which radionuclides will be modeled in TSPA-SR and provides radionuclide gram inputs for CSNF and co-disposal waste packages for TSPA-SR.

3. ☐ Model — Check all that apply

Type of Model:
- ☐ Conceptual Model
- ☐ Abstraction Model
- ☐ Mathematical Model
- ☐ System Model
- ☐ Process Model

Intended Use of Model:
- ☐ Input to Calculation
- ☐ Input to another Analysis or Model
- ☐ Input to Technical Document
- ☐ Input to other Technical Products

Describe Use:

4. Title:

Inventory Abstraction

5. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-WIS-MD-000006 REV. 00

6. Total Attachments: 1

7. Attachment Numbers - No. of Pages in Each: I(12)

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12. Remarks:

Kathy Economy is technical checker for Sections 1 through 8. Bradford Colton is compliance checker for entire document and technical checker for Attachment I.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD
Complete Only Applicable Items

2. Analysis or Model Title:

Inventory Abstraction

3. Document Identifier (including Rev. No. and Change No., if applicable):

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4. Revision/Change No.	5. Description of Revision/Change
REV 00	Initial Issue

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TABLES

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ACRONYMS AND ABBREVIATIONS

BWR	Boiling Water Reactor
CLST IRSR	Container Life and Source Term Issue Resolution Status Report
CSNF	Commercial Spent Nuclear Fuel
DOE	U.S. Department of Energy
DHLW	Defense High-level Waste
DSNF	Defense Spent Nuclear Fuel
EBS	Engineered Barrier System
EPA	Environmental Protection Agency
FEIS	Final Environmental Impact Statement
IPA	Iterative Performance Assessment
KTI	Key Technical Issue
NAS	National Academy of Sciences
NRC	U.S. Nuclear Regulatory Commission
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description, DOE/RW-0333P
PWR	Pressurized Water Reactor
SNF	Spent Nuclear Fuel
TSPA-FEIS	Total System Performance Assessment for the Final Environmental Impact Statement
TBV	To Be Verified
TDMS	Technical Data Management System
TSPA	Total System Performance Assessment
TSPA-SR	Total System Performance Assessment for the Site Recommendation
TSPA-VA	Total System Performance Assessment for the Viability Assessment

Ac	Actinium
Am	Americium
Ba	Barium
Be	Beryllium
Bi	Bismuth
Bk	Berkelium

ACRONYMS AND ABBREVIATIONS (Continued)

C	Carbon
Ca	Calcium
Ce	Cerium
Cf	Californium
Cm	Curium
Co	Cobalt
Cs	Cesium
Eu	Europium
Fe	Iron
Fr	Francium
Hf	Hafnium
Ho	Holmium
I	Iodine
La	Lanthanum
Lu	Lutetium
Nb	Niobium
Ni	Nickel
Np	Neptunium
Pa	Protactinium
Pb	Lead
Pm	Promethium
Po	Polonium
Pr	Praseodymium
Pu	Plutonium
Ra	Radium
Se	Selenium
Sm	Samarium
Sn	Tin
Sr	Strontium
Ta	Tantalum
Tb	Terbium
Tc	Technetium
Te	Tellurium
Th	Thorium

ACRONYMS AND ABBREVIATIONS (Continued)

Tm	Thulium
U	Uranium
Y	Yttrium
Zn	Zinc
Zr	Zirconium

1. PURPOSE

The purpose of the inventory abstraction as directed by the development plan (CRWMS M&O 1999b) is to:

- Interpret the results of a series of relative dose calculations (CRWMS M&O 1999c, 1999d),
- Recommend, including a basis thereof, a set of radionuclides that should be modeled in the Total System Performance Assessment in Support of the Site Recommendation (TSPA-SR) and the Total System Performance Assessment in Support of the Final Environment Impact Statement (TSPA-FEIS),
- Provide initial radionuclide inventories for the TSPA-SR and TSPA-FEIS models, and
- Answer the U.S. Nuclear Regulatory Commission (NRC)'s *Issue Resolution Status Report Key Technical Issue: Container Life and Source Term* (CLST IRSR) (NRC 1999) key technical issue (KTI): "The rate at which radionuclides in SNF [Spent Nuclear Fuel] are released from the EBS [Engineered Barrier System] through the oxidation and dissolution of spent fuel" (Subissue 3).

The scope of the radionuclide screening analysis encompasses the period from 100 years to 10,000 years after the potential repository at Yucca Mountain is sealed for scenarios involving the breach of a waste package and subsequent degradation of the waste form as required for the TSPA-SR calculations. By extending the time period considered to one million years after repository closure, recommendations are made for the TSPA-FEIS. The waste forms included in the inventory abstraction are Commercial Spent Nuclear Fuel (CSNF), Defense Spent Nuclear Fuel (DSNF), Defense High-Level Waste (DHLW), Naval Spent Nuclear Fuel (SNF), and U.S. Department of Energy (DOE) plutonium waste.

The intended use of this analysis is in TSPA-SR and TSPA-FEIS. Based on the recommendations made here, models for release, transport, and possibly exposure will be developed for the isotopes that would be the highest contributors to the dose given a release to the accessible environment. The inventory abstraction is important in assessing system performance because radionuclide screening determines the scope for several TSPA models, and the abstraction provides input to the TSPA.

2. QUALITY ASSURANCE

The Quality Assurance (QA) program applies to the development of this analysis documentation. The Performance Assessment Operations responsible manager has evaluated the technical document development activity in accordance with QAP-2-0, *Conduct of Activities*. The QAP-2-0 activity evaluation, *Conduct of Performance Assessment* (CRWMS M&O 1999a), has determined that the preparation and review of this technical document is subject to *Quality Assurance Requirements and Description* (QARD) DOE/RW-0333P (DOE 2000) requirements. Preparation of this analysis did not require classification of items in accordance with QAP-2-3, *Classification of Permanent Items* as this activity is not a field activity. Therefore, an evaluation in accordance with NLP-2-0, *Determination of Importance Evaluations* was not required.

3. COMPUTER SOFTWARE AND MODEL USAGE

3.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK

None used.

3.2 COMMERCIALLY AVAILABLE SOFTWARE USED

Microsoft's Excel 97 SR-2, a commercially available standard spreadsheet software package, was used for manipulation of inputs in Attachment I. Excel is an appropriate application because the calculations require only simple mathematical expressions and operations that are standard in Excel to derive the final results.

3.3 MODELS

None used.

4. INPUTS

4.1 DATA AND PARAMETERS

All of the input for this analysis comes from two sources:

- *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c)
- *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Td (CRWMS M&O 1999d) to be used for TSPA-FEIS calculations.

Sections 4.1.1 and 4.1.2, respectively, provide a summary of the information in these two transmittals.

4.1.1 Relative Contribution of Individual Radionuclides to Inhalation and Ingestion Dose – 10,000 Years

In the *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c), the relative importance of individual radionuclides when estimating inhalation and ingestion doses was determined. "Relative importance" as it is used here means the importance of one radionuclide in a dose calculation when compared to another radionuclide. The higher dose contributors have higher relative importance.

The analytical method used to determine the relative importance to the dose involved five steps. First, for the waste form under consideration, the relative dose contribution from an individual radionuclide was calculated by multiplying its inventory abundance (curies in the waste form) by the radionuclide's dose conversion factor. This gives a number that is not significant by itself, but when compared to values derived in the same manner for other radionuclides in the waste form, the radionuclide that is the higher contributor to the dose can be determined. Second, the individual radionuclides were ranked with the highest contributor to the dose given the highest ranking. Third, each relative dose value calculated in the first step was converted to a percent contribution to the dose by summing all of the values calculated in the first step, calling this the total, and dividing each individual value by the total and multiplying by 100. At this point one knows the percent contribution to the total dose for each radionuclide. Fourth, a cumulative sum of the percent dose contributions was calculated for each radionuclide in its ranked order. After step four, when a radionuclide is added to the calculation, the percentage of the dose that is captured in the calculation is known. Finally, the fifth step is to choose radionuclides for the calculation (starting with the highest ranked radionuclide) to assure a reasonable estimate of the dose. For this screening analysis, the goal was to identify the radionuclides that contribute to 95% of the dose.

4.1.1.1 Screening Based on Inventory Abundance

The analytical method described above identifies which radionuclides should be modeled if all of the radionuclides in a waste form are released to the environment in proportion to their inventory abundance. Thus, *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c) examines eight waste forms: an average Pressurized Water Reactor (PWR) SNF assembly, a bounding PWR SNF assembly, an average Boiling Water Reactor (BWR) SNF assembly, a bounding BWR SNF assembly, an average DSNF canister, a bounding DSNF canister, an average DHLW canister, and a bounding DHLW canister.

Sometimes radionuclides are not released in proportion to their inventory abundance. Factors that can affect releases of radionuclides, depending on the scenario being considered, include radionuclide longevity, element solubility, and element transport affinity. Consequently, screening on inventory alone is not bounding. The screening approach used here involves grouping the radionuclides into subsets that have similar characteristics (radionuclide longevity, element solubility, and/or element transport affinity). Radionuclides that may be important given a variety of operative transport mechanisms are identified by grouping the radionuclides into subsets and screening each subset by itself.

4.1.1.2 Screening Based on Radionuclide Longevity

If a radionuclide has a short half-life, it will have a higher activity in the waste form at early times (close to repository closure), but at later times, the radionuclide will have all but disappeared from the waste form. Therefore, it is important to examine the waste forms at a number of times, especially if the phenomenon that ultimately leads to a release occurs at later times. *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c) examines waste forms at 100; 200; 300; 400; 500; 1,000; 2,000; 5,000; and 10,000 years.

4.1.1.3 Screening Based on Element Solubility

If a radionuclide is not soluble in the near-field environment around the waste package, it may not be released to the environment via groundwater transport, even if it is available in high abundance. Therefore, it is important to examine alternative hypotheses about element solubility and determine which radionuclides are the highest contributors to the dose if some of the more abundant radionuclides are not released because of low solubility. *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c) examines one solubility hypothesis: a hypothesis that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble in the near-field environment.

4.1.1.4 Screening Based on Transport Affinity

Transport affinity is used here as a global term that describes a radionuclide's potential for movement from the source to the environment. The movement can be due to a number of mechanisms: matrix diffusion, fracture flow, or colloidal transport. Transport affinity is not a measurable property but a qualitative description of the likelihood of transport. If a group of radionuclides transports via a particular mechanism and that mechanism dominates release, the group of radionuclides will be preferentially released (relative to radionuclides not in the group) to the environment.

The dominant transport mechanism for TSPA will not be known until the analyses supporting development of TSPA-SR transport models are complete. Consequently, all of the transport mechanisms must be considered. The *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c) does this by dividing the radionuclides into three groups: 1) highly sorbing, 2) moderately sorbing, and 3) slightly to non-sorbing. The hypotheses are: 1) highly sorbing radionuclides are most likely to transport via colloid transport, 2) moderately sorbing radionuclides are most likely to transport via fracture flow (they do not necessarily absorb to colloids and are retained by matrix diffusion), and 3) slightly to non-sorbing radionuclides are most likely to transport via advection and and/or diffusion. Each one of the groups of radionuclides was examined individually. In other words, the relative dose contribution from one highly sorbing radionuclide was compared to the relative dose contribution from the other highly sorbing radionuclides. Similarly, moderately sorbing radionuclides were compared one to another and non-sorbing radionuclides were compared one to another. The distribution of radionuclides based on their sorption level is reflected in Tables 3 through 16.

4.1.1.5 Results of Relative Inhalation and Ingestion Dose Calculations; 100 – 10,000 Years

The results reported in the *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb, DTN SN9910T0810599.001 (CRWMS M&O 1999c) are shown in Tables 1 through 16.

Table 1. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Radionuclides are Released in Proportion to Their Inventory Abundance; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	BWR, DHLW	Ingestion	100 – 200 years
Cs-137	DHLW	Ingestion	100 years
Ac-227	DHLW	Inhalation	10,000 years
Pu-238	ALL	Inhalation, ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years
Am-241	ALL	Inhalation, ingestion	100 – 2,000 years
Am-243	PWR	Inhalation, Ingestion	100 – 10,000 years

Table 2. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Radionuclides Are Released in Proportion to Their Inventory Abundance; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	ALL	Inhalation, ingestion	100 – 200 years
Cs-137	DHLW, BWR, DSNF	Ingestion	100 years
Ac-227	DSNF	Inhalation, ingestion	1000 – 10,000 years
Pa-231	DSNF	Ingestion	1,000 – 2,000 years
Th-229	DSNF	Inhalation, ingestion	100 – 10,000 years
U-232	DSNF	Inhalation	100 years
U-233	DSNF	Inhalation, ingestion	100 – 10,000 years
U-234	DSNF	Inhalation	2000 years
Pu-238	ALL	Inhalation, ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years
Am-241	ALL	Inhalation, ingestion	100 – 2,000 years
Am-243	PWR, BWR	Inhalation, ingestion	2,000 – 10,000 years

Table 3. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Radionuclide Release is Mitigated by the Element Solubility Hypothesis[a]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	ALL	Ingestion	100 – 200 years
Cs-137	DHLW	Ingestion	100 years
Pu-238	ALL	Inhalation, ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 - 10,000 years

[a] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 4. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Radionuclide Release is Mitigated by the Element Solubility Hypothesis[a]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	ALL	Ingestion	100 – 200 years
Cs-137	DHLW, BWR, DSNF	Ingestion	100 years
U-232	DSNF	Inhalation	100 – 200 years
U-233	DSNF	Inhalation, ingestion	100 – 10,000 years
U-234	DSNF	Inhalation, ingestion	100 – 10,000 years
Pb-210	DHLW	Ingestion	5,000 - 10,000 years
Pu-238	ALL	Inhalation, ingestion	100 – 1,000 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years

[a] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 5. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Highly Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	ALL	Inhalation	100 – 200 years
Cs-137	DHLW	Inhalation	100 years
Pu-238	ALL	Inhalation, ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years

[a] Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 6. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Highly Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	ALL	Ingestion	100 – 200 years
Cs-137	DHLW, BWR, DSNF	Ingestion	100 years
Pu-238	ALL	Inhalation, Ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years

(a) Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
(b) The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 7. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Moderately Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Ni-63	PWR, BWR	Ingestion	100 years
U-232	DSNF	Inhalation, ingestion	10,000 years
U-233	DHLW, DSNF	Inhalation, ingestion	100 – 5,000 years
U-234	ALL	Inhalation, ingestion	100 – 10,000 years
U-236	PWR, BWR	Inhalation, ingestion	100 – 10,000 years
Np-237	ALL	Inhalation, ingestion	100 – 10,000 years
U-238	ALL	Inhalation, ingestion	100 – 10,000 years

(a) Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
(b) The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 8. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Moderately Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Ni-63	PWR, BWR	Ingestion	100 – 200 years
U-232	PWR, DSNF	Inhalation	100 years
U-233	DSNF	Inhalation, ingestion	100 – 10,000 years
U-234	ALL	Inhalation, ingestion	100 – 10,000 years
U-236	PWR, BWR	Inhalation, ingestion	100 – 10,000 years
Np-237	DHLW, BWR, DSNF	Inhalation, ingestion	100 – 10,000 years
U-238	BWR, PWR	Inhalation, ingestion	100 – 10,000 years

(a) Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
(b) The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 9. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Slightly to Non-sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
C-14	DSNF, BWR	Ingestion	100 – 5,000 years
Tc-99	ALL	Inhalation, ingestion	100 – 10,000 years
I-129	ALL	Inhalation, ingestion	100 – 10,000 years

[a] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 10. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Slightly to Non-sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
C-14	DSNF, BWR	Inhalation, ingestion	100 – 10,000 years
Tc-99	ALL	Inhalation, ingestion	100 – 10,000 years
I-129	PWR, BWR, DSNF	Inhalation, ingestion	100 – 10,000 years

[a] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 11. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Highly Sorbing Transport Group[a] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	BWR, DHLW	Ingestion	100 – 200 years
Cs-137	DHLW	Ingestion	100 years
Pu-238	ALL	Inhalation, ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years
Am-241	ALL	Inhalation, ingestion	100- 5,000 years

[a] Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 12. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Highly Sorbing Transport Group[(a)] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[(b)]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Sr-90	All	Ingestion	100 – 200 years
Cs-137	DHLW, DSNF, BWR	Ingestion	100 years
Th-229	DSNF	Inhalation, ingestion	1,000 – 10,000 years
Ac-227	DSNF	Inhalation, ingestion	1,000 – 10,000 years
Pu-238	ALL	Inhalation, ingestion	100 – 500 years
Pu-239	ALL	Inhalation, ingestion	100 – 10,000 years
Pu-240	ALL	Inhalation, ingestion	100 – 10,000 years
Am-241	ALL	Inhalation, ingestion	100 – 5,000 years
Am-243	PWR, BWR	Inhalation, ingestion	2,000 – 10,000 years

(a) Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
(b) The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 13. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Moderately Sorbing Transport Group[(a)] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[(b)]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Ni-63	PWR, BWR	Ingestion	100 years
Np-237	ALL	Inhalation, ingestion	100 – 10,000 years
U-232	DSNF, DHLW	Inhalation, ingestion	10,000 years
U-233	DSNF, DHLW	Inhalation, ingestion	100 –5,000 years
U-234	ALL	Inhalation, ingestion	100 –10,000 years
U-236	PWR,BWR, DHLW	Inhalation, ingestion	100 –10,000 years
U-238	ALL	Inhalation, ingestion	100 –10,000 years

(a) Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
(b) The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 14. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Moderately Sorbing Transport Group[a] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Ni-63	PWR, BWR	Ingestion	100 – 200 years
Np-237	DHLW, DSNF, BWR	Inhalation, Ingestion	100 – 10,000 years
U-232	PWR, DSNF	Ingestion	100 years
U-233	DSNF	Inhalation, Ingestion	100 - 10,000 years
U-234	ALL	Inhalation, ingestion	100 –10,000 years
U-236	PWR,BWR	Inhalation, ingestion	100 –10,000 years
U-238	BWR, PWR	Inhalation, ingestion	100 –10,000 years

[a] Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 15. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Slightly to Non-sorbing Transport Group[a] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
C-14	DSNF, BWR	Ingestion	100 – 5,000 years
Tc-99	ALL	Inhalation, ingestion	100 – 10,000 years
I-129	ALL	Ingestion	100 –10,000 years

[a] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 16. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Slightly to Non-sorbing Transport Group[a] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 100 to 10,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
C-14	BWR, DSNF	Ingestion	100 – 10,000 years
Tc-99	ALL	Inhalation, ingestion	100 – 10,000 years
I-129	PWR,DSNF,BWR	Inhalation, ingestion	100 –10,000 years

[a] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

4.1.2 Relative Contribution of Individual Radionuclides to Inhalation and Ingestion Dose – One Million Years

Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR), R&E-PA-99217.Td (CRWMS M&O 1999d), is identical to *Input Transmittal for Status of the Radionuclide Screening for the Total Systems Performance Assessment - Site Recommendation (TSPA-SR)*, R&E-PA-99217.Tb (CRWMS M&O 1999c) in every respect except that the assumptions have been extended to include the times that are required for the Total System Performance Assessment (TSPA) calculations in support of the Final Environmental Impact Statement (FEIS). The times considered are 20,000; 30,000; 100,000; 300,000; and 1,000,000 years after repository closure.

4.1.2.1 Results of Relative Inhalation and Ingestion Dose Calculations; 100 – 1,000,000 Years

The results reported in CRWMS M&O 1999d, are shown in Tables 17 through 32 (DTN SN9912T0810599.003). This is the input for the radionuclide screening analysis for the TSPA calculations in support of the FEIS.

Table 17. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Radionuclides are Released in Proportion to Their Inventory Abundance; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Ingestion	30,000 – 1,000,000 years
Ra-226	ALL	Ingestion	100,000 – 1,000,000 years
Ac-227	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Th-229	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Th-230	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pa-231	ALL	Inhalation, ingestion	300,000 – 1,000,000 years
U-233	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
U-236	BWR, DSNF, DHLW	Inhalation, ingestion	100,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 100,000 years
Pu-240	ALL	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	BWR, DSNF, PWR	Inhalation, ingestion	30,000 – 1,000,000 years

Table 18. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Radionuclides are Released in Proportion to Their Inventory Abundance; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Ingestion	20,000 – 1,000,000 years
Ra-226	ALL	Ingestion	100,000 – 1,000,000 years
Ac-227	BWR, DSNF, PWR	Inhalation, ingestion	30,000 – 1,000,000 years
Th-229	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Th-230	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Th-232	DSNF	Inhalation	1,000,000 years
Pa-231	DSNF	Ingestion	1,000,000 years
U-233	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-234	BWR, DHLW, PWR	Inhalation, ingestion	30,000 – 1,000,000 years
Np-237	BWR, DSNF, DHLW	Inhalation, ingestion	100,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 100,000 years
Pu-240	BWR, DHLW, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
Pu-242	BWR, PWR	Inhalation, ingestion	30,000 – 1,000,000 years
Am-243	BWR, PWR	Inhalation, ingestion	20,000 – 30,000 years

Table 19. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Radionuclide Release is Mitigated by the Element Solubility Hypothesis[(a)]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Ra-226	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
U-233	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
U-235	DSNF	Inhalation	20,000 – 1,000,000 years
U-236	ALL	Inhalation	30,000 – 1,000,000 years
U-238	ALL	Inhalation	100,000 – 1,000,000 years
Np-237	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 300,000 years
Pu-240	ALL	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	BWR, DSNF, PWR	Inhalation, ingestion	100,000 – 1,000,000 years

(a) The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 20. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Radionuclide Release Mitigated by the Element Solubility Hypothesis[a]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Ra-226	ALL	Ingestion	20,000 – 1,000,000 years
U-233	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-236	BWR, DSNF, PWR	Inhalation, ingestion	300,000 – 1,000,000 years
U-238	PWR, DHLW	Inhalation	300,000 – 1,000,000 years
Np-237	BWR, DSNF, DHLW	Inhalation, ingestion	100,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 100,000 years
Pu-240	ALL	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	BWR, DHLW, PWR	Inhalation, ingestion	30,000 – 1,000,000 years

[a] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 21. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Highly Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Ra-226	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pa-231	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pu-240	ALL	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	ALL	Inhalation, ingestion	20,000 – 300,000 years

[a] Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 22. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Highly Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Ra-226	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 300,000 years
Pu-240	ALL	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	ALL	Inhalation, ingestion	100,000 – 1,000,000 years

[a] Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 23. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Moderately Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
U-233	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-236	BWR, DSNF, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
U-238	BWR, DSNF, DHLW	Inhalation, ingestion	20,000 – 1,000,000 years
Np-237	ALL	Inhalation, ingestion	20,000 – 1,000,000 years

[a] Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 24. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Moderately Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
U-233	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-236	BWR, DSNF, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
U-238	DHLW, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
Np-237	BWR, DSNF, DHLW	Inhalation, ingestion	20,000 – 1,000,000 years

[a] Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 25. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Slightly to Non-Sorbing Transport Group[a] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Tc-99	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
I-129	ALL	Inhalation, ingestion	20,000 – 1,000,000 years

[a] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 26. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Slightly to Non-Sorbing Transport Group[(a)] is Released and Radionuclide Release is Mitigated by the Element Solubility Hypothesis[(b)]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Tc-99	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
I-129	ALL	Inhalation, ingestion	20,000 – 1,000,000 years

[(a)] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[(b)] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 27. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Highly Sorbing Transport Group[(a)] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[(b)]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Ra-226	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Ac-227	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Th-229	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Th-230	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pa-231	DSNF, PWR	Inhalation, ingestion	300,000 – 1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Pu-240	ALL	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	BWR, PWR	Inhalation, ingestion	100,000 – 1,000,000 years

[(a)] Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.
[(b)] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 28. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Highly Sorbing Transport Group[(a)] is Transported and Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[(b)]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Pb-210	ALL	Ingestion	100,000 – 1,000,000 years
Ra-226	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Th-229	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
Th-230	ALL	Inhalation, ingestion	100,000 – 1,000,000 years
Pa-231	DSNF	Ingestion	1,000,000 years
Pu-239	ALL	Inhalation, ingestion	20,000 – 100,000 years
Pu-240	BWR, DHLW, PWR	Inhalation, ingestion	20,000 – 30,000 years
Pu-242	BWR, PWR	Inhalation, ingestion	10,000 – 1,000,000 years
Am-243	BWR, DSNF, PWR	Inhalation, ingestion	20,000 – 1,000,000 years

[(a)] Ca, Co, Sr, Ac, Am, Be, Bi, Ce, Cm, Cs, Fe, Hf, Ho, Nb, Pa, Pb, Po, Pu, Ra, Sm, Sn, Ta, Te, Th, Y, Zn, Zr, Ba, Eu, Bk, Cf, Fr, La, Lu, Nd, Pm, Pr, Tb, and Tm are the highly sorbing elements.

[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 29. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Moderately Sorbing Transport Group[a] is Transported And Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
U-233	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-236	BWR, DSNF, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
U-238	BWR, DSNF, DHLW	Inhalation, ingestion	20,000 – 1,000,000 years
Np-237	ALL	Inhalation, ingestion	20,000 – 1,000,000 years

[a] Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 30. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Moderately Sorbing Transport Group[a] is Transported And Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
U-233	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-234	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
U-236	BWR, DSNF, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
U-238	DHLW, PWR	Inhalation, ingestion	20,000 – 1,000,000 years
Np-237	BWR, DSNF, DHLW	Inhalation, ingestion	20,000 – 1,000,000 years

[a]Ni, Np, Ag, Cd, K, Mn, Pd, Rb, Ru, Sb, U, and Se are the moderately sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 31. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Average Waste Forms When Only the Slightly to Non-sorbing Transport Group[a] is Transported And Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[b]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Tc-99	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
I-129	ALL	Inhalation, ingestion	20,000 – 1,000,000 years

[a] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[b] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

Table 32. Radionuclides Required to Account for Ninety-five Percent of the Inhalation and Ingestion Dose for Bounding Waste Forms When Only the Slightly to Non-sorbing Transport Group[(a)] is Transported And Radionuclide Release is Not Mitigated by the Element Solubility Hypothesis[(b)]; 20,000 to 1,000,000 Years

Radionuclides Required to Account for 95% of the Dose	Applicable to the Following Waste Forms	Applicable to the Following Exposure Pathways	Applicable to the Following Time Periods After Repository Closure
Tc-99	ALL	Inhalation, ingestion	20,000 – 1,000,000 years
I-129	BWR, DSNF, PWR	Inhalation, ingestion	20,000 – 1,000,000 years

[(a)] C, H, I, Mo, P, Re, Tc, Br, Si, Cl, V, Ar, At, Kr, and S are the slightly to non-sorbing elements.
[(b)] The element solubility hypothesis is that Am, Cm, Zr, Th, Nb, Pa, and Sn are not soluble.

4.2 CRITERIA

There are no specific criteria identified in the project requirements documents (i.e., System Description Documents). Programmatic requirements for this document are listed in the development plan (CRWMS M&O 1999b) which specifies that all analyses described herein must address applicable NRC issue resolution status report (IRSR) criteria (NRC 1999). The NRC criteria are specified in the CLST IRSR Subissue 3: "The rate at which radionuclides in SNF [Spent Nuclear Fuel] are released from the EBS [Engineered Barrier System] through the oxidation and dissolution of spent fuel." The following is a summary of the NRC review and acceptance criteria outlined in the CLST IRSR that are relevant to analyses for Subissue 3 and this analysis in particular (NRC 1999).

4.2.1 Acceptance Criteria Applicable to All Six Subissues from the CLST IRSR

- The collection and documentation of data, as well as development and documentation of analyses, methods, models, and codes, shall be accomplished under approved quality assurance and control procedures and standards.

- The structure and organization of process and abstracted models shall be found to adequately incorporate either important design features, physical phenomena, and/or coupled processes.

4.2.2 Acceptance Criteria for Subissue 3 from the CLST IRSR

- All categories of SNF planned for disposal at the proposed YM repository shall be considered.

- The selection of radionuclides tracked in the release models from SNF and their related release parameters shall be adequately justified.

4.3 CODES AND STANDARDS

There are no codes and standards associated with this analysis. The output from this analysis will be used in the TSPA-SR, which will be compared, according to the DOE interim guidance

(Dyer 1999), to specific Subparts/Sections of the proposed NRC high-level waste regulation, 10 CFR Part 63 (64 FR 8640). The DOE interim guidance directs the use of specific Subparts/Sections of the proposed NRC high-level waste regulation, 10 CFR Part 63 (64 FR 8640). The subpart of the proposed regulation that is relevant to the TSPA-SR use of this analysis is Subpart E, Section 114 (Requirements for Performance Assessment).

5. ASSUMPTIONS

The following assumptions produce bounding results. Bounding in this context means that the subset of radionuclides recommended for modeling in TSPA-SR is larger than it would be if more limiting assumptions were made. The assumptions produce bounding results such that further confirmation is not needed.

5.1 The time at which an exposure may occur is unknown. A direct release to the environment due to volcanic or tectonic activity is equally likely at 100 years as it is at 10,000 years. Work is ongoing to determine probable failure times for waste packages. However, uncertainty about waste package failure time remains and is currently only bounded by the time of repository closure and 10,000 years (the regulatory time period in the proposed regulation 10 CFR Part 63 [64 FR 8640]). Consequently, a bounding analysis would address the possibility that waste packages could fail as soon as the repository is closed. This premise is used in Sections 6.3, 6.4, and 6.5 where the relative dose contribution from each radionuclide is examined at early times and at later times up to 10,000 years.

5.2 All waste forms disposed in the repository could contribute to the dose. Current thinking in performance assessment is that several modeling scenarios will lead to failure of only a few (probably less than 10) waste packages prior to 10,000 years. This means that obscure waste forms, even though they may not be prevalent in the repository, could contribute to the dose. This premise is used in Sections 6.3, 6.4, and 6.5 where the relative dose contribution from individual PWR, BWR, and DSNF packages is examined.

5.3 Inhalation and ingestion exposure pathways could contribute to the dose. At present, the scenarios and supporting data for the TSPA-SR are not completely defined. Without that information, it is not possible to determine which exposure pathway will dominate the dose. In particular, for a direct release under volcanic conditions, inhalation may dominate the dose. On the other hand, when radionuclides migrate from an undisturbed repository to a groundwater source, ingestion may dominate the dose. This premise is used in Sections 6.3, 6.4, and 6.5 where the relative dose-contributions for both inhalation and ingestion doses are examined.

5.4 Even radionuclides that are traditionally treated as insoluble could find a migration pathway to the accessible environment. Justification for this supposition lies in the fact that the chemical environment surrounding the waste form is highly uncertain. There is a probability that under atypical conditions low pH waters could be produced around the waste form. Elements that would normally be considered insoluble can dissolve in low pH waters. In addition, even if an element is insoluble, it can be bound up in waste form colloids and then become a transportable entity. This premise is used in Sections 6.4 and 6.5.

5.5 The dominant groundwater transport mechanism for radionuclide movements is unknown. At present, the balance between matrix diffusion, fracture flow, and colloidal transport is unknown. Without that information, it is not possible to determine which transport pathway will dominate the release of radionuclides. Therefore, as a bounding approach, the primary radionuclides that transport via each of the pathways are determined to assure that an adequate dose will be calculated in TSPA. This premise is used in Sections 6.4 and 6.5 where the primary dose contributors from each of three distinct transport groups, highly sorbing, moderately sorbing, and slightly to non-sorbing, are examined.

Given the assumptions listed above, all radionuclides that could significantly contribute to the dose will be modeled in TSPA-SR. The assumptions listed below determine which radionuclides do not need to be modeled in TSPA-SR because they will not contribute significantly to the dose. The following assumptions are bounding to the degree that further confirmation is not necessary.

5.6 Any radionuclide with a half-life less than twenty years will not contribute significantly to the dose for post-closure scenarios. Since this is a post-closure screening analysis, radionuclides with half-lives less than twenty years will have decayed significantly (less than 3 percent remaining by 100 years) by the time the repository closes. This premise is used in Sections 6.3, 6.4, and 6.5.

5.7 A dose cut-off of ninety-five percent is adequate for the TSPA-SR. Radionuclide screening means that only a subset of the full inventory of radionuclides will be modeled in TSPA-SR and, inherently a cut-off value must be chosen. This cut-off value was chosen because the resultant uncertainties introduced by using the 95% cut-off limit are negligible compared to the overall uncertainties incorporated in the TSPA-SR model. The 95% cut-off value is used in Sections 6.3, 6.4, and 6.5.

All of the preceding assumptions outlined for the TSPA-SR also apply to the analysis for the TSPA-FEIS except that the time period defined for the FEIS is extended to one million years.

6. RADIONUCLIDE SCREENING ANALYSIS AND INVENTORY ABSTRACTION

6.1 REGULATORY FRAMEWORK

The Nuclear Waste Policy Act of 1982 directed the NRC to develop technical criteria for DHLW disposal in mined geologic repositories. The NRC was directed in part to develop disposal criteria that are consistent with environmental standards promulgated by the U.S. Environmental Protection Agency (EPA) pursuant to the Nuclear Waste Policy Act of 1982. To meet this obligation, the NRC promulgated technical criteria in 10 CFR 60 (in 1983) on the assumption that the EPA would issue standards limiting cumulative radionuclide releases from a geologic repository in 40 CFR 191. Thus, 10 CFR 60, the governing NRC regulation for the proposed Yucca Mountain repository from 1983 to 1998, became a generic standard intended to be consistent with standards established two years later (in 1985) by the EPA in 40 CFR 191.

Two years after 10 CFR 60 was published, the EPA issued final standards in 40 CFR Part 191, which not only contained cumulative release limits but also provided criteria for individual and ground-water protection that had not been included in the EPA's rulemaking proposal. Further, in 1992, Congress directed the EPA to contract with the National Academy of Sciences (NAS) to advise EPA on the appropriate technical basis for public health and safety standards governing the proposed Yucca Mountain repository. In its final report, NAS recommended an approach and content that is significantly different from that adopted by EPA for its disposal standards in 40 CFR 191, as well as from those adopted by NRC for its existing generic regulations in 10 CFR 60.

As a result, the NRC is proposing new licensing criteria for disposal of spent nuclear fuel and high-level radioactive wastes in the proposed geologic repository at Yucca Mountain, Nevada (64 FR 8640). The licensing criteria will address the performance of the proposed repository system at Yucca Mountain over a 10,000-year regulatory period. Having considered both technical and policy concerns, the NRC decided that a 10,000-year period should be used to evaluate compliance with the system performance. In addition, the performance requirements proposed by the NRC are designed to implement a health-based, safety objective for long-term repository performance that is fully protective of the public health and safety, and the environment, and is consistent with national and international recommendations for radiation protection standards.

The importance of this regulatory evolution for radionuclide screening is two-fold. First, performance assessment calculations for the Site Recommendation will encompass a time frame of 10,000 years. Second, there has been a shift from regulation based on radionuclide release limits to regulation based on radiation dose. Radionuclide screening for the last three performance assessments has been based in large part on the release limits set in 40 CFR 191 and has considered times up to a million years. Now, radionuclide screening for TSPA-SR must focus on the contribution that each radionuclide makes to the radiation dose within a 10,000-year time frame.

6.2 PREVIOUS RADIONUCLIDE SCREENING ACTIVITIES

Radionuclide screening started with the 1993 TSPA (Wilson et. al. 1994) and was carried forward into the 1995 TSPA (CRWMS M&O 1995) and the Total System Performance Assessment in Support of the Viability Assessment (TSPA-VA) (CRWMS M&O 1998). Initially, a radionuclide was selected for the 1993 TSPA (Wilson et al. 1994) if its inventory, normalized to the release limits established by the EPA in 40 CFR 191, contributed at least some fraction of the total potential release over the time period from one thousand years to one million years. This resulted in a total of 86 radionuclides.

A second screening method used a simple spreadsheet release, dilution, and ingestion model to determine the potential contribution of each radionuclide to the individual dose over a time period up to one million years. The fractional contribution of each radionuclide to the total dose was determined. Any radionuclide that contributed less than 0.005 percent to the total dose was not included such that the total contribution to dose from radionuclides that were excluded was 0.01 percent (CRWMS M&O 1995). A total of 37 radionuclides met this criterion (Table 33).

A radionuclide was included in the TSPA-VA (CRWMS M&O 1998) if it had: (1) a high solubility, (2) a low sorption affinity, (3) a significant inventory, (4) a high dose conversion factor, and (5) a long half-life. Based on these five criteria, performance assessment reduced the number of radionuclides considered in the TSPA-VA (CRWMS M&O 1998) to a total of nine as shown in Table 33.

In an activity parallel to the TSPA, the NRC performed (Wescott et. al. 1995) an Iterative Performance Assessment (IPA). For the IPA, the NRC screened radionuclides to include only the major contributors to cumulative release and dose (Table 33). A radionuclide was retained in the IPA inventory if, in preliminary calculations, it contributed more than one percent of the EPA cumulative release limit for that radionuclide from 40 CFR 191. The screening analysis also checked the maximum dose to a farm family, to see if any of the radionuclides that might have been screened out on the basis of cumulative release should have been kept on the basis of dose.

Table 33. Radionuclides Included in Previous TSPAs

Performance Assessment	Radionuclides Included In The Performance Assessment
1993 and 1995 TSPA	C-14, Ni-59, Se-79, Nb-93m, Nb-94, Tc-99, Zr-99, I-129, Cs-135, Pd-107, Sn-126, Sm-151, Pb-210, Ra-226, Ra-228, Ac-227, Th-229, Th-230, Pa-231, Th-232, U-233, U-234, U-235, U-236, Np-237, U-238, Pu-238, Pu-239, Pu-240, Pu-241, Am-241, Am-242m, Pu-242, Am-243, Cm-244, Cm-245, Cm-246
TSPA-VA	C-14, Se-79, Tc-99, I-129, Pa-231, U-234, Np-237, Pu-239, Pu-242
NRC IPA	C-14, Ni-59, Se-79, Nb-94, Tc-99, I-129, Cs-135, Cs-137, Pb-210, Ra-226, Th-230, U-234, Np-237, U-238, Pu-239, Pu-240, Am-241, Am-243, Cm-245, Cm-246

6.3 SCREENING FOR THE DISRUPTIVE EVENTS SCENARIOS

The TSPA-SR will include a direct release via a disruptive event scenario. A direct surface release may occur as a result of an eruptive center (i.e., a volcanic vent) that transports waste to the surface resulting in dispersal of contaminated volcanic ash in the vicinity of the eruption. For this scenario, radionuclide screening can only be based on inventory abundance and radionuclide longevity. Element solubility and transport-affinity are not relevant for a direct release scenario. As a result, the radionuclides listed in Tables 1 and 2 (for TSPA-SR) and Tables 17 and 18 (for the FEIS) account for 95 percent of the dose. These are the radionuclides that are prevalent in the inventory over the duration of the calculation, and therefore, they will contribute the most to the dose.

6.4 SCREENING FOR THE NOMINAL RELEASE SCENARIOS

The TSPA-SR will also include a nominal release scenario. The nominal release scenario involves an undisturbed repository. Over time, water seeps into the repository and corrodes the waste package materials until some waste packages fail. At that point water comes in contact with the waste form, and radionuclides released into the water can migrate from the repository to the accessible environment. For nominal release, radionuclide screening must consider inventory abundance, radionuclide longevity, and transport-affinity.

Tables 11 through 16 (for TSPA-SR) and Tables 27 through 32 (for the FEIS) list the isotopes that account for ninety-five percent of the dose if inventory abundance, radionuclide longevity, and transport affinity are the criteria considered for the screening. With the exception of Ni-63, Sr-90, and Cs-137, all of the isotopes listed in Tables 11 through 16 (for TSPA-SR) and Tables 27 through 32 (for the FEIS) should be modeled in the nominal release scenario. Ni-63, Sr-90, and Cs-137 can be eliminated from the TSPA-SR and FEIS analyses in the nominal case because their contribution is limited to 200 years after repository closure. It is believed that given the time required to produce waste package failures and the groundwater travel time, Ni-63, Sr-90, and Cs-137 will decay entirely before they ever reach the accessible environment.

6.5 SCREENING FOR THE HUMAN INTRUSION SCENARIOS

The TSPA-SR will include a human intrusion scenario. The human intrusion scenario involves a drilling event where a waste package is breached and radioactive material is pushed into the saturated zone. Once released to the saturated zone, radionuclides can migrate from the repository to the accessible environment. For this scenario, screening should be based on inventory abundance, radionuclide longevity, and transport affinity.

Tables 11 through 16 (for TSPA-SR) and Tables 27 through 32 (for the FEIS) list the isotopes that account for 95 percent of the dose if inventory abundance, radionuclide longevity, and transport affinity are the criteria considered for the screening. All of the isotopes listed in Tables 11 through 16 (for TSPA-SR) and Tables 27 through 32 (for the FEIS) should be modeled in the human intrusion scenario. Ni-63, Sr-90, and Cs-137 cannot be eliminated from the TSPA-SR analyses for human intrusion because the drilling event accelerates waste package breach, and given uncertainties in groundwater travel time, Ni-63, Sr-90, and Cs-137 may not decay entirely before they reach the accessible environment.

6.6 RADIONUCLIDE INVENTORY IN GRAMS FOR CSNF AND CO-DISPOSAL WASTE PACKAGES FOR TSPA-SR

The radionuclide inventory in grams, shown in Table 34, was developed in Attachment I based on average waste form characteristics and should be used for initial radionuclide inventories in CSNF and co-disposal waste packages for TSPA-SR and TSPA-FEIS. This data has been submitted to the Technical Data Management System (DTN: SN0003T0810599.010).

7. CONCLUSIONS

7.1 RECOMMENDATIONS FOR TSPA-SR

Examining relative inhalation and ingestion doses from 100 to 10,000 years for average and bounding spent nuclear fuel and high-level waste leads to the following conclusions.

For a direct release from a disruptive event scenario, Sr-90, Cs-137, Ac-227, Th-229, Pa-231, U-232, U-233, U-234, Pu-238, Pu-239, Pu-240, Am-241, Am-243 should be modeled in the TSPA-SR. These are the isotopes that contribute most to the dose when release is not mitigated by either solubility or transport.

Nominal release calculations for TSPA-SR should include C-14, Tc-99, I-129, Ac-227, Th-229, U-232, U-233, U-234, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Am-241, Am-243. By modeling the plutonium isotopes (Pu-238, Pu-239, Pu-240), the americium isotopes (Am-241, Am-243), Th-229, and Ac-227, doses that could result from colloidal transport of radioactive material to the biosphere will be adequately represented in the TSPA-SR. By modeling C-14, Tc-99, I-129, the uranium isotopes (U-232, U-233, U-234, U-236, U-238), and Np-237, doses that could result from transport of solutes, either by fracture flow or matrix diffusion, will be adequately represented in the TSPA-SR.

Human intrusion calculations in TSPA-SR should include C-14, Tc-99, I-129, Ac-227, Th-229, U-232, U-233, U-234, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Am-241, Am-243. The justification for this list of radionuclides is the same as that for nominal release discussed above. However, Ni-63, Sr-90 and Cs-137 should be included for the human intrusion scenario because a human intrusion event could occur as early as 100 years.

For the radionuclides identified above for the various scenarios, Table 34 provides initial values, in grams, for each radionuclide based on average waste form characteristics.

7.2 RECOMMENDATIONS FOR TSPA IN SUPPORT OF THE FEIS

All of the recommendations cited in Section 7.1 for the TSPA-SR apply to the TSPA calculations in support of the FEIS. In addition, a few radionuclides should be added to the FEIS analyses because dose estimates out to one million years will be produced. For all scenarios, Pb-210, Ra-226, Th-230, and Pu-242 should be added to the TSPA-SR model, and Pa-231 should be added for human intrusion and nominal release. Initial values for these radionuclides based on average waste form characteristics are provided in Table 34.

Table 34. Average Radionuclide Inventory in Grams in CSNF and Co-disposal Waste Packages for TSPA-SR[(a)]

	Grams in TSPA-SR CSNF Packages	Grams in TSPA-SR Co-disposal Packages	
Isotope		From Spent Fuel	From DHLW glass
Ac-227	3.09E-06	1.05E-04	4.36E-04
Am-241	8.76E+03	7.87E+01	5.43E+01
Am-243	1.29E+03	1.68E+00	1.55E+00
C-14	1.37E+00	6.63E-01	7.11E-03
Cs-137	5.34E+03	5.52E+02	4.04E+02
I-129	1.80E+03	8.08E+01	4.41E+01
Ni-63	5.53E+01	6.48E-01	3.17E-01
Np-237	4.74E+03	4.26E+02	1.78E+02
Pa-231	9.87E-03	3.02E-01	7.44E-01
Pb-210	0.00E+00	1.38E-08	1.31E-07
Pu-238	1.51E+03	8.79E+01	5.69E+01
Pu-239	4.38E+04	2.13E+03	3.52E+03
Pu-240	2.09E+04	4.55E+02	3.39E+02
Pu-242	5.41E+03	1.15E+01	6.25E+00
Ra-226	0.00E+00	2.21E-06	1.52E-05
Ra-228	0.00E+00	6.46E-06	6.51E-06
Sr-90	2.24E+03	3.01E+02	2.67E+02
Tc-99	7.68E+03	4.53E+02	7.01E+02
Th-229	0.00E+00	2.46E-02	3.79E-03
Th-230	1.84E-01	1.75E-02	7.00E-03
Th-232	0.00E+00	1.38E+04	1.59E+04
U-232	1.01E-02	1.37E-01	7.64E-04
U-233	7.00E-02	1.98E+02	1.02E+01
U-234	1.83E+03	2.77E+02	3.39E+01
U-235	6.28E+04	1.74E+04	1.56E+03
U-236	3.92E+04	5.27E+03	3.65E+01
U-238	7.92E+06	4.67E+05	7.86E+05

[(a)] This data has been submitted to the TDMS with the following DTN: SN0003T0810599.010

7.3 DIFFERENCES FROM NRC IPA

The radionuclides recommended for TSPA-SR and TSPA-FEIS differ slightly from those being modeled in the NRC IPA. Namely, the Curium isotopes (Cm-245 and Cm-246), Ni-59, Se-79, Cl-36, and Nb-94 are not included in the list for TSPA-SR or TSPA-FEIS. Differences between the TSPA-SR list and the NRC list can be attributed to:

- Differences in the inventory data used as a basis for the analysis (this analysis used the most recent inventory data available to the Yucca Mountain project).
- Differences in the screening technique; specifically, this analysis looked at three transport groups rather than the inventory of radionuclides as a whole.

7.4 IMPACT OF TBV INPUTS

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the Document Input Reference System database.

While the inputs to this analysis are developed data, To Be Verified (TBV), the analysis itself is by nature generic and does not rely so much on the quantitative values associated with the input but more on the qualitative trends shown in the data. As a result, changes to the inputs will have negligible impact on the conclusions that have been drawn from this analysis.

7.5 UNCERTAINTIES AND RESTRICTIONS FOR SUBSEQUENT USE

The assumptions made in this analysis are considered bounding to the degree that further confirmation is not needed for the set of radionuclides determined in this analysis. The radionuclide inventory values presented in Table 34 will be valid only for the configurations shown in Table I-1.

8. INPUTS AND REFERENCES

8.1 DOCUMENTS CITED

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8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 60. Energy: Disposal of High-Level Radioactive Wastes in Geologic Repositories. Readily Available.

40 CFR 191. Protection of Environment: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes. Readily Available.

64 FR 8640. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada. Proposed rule 10 CFR 63. Readily Available.

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QAP-2-3, Rev 10. *Classification of Permanent Items*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL19990316.0006.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

DTN SN0003T0810599.009. Revised Waste Package Radionuclide Inventory Approximations for TSPA-SR. Submittal date: 03/14/00.

DTN SN9910T0810599.001. Relative Contribution of Individual Radionuclides to Inhalation and Ingestion Dose; Ten Thousand Years. Submittal date: 10/25/99.

DTN SN9912T0810599.003. Relative Contribution of Individual Radionuclides to Inhalation and Ingestion Dose; One Million Years. Submittal date: 12/08/99.

9. ATTACHMENTS

Attachment-Title	Pages
I - Calculation of Radionuclide Inventory in Grams per Waste Package for TSPA-SR	12

ATTACHMENT I: CALCULATION OF RADIONUCLIDE INVENTORY IN GRAMS PER WASTE PACKAGE FOR TSPA-SR

1. PURPOSE

The purpose of this attachment is to develop initial radionuclide inventories for CSNF and co-disposal waste packages that will be used as input to TSPA-SR models.

2. INPUTS

2.1 DATA AND PARAMETERS

This attachment has three sources of input. The first source of input is an interoffice correspondence from E.P. Stroupe to D.R. Wilkins (Stroupe 2000). The second source of input is the input transmittal, *Waste Package Radionuclide Inventory Approximations for TSPA-SR*, 00085.T (CRWMS M&O 2000). The third source of input is the Revised Waste Package Radionuclide Inventory Approximations for TSPA-SR (DTN SN0003T0810599.009). The following is a summary of the information that these sources provide.

2.1.1 Approach to Implementing the Site Recommendation Design Baseline

The interoffice correspondence from E.P. Stroupe to D.R. Wilkins (Stroupe 2000) directs that the attachment included with the correspondence be considered "management edict" as defined in AP-3.15Q, *Managing Technical Product Inputs*. Therefore, the material can be used without an attached TBV. The correspondence specifies the loading configurations and number of CSNF and DSNF waste packages, which are summarized in Table I-1.

2.1.2 Waste Package Radionuclide Inventory Approximations for TSPA-SR

Waste Package Radionuclide Inventory Approximations for TSPA-SR, 00085.T (CRWMS M&O 2000) provides a description of how average radionuclide activities for each of the thirteen waste package configurations listed in Table I-1 were derived. It includes the isotopes that are identified as important for dose calculations in a direct release, human intrusion, and nominal release scenario (identified in Section 7 of this report). While this input transmittal describes how the calculation of average radionuclide activities for the waste package configurations was performed, the data from the transmittal has been superceded by the data that was submitted to the TDMS under DTN SN0003T0810599.009 (Section 2.1.3).

2.1.3 Revised Waste Package Radionuclide Inventory Approximations for TSPA-SR

The average radionuclide activities provided in Revised Waste Package Radionuclide Inventory Approximations for TSPA-SR (DTN SN0003T0810599.009) were used as inputs to the analysis described in this attachment and are shown in Tables I-2, I-3, and I-4.

3. RADIONUCLIDE INVENTORY

A TSPA involves the analysis of engineered and natural systems to determine the potential long-term release of radionuclides from a nuclear waste repository to a location where a regulatory standard is applied. In TSPA, models for the behavior of the waste forms, the waste packages, the near-field environment, the far-field environment, and the biosphere are applied to determine the performance of a proposed repository. One cornerstone of determining repository performance is knowing the chemical and radiological composition of the wastes destined for disposal in the repository. This attachment addresses the radiological composition of the wastes.

Table I-1. Design Basis Waste Package Configurations for TSPA-SR

Configuration Number	Type of Fuel	Description	Number of Waste Packages
Configuration 1	CSNF	Waste package with absorber plates for criticality control that will hold a capacity of 21 PWR assemblies.	4500
Configuration 2	CSNF	Waste packages with control rods for criticality control that will hold a capacity of 21 PWR assemblies.	100
Configuration 3	CSNF	Waste package with absorber plates for criticality control that will hold a capacity of 12 PWR assemblies.	170
Configuration 4	CSNF	Waste package with absorber plates for criticality control that will hold a capacity of 44 BWR assemblies.	3000
Configuration 5	CSNF	Waste package with thick absorber plates for criticality control that will hold a capacity of 24 BWR assemblies.	90
Configuration 6	DSNF/DHLW	Waste package containing five short DHLW glass canisters and one short DSNF canister.	1100
Configuration 7	DSNF/DHLW	Waste package containing 5 long DHLW glass canisters and one long DSNF canister.	1500
Configuration 8	DSNF/DHLW	Waste package containing 5 long DHLW glass canisters and one short DSNF canister.	130
Configuration 9	DHLW	Waste package containing 5 long DHLW glass canisters.	600
Configuration 10	DSNF/DHLW	Waste package containing 2 multi-canister overpacks and 2 long DHLW glass canisters.	160
Configuration 11	Naval Fuel	Waste package containing one short Naval canister.	210
Configuration 12	Naval Fuel	Waste package containing one long Naval canister.	110
Configuration 13	Immobilized Plutonium Waste Form	Waste package containing 5 Immobilized Plutonium Waste Form canisters.	100

Table I-2. Average Radionuclide Activities for CSNF Waste Package Configurations

	Configuration Number				
	1	2	3	4	5
	Average Curies in a Waste Package Configuration				
Ac-227	3.26E-04	2.90E-04	1.92E-04	7.70E-05	1.43E-05
Am-241	3.74E+04	1.66E+04	2.50E+04	2.08E+04	2.03E+03
Am-243	3.23E+02	3.32E+01	2.53E+02	1.73E+02	1.41E+00
C-14	6.05E+00	1.15E+01	4.18E+00	6.25E+00	7.03E-01
Cs-137	5.44E+05	1.52E+05	4.78E+05	3.61E+05	2.64E+04
I-129	3.65E-01	1.44E-01	2.70E-01	2.46E-01	2.88E-02
Ni-63	4.01E+03	3.19E+03	3.08E+03	1.92E+03	4.18E+02
Np-237	4.18E+00	1.55E+00	3.04E+00	2.26E+00	2.16E-01
Pa-231	5.48E-04	4.98E-04	3.74E-04	3.56E-04	1.88E-04
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu-238	3.28E+04	4.68E+03	2.64E+04	1.69E+04	3.34E+02
Pu-239	3.28E+03	2.42E+03	2.34E+03	1.98E+03	6.48E+02
Pu-240	5.44E+03	2.31E+03	4.00E+03	3.94E+03	4.37E+02
Pu-242	2.52E+01	4.56E+00	1.93E+01	1.66E+01	3.31E-01
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	3.59E+05	1.13E+05	3.17E+05	2.42E+05	2.03E+04
Tc-99	1.51E+02	6.72E+01	1.11E+02	1.06E+02	1.45E+01
Th-229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th-230	4.26E-03	5.96E-03	2.34E-03	3.14E-03	2.81E-03
Th-232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	2.90E-01	3.70E-02	2.36E-01	1.32E-01	2.69E-03
U-233	9.01E-04	4.98E-04	5.46E-04	3.72E-04	2.40E-05
U-234	1.32E+01	1.21E+01	9.00E+00	8.98E+00	4.85E+00
U-235	1.56E-01	3.09E-01	1.06E-01	1.00E-01	1.53E-01
U-236	2.96E+00	1.66E+00	2.15E+00	2.01E+00	3.94E-01
U-238	2.84E+00	2.52E+00	2.03E+00	2.49E+00	1.32E+00

Table I-3. Average Radionuclide Activities from DSNF for Co-disposal Waste Package Configurations

	Configuration Number							
	6	7	8	9	10	11	12	13
	Average Curies in a Waste Package Configuration							
Ac-227	1.61E-04	1.96E-02	1.61E-04	N/A	9.55E-05	1.26E-04	1.56E-04	N/A
Am-241	6.08E+01	3.66E+02	6.08E+01	N/A	2.60E+03	4.90E+01	6.73E+01	N/A
Am-243	2.45E-01	4.64E-01	2.45E-01	N/A	3.80E-01	6.19E-01	1.13E+00	N/A
C-14	8.33E-02	1.03E-01	8.33E-02	N/A	3.36E+00	2.71E+01	4.61E+01	N/A
Cs-137	9.27E+03	1.03E+04	9.27E+03	N/A	4.95E+04	4.39E+05	5.45E+05	N/A
I-129	5.00E-03	3.07E-03	5.00E-03	N/A	3.04E-02	1.13E-01	1.40E-01	N/A
Ni-63	5.87E+00	5.38E+01	5.87E+00	N/A	1.51E+01	1.33E+02	2.32E+02	N/A
Np-237	2.37E-02	2.31E-02	2.37E-02	N/A	3.58E-01	2.91E+00	4.03E+00	N/A
Pa-231	3.73E-04	3.67E-02	3.73E-04	N/A	1.28E-04	6.40E-04	7.90E-04	N/A
Pb-210	1.45E-08	2.56E-06	1.45E-08	N/A	6.96E-10	7.57E-07	9.06E-07	N/A
Pu-238	4.72E+01	1.58E+02	4.72E+01	N/A	5.89E+02	1.43E+04	2.27E+04	N/A
Pu-239	8.52E+00	2.14E+02	8.52E+00	N/A	1.14E+03	1.30E+01	1.80E+01	N/A
Pu-240	9.66E+00	1.88E+02	9.66E+00	N/A	6.65E+02	9.94E+00	1.37E+01	N/A
Pu-242	2.30E-02	5.04E-02	2.30E-02	N/A	3.20E-01	5.66E-02	8.97E-02	N/A
Ra-226	4.73E-08	3.29E-06	4.73E-08	N/A	1.06E-05	5.56E-06	6.30E-06	N/A
Ra-228	6.59E-08	4.58E-03	6.59E-08	N/A	9.50E-09	3.30E-07	5.30E-07	N/A
Sr-90	8.44E+03	7.28E+03	8.44E+03	N/A	3.73E+04	4.19E+05	4.19E+05	N/A
Tc-99	2.26E+00	1.32E+00	2.26E+00	N/A	1.39E+01	6.70E+01	8.18E+01	N/A
Th-229	4.94E-08	1.37E-02	4.94E-08	N/A	8.62E-08	6.09E-06	9.89E-06	N/A
Th-230	1.93E-06	5.22E-04	1.93E-06	N/A	9.45E-06	1.89E-03	2.07E-03	N/A
Th-232	9.46E-09	3.97E-03	9.46E-09	N/A	1.12E-09	3.76E-07	6.57E-07	N/A
U-232	3.72E-04	7.78E+00	3.72E-04	N/A	0.00E+00	3.20E-01	4.86E-01	N/A
U-233	1.89E-05	4.98E+00	1.89E-05	N/A	5.29E-05	1.77E-03	2.97E-03	N/A
U-234	1.42E-02	3.67E-01	1.42E-02	N/A	4.49E+00	1.66E+01	1.80E+01	N/A
U-235	1.89E-02	9.29E-03	1.89E-02	N/A	1.71E-01	2.60E-01	2.51E-01	N/A
U-236	3.45E-02	3.45E-02	3.45E-02	N/A	6.50E-01	3.31E+00	4.00E+00	N/A
U-238	8.11E-03	2.55E-02	8.11E-03	N/A	3.53E+00	1.08E-03	1.23E-03	N/A

Table I-4. Average Radionuclide Activities from DHLW for Co-disposal Waste Package Configurations

	Configuration Number							
	6	7	8	9	10	11	12	13
	Average Curies in a Waste Package Configuration							
Ac-227	1.11E-02	4.85E-02	4.85E-02	4.85E-02	1.94E-02	N/A	N/A	1.83E-06
Am-241	2.49E+02	2.46E+01	2.46E+01	2.46E+01	9.84E+00	N/A	N/A	4.00E+03
Am-243	1.02E+00	3.21E-03	3.21E-03	3.21E-03	1.28E-03	N/A	N/A	8.15E-01
C-14	1.13E-01	3.30E-05	3.30E-05	3.30E-05	1.32E-05	N/A	N/A	0.00E+00
Cs-137	8.81E+04	1.34E+04	1.34E+04	1.34E+04	5.34E+03	N/A	N/A	9.15E+04
I-129	4.14E-03	1.11E-02	1.11E-02	1.11E-02	4.42E-03	N/A	N/A	0.00E+00
Ni-63	1.49E+01	2.31E+01	2.31E+01	2.31E+01	9.22E+00	N/A	N/A	1.10E+01
Np-237	3.13E-01	4.90E-02	4.90E-02	4.90E-02	1.96E-02	N/A	N/A	3.41E-01
Pa-231	1.22E-02	5.40E-02	5.40E-02	5.40E-02	2.16E-02	N/A	N/A	5.90E-06
Pb-210	1.28E-06	1.65E-05	1.65E-05	1.65E-05	6.60E-06	N/A	N/A	1.35E-07
Pu-238	3.11E+03	6.65E-01	6.65E-01	6.65E-01	2.66E-01	N/A	N/A	3.84E+03
Pu-239	5.32E+01	1.35E+01	1.35E+01	1.35E+01	5.40E+00	N/A	N/A	7.65E+03
Pu-240	3.03E+01	3.07E+00	3.07E+00	3.07E+00	1.23E+00	N/A	N/A	2.61E+03
Pu-242	4.11E-02	4.00E-04	4.00E-04	4.00E-04	1.60E-04	N/A	N/A	5.00E-01
Ra-226	8.06E-06	2.18E-05	2.18E-05	2.18E-05	8.72E-06	N/A	N/A	5.60E-07
Ra-228	4.10E-03	9.75E-04	9.75E-04	9.75E-04	3.90E-04	N/A	N/A	1.90E-03
Sr-90	9.84E+04	1.08E+04	1.08E+04	1.08E+04	4.32E+03	N/A	N/A	1.03E+05
Tc-99	1.74E+01	1.13E+01	1.13E+01	1.13E+01	4.50E+00	N/A	N/A	1.52E+01
Th-229	2.03E-04	1.29E-03	1.29E-03	1.29E-03	5.14E-04	N/A	N/A	3.80E-08
Th-230	3.99E-04	5.05E-05	5.05E-05	5.05E-05	2.02E-05	N/A	N/A	9.55E-05
Th-232	4.23E-03	8.75E-04	8.75E-04	8.75E-04	3.50E-04	N/A	N/A	2.00E-03
U-232	3.83E-03	2.69E-02	2.69E-02	2.69E-02	1.07E-02	N/A	N/A	0.00E+00
U-233	7.71E-03	1.64E-01	1.64E-01	1.64E-01	6.56E-02	N/A	N/A	3.52E-05
U-234	4.60E-01	1.20E-01	1.20E-01	1.20E-01	4.78E-02	N/A	N/A	4.71E-01
U-235	5.49E-04	5.00E-03	5.00E-03	5.00E-03	2.00E-03	N/A	N/A	1.13E-02
U-236	1.34E-03	3.31E-03	3.31E-03	3.31E-03	1.32E-03	N/A	N/A	1.94E-03
U-238	9.58E-02	3.96E-01	3.96E-01	3.96E-01	1.58E-01	N/A	N/A	2.02E-01

3.1 RADIOACTIVE MATERIALS PROPOSED FOR DISPOSAL IN THE POTENTIAL YUCCA MOUNTAIN REPOSITORY

Radioactive materials that would be placed in a proposed repository at Yucca Mountain are primarily irradiated nuclear fuel elements or solidified waste from reprocessing of irradiated reactor fuel.

Irradiated fuel will come from commercial utilities, either PWR or BWR assemblies, and from the DOE which has commercial fuels and fuels from reactors used in defense-related programs (CRWMS M&O 1998).

DHLW is the result of reprocessing spent nuclear fuel (some CSNF but mostly DSNF). Four DOE sites, the Savannah River Site, Hanford, the Idaho National Engineering and Environment Laboratory, and West Valley report having high-level waste in storage (CRWMS M&O 1998).

Aside from irradiated nuclear fuel and high-level waste, the DOE also has a plutonium surplus that has been proposed for disposal at the Yucca Mountain repository (CRWMS M&O 1998). Some of the plutonium will become PWR mixed-oxide reactor fuel that would be irradiated in commercial reactors. The plutonium that is not converted to mixed-oxide fuel will be immobilized in plutonium-ceramic disks that will be placed in DHLW canisters that are subsequently filled with a DHLW glass.

3.2 RADIOACTIVE ISOTOPES

Radioactive isotopes contained in the materials destined for disposal at Yucca Mountain include fission products from nuclear fission during reactor operations, assorted actinides from neutron capture in uranium and plutonium, light elements, and activation products from neutron irradiation of structural materials and trace elements. The isotopes that were recommended for modeling in TSPA-SR (Section 7 of this report) are: Ac-227, Am-241, Am-243, C-14, Ni-63, Cs-137, I-129, Np-237, Pa-231, Pb-210, Pu-238, Pu-239, Pu-240, Pu-242, Ra-226, Ra-228, Sr-90, Tc-99, Th-229, Th-230, Th-232, U-232, U-233, U-234, U-235, U-236, and U-238.

3.3 WASTE PACKAGES FOR TSPA-SR

The TSPA-SR will model two basic waste packages, a representative waste package for CSNF and a representative waste package for DSNF and DHLW (referred to henceforth as a co-disposal package). All of the waste forms that are counted as part of the CSNF allocation for Yucca Mountain are represented by an average CSNF waste package in TSPA-SR. All of the waste forms that are counted as part of the DOE allocation for Yucca Mountain are represented by an average co-disposal waste package. This includes Naval SNF waste packages which will not contain DHLW and DHLW packages which will not contain SNF. All packages are represented by the average.

3.4 COMMERCIAL SPENT NUCLEAR FUEL WASTE PACKAGES

3.4.1 Number of Waste Packages

The number of CSNF waste packages that should be modeled in TSPA-SR is the sum of the values for Configurations 1 through 5 in Table I-1. The total is 7,860 CSNF waste packages.

3.4.2 Radionuclide Inventories

Table I-5 shows how the radionuclide activities (from Table I-2) for each of the CSNF waste package configurations (Configurations 1 through 5 in Table I-1) were combined to produce the inventory in grams of radionuclides for a CSNF waste package for TSPA-SR. The calculation was performed in an Excel spreadsheet using Equations I-1 and I-2.

$$(a_i)_{\substack{\text{A CSNF Waste}\\ \text{Package for TSPA-SR}}} = \frac{(4500)\bullet(a_i)_1 + (100)\bullet(a_i)_2 + (170)\bullet(a_i)_3 + (3000)\bullet(a_i)_4 + (90)\bullet(a_i)_5}{7860} \quad \text{Eq (I-1)}$$

Where:

$(a_i)_1$ is the activity in curies of isotope "i" in an average CSNF waste package with Configuration 1.
$(a_i)_2$ is the activity in curies of isotope "i" in an average CSNF waste package with Configuration 2.
$(a_i)_3$ is the activity in curies of isotope "i" in an average CSNF waste package with Configuration 3.
$(a_i)_4$ is the activity in curies of isotope "i" in an average CSNF waste package with Configuration 4.
$(a_i)_5$ is the activity in curies of isotope "i" in an CSNF average waste package with Configuration 5.

All activity values are from Table I-2.

$$(m_i)_{\substack{\text{A CSNF Waste}\\ \text{Package for TSPA-SR}}} = \frac{B\bullet MW_i\bullet t_i\bullet(a_i)_{\substack{\text{A CSNF Waste}\\ \text{Package for TSPA-SR}}}}{\ln(2)\bullet N_a} \quad \text{Eq (I-2)}$$

Where:

m_i is the average grams of isotope "i" in an average CSNF waste package for TSPA-SR.
a_i is the average activity in curies of isotope "i" in a CSNF waste package for TSPA-SR (from Equation I-1).
MW_i is the molecular weight in grams per mole of isotope "i" (Walker and Miller 1984).
t_i is the half-life of isotope "i" in seconds (Walker and Miller 1984).
N_a is Avogadro's number, 6.022045E+23 (Walker and Miller 1984).
B is the conversion from curies to decays per second, 3.7E+10 (Walker and Miller 1984).

Table I-5. Calculation of Radionuclide Inventory in Grams in a CSNF Waste Package for TSPA-SR

Configuration	1	2	3	4	5			
	Number of Waste Packages							
	4500	100	170	3000	90			
	Fraction of Waste Packages					Curies per CSNF Waste Package	Specific Activity Ci/gram	Grams per CSNF Waste Package
	0.57	0.01	0.02	0.38	0.01			
Isotope	Weighted Value Of Curies Per Waste Package Configuration							
Ac-227	1.86E-04	3.69E-06	4.15E-06	2.94E-05	1.63E-07	2.24E-04	7.24E+01	3.09E-06
Am-241	2.14E+04	2.11E+02	5.40E+02	7.93E+03	2.33E+01	3.01E+04	3.44E+00	8.76E+03
Am-243	1.85E+02	4.22E-01	5.48E+00	6.62E+01	1.61E-02	2.57E+02	2.00E-01	1.29E+03
C-14	3.46E+00	1.46E-01	9.03E-02	2.38E+00	8.05E-03	6.09E+00	4.46E+00	1.37E+00
Cs-137	3.11E+05	1.94E+03	1.03E+04	1.38E+05	3.02E+02	4.62E+05	8.65E+01	5.34E+03
I-129	2.09E-01	1.83E-03	5.84E-03	9.40E-02	3.30E-04	3.11E-01	1.73E-04	1.80E+03
Ni-63	2.30E+03	4.06E+01	6.67E+01	7.34E+02	4.78E+00	3.14E+03	5.68E+01	5.53E+01
Np-237	2.39E+00	1.97E-02	6.57E-02	8.63E-01	2.48E-03	3.34E+00	7.05E-04	4.74E+03
Pa-231	3.14E-04	6.33E-06	8.10E-06	1.36E-04	2.15E-06	4.66E-04	4.72E-02	9.87E-03
Pb-210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.64E+01	0.00E+00
Pu-238	1.88E+04	5.96E+01	5.71E+02	6.43E+03	3.82E+00	2.58E+04	1.71E+01	1.51E+03
Pu-239	1.88E+03	3.07E+01	5.06E+01	7.56E+02	7.42E+00	2.72E+03	6.21E-02	4.38E+04
Pu-240	3.11E+03	2.94E+01	8.64E+01	1.50E+03	5.00E+00	4.74E+03	2.27E-01	2.09E+04
Pu-242	1.44E+01	5.80E-02	4.18E-01	6.35E+00	3.79E-03	2.13E+01	3.93E-03	5.41E+03
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.89E-01	0.00E+00
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.72E+02	0.00E+00
Sr-90	2.06E+05	1.43E+03	6.85E+03	9.24E+04	2.32E+02	3.06E+05	1.37E+02	2.24E+03
Tc-99	8.66E+01	8.55E-01	2.41E+00	4.03E+01	1.66E-01	1.30E+02	1.70E-02	7.68E+03
Th-229	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E-01	0.00E+00
Th-230	2.44E-03	7.59E-05	5.06E-05	1.20E-03	3.22E-05	3.80E-03	2.06E-02	1.84E-01
Th-232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-07	0.00E+00
U-232	1.66E-01	4.70E-04	5.11E-03	5.04E-02	3.08E-05	2.22E-01	2.20E+01	1.01E-02
U-233	5.16E-04	6.33E-06	1.18E-05	1.42E-04	2.75E-07	6.76E-04	9.66E-03	7.00E-02
U-234	7.56E+00	1.54E-01	1.95E-01	3.43E+00	5.55E-02	1.14E+01	6.24E-03	1.83E+03
U-235	8.95E-02	3.93E-03	2.30E-03	3.83E-02	1.75E-03	1.36E-01	2.16E-06	6.28E+04
U-236	1.70E+00	2.11E-02	4.65E-02	7.67E-01	4.51E-03	2.53E+00	6.47E-05	3.92E+04
U-238	1.62E+00	3.21E-02	4.39E-02	9.49E-01	1.51E-02	2.66E+00	3.36E-07	7.92E+06

3.5 CO-DISPOSAL WASTE PACKAGES

3.5.1 Number of Waste Packages

The number of co-disposal waste packages that should be modeled in TSPA-SR is the sum of the values for Configurations 6 through 13 in Table I-1. The total is 3,910 co-disposal waste packages.

3.5.2 DSNF Radionuclide Inventories

Table I-6 shows how the radionuclide activities (from Table I-3) for DSNF in each of the co-disposal waste package configurations (Configurations 6 through 13 in Table I-1) were combined to produce the inventory in grams of radionuclides from DSNF for a co-disposal waste package for TSPA-SR. The calculation was performed in an Excel spreadsheet using Equations I-3 and I-4.

$$(a_i)_{\text{DSNF in a Co-disposal Waste Package for TSPA-SR}} = \frac{(1100)\bullet(a_i)_6 + (1500)\bullet(a_i)_7 + (130)\bullet(a_i)_8 + (160)\bullet(a_i)_{10}}{3910} + \frac{(210)\bullet(a_i)_{11} + (110)\bullet(a_i)_{12}}{3910} \qquad \text{Eq (I-3)}$$

Where:

$(a_i)_6$ is the activity from DSNF in curies of isotope "i" in an average waste package with Configuration 6.
$(a_i)_7$ is the activity from DSNF in curies of isotope "i" in an average waste package with Configuration 7.
$(a_i)_8$ is the activity from DSNF in curies of isotope "i" in an average waste package with Configuration 8.
$(a_i)_{10}$ is the activity from DSNF in curies of isotope "i" in an average waste package with Configuration 10.
$(a_i)_{11}$ is the activity from DSNF in curies of isotope "i" in an average waste package with Configuration 11.
$(a_i)_{12}$ is the activity from DSNF in curies of isotope "i" in an average waste package with Configuration 12.

All activity values are from Table I-3.

$$(m_i)_{\text{DSNF in a Co-disposal Waste Package for TSPA-SR}} \quad \frac{B\bullet MW_i\bullet t_i\bullet(a_i)_{\text{DSNF in a Co-disposal Waste Waste Package for TSPA-SR}}}{\ln(2)\bullet N_a} \qquad \text{Eq (I-4)}$$

Where:

m_i is the average grams of isotope "i" from DSNF in a co-disposal waste package for TSPA-SR.
a_i is the average activity in curies of isotope "i" from DSNF in a co-disposal waste package for TSPA-SR (from Equation I-3).
MW_i is the molecular weight in grams per mole of isotope "i" (Walker and Miller 1984).
t_i is the half-life of isotope "i" in seconds (Walker and Miller 1984).
N_a is Avogadro's number, 6.022045E+23 (Walker and Miller 1984).
B is the conversion from curies to decays per second, 3.7E+10 (Walker and Miller 1984).

3.5.3 DHLW Radionuclide Inventories

Table I-7 shows how the radionuclide activities (from Table I-4) for DHLW in each of the co-disposal waste package configurations (Configurations 6 through 13 in Table I-1) were combined to produce the inventory in grams of radionuclides from DHLW for a co-disposal waste package for TSPA-SR. The calculation was performed in an Excel spreadsheet using Equations I-5 and I-6.

$$(a_i)_{\text{DHLW in a Co-disposal Waste Package for TSPA-SR}} = \frac{(1100)\bullet(a_i)_6 + (1500)\bullet(a_i)_7 + (130)\bullet(a_i)_8 + (600)\bullet(a_i)_9}{3910} + \frac{(160)\bullet(a_i)_{10} + (100)\bullet(a_i)_{13}}{3910} \quad \text{Eq (I-5)}$$

Where:

$(a_i)_6$ is the activity from DHLW in curies of isotope “i” in an average waste package with Configuration 6.
$(a_i)_7$ is the activity from DHLW in curies of isotope “i” in an average waste package with Configuration 7.
$(a_i)_8$ is the activity from DHLW in curies of isotope “i” in an average waste package with Configuration 8.
$(a_i)_9$ is the activity from DHLW in curies of isotope “i” in an average waste package with Configuration 9.
$(a_i)_{10}$ is the activity from DHLW in curies of isotope “i” in an average waste package with Configuration 10.
$(a_i)_{13}$ is the activity from DHLW in curies of isotope “i” in an average waste package with Configuration 13.

All activity values are from Table I-4.

$$(m_i)_{\text{DHLW in a Co-disposal Waste Package for TSPA-SR}} \quad \frac{B\bullet MW_i\bullet t_i\bullet(a_i)_{\text{DHLW in a Co-disposal Waste Package for TSPA-SR}}}{\ln(2)\bullet N_a} \quad \text{Eq (I-6)}$$

Where:

m_i is the average grams of isotope “i” from DHLW in a co-disposal waste package for TSPA-SR.
a_i is the average activity in curies of isotope “i” from DHLW in a co-disposal waste package for TSPA-SR (from Equation I-5).
MW_i is the molecular weight in grams per mole of isotope “i” (Walker and Miller 1984).
t_i is the half-life of isotope “i” in seconds (Walker and Miller 1984).
N_a is Avogadro’s number, 6.022045E+23 (Walker and Miller 1984).
B is the conversion from curies to decays per second, 3.7E+10 (Walker and Miller 1984).

Table I-6. Calculation of Radionuclide Inventory in Grams from DSNF in a Co-disposal Waste Package for TSPA-SR

Configuration	6	7	8	9	10	11	12	13			
	Number Of Waste Packages								Curies from DSNF In a Co-disposal Waste Package	Specific Activity Ci/gram	Grams from DSNF In a Co-disposal Waste Package
	1100	1500	130	600	160	210	110	100			
	Fraction of Waste Packages										
	0.28	0.38	0.03	0.15	0.04	0.05	0.03	0.03			
Isotope	Weighted Value Of Curies Per Waste Package Configuration										
Ac-227	4.52E-05	7.53E-03	5.34E-06	N/A	3.91E-06	6.77E-06	4.39E-06	N/A	7.59E-03	7.24E+01	1.05E-04
Am-241	1.71E+01	1.40E+02	2.02E+00	N/A	1.06E+02	2.63E+00	1.89E+00	N/A	2.70E+02	3.44E+00	7.87E+01
Am-243	6.89E-02	1.78E-01	8.15E-03	N/A	1.55E-02	3.32E-02	3.18E-02	N/A	3.36E-01	2.00E-01	1.68E+00
C-14	2.34E-02	3.95E-02	2.77E-03	N/A	1.38E-01	1.46E+00	1.30E+00	N/A	2.96E+00	4.46E+00	6.63E-01
Cs-137	2.61E+03	3.94E+03	3.08E+02	N/A	2.02E+03	2.36E+04	1.53E+04	N/A	4.78E+04	8.65E+01	5.52E+02
I-129	1.41E-03	1.18E-03	1.66E-04	N/A	1.24E-03	6.07E-03	3.94E-03	N/A	1.40E-02	1.73E-04	8.08E+01
Ni-63	1.65E+00	2.06E+01	1.95E-01	N/A	6.16E-01	7.14E+00	6.53E+00	N/A	3.68E+01	5.68E+01	6.48E-01
Np-237	6.68E-03	8.84E-03	7.89E-04	N/A	1.47E-02	1.56E-01	1.13E-01	N/A	3.01E-01	7.05E-04	4.26E+02
Pa-231	1.05E-04	1.41E-02	1.24E-05	N/A	5.22E-06	3.44E-05	2.22E-05	N/A	1.42E-02	4.72E-02	3.02E-01
Pb-210	4.07E-09	9.81E-07	4.82E-10	N/A	2.85E-11	4.07E-08	2.55E-08	N/A	1.05E-06	7.64E+01	1.38E-08
Pu-238	1.33E+01	6.05E+01	1.57E+00	N/A	2.41E+01	7.68E+02	6.39E+02	N/A	1.51E+03	1.71E+01	8.79E+01
Pu-239	2.40E+00	8.21E+01	2.83E-01	N/A	4.66E+01	6.98E-01	5.06E-01	N/A	1.33E+02	6.21E-02	2.13E+03
Pu-240	2.72E+00	7.22E+01	3.21E-01	N/A	2.72E+01	5.34E-01	3.85E-01	N/A	1.03E+02	2.27E-01	4.55E+02
Pu-242	6.47E-03	1.93E-02	7.64E-04	N/A	1.31E-02	3.04E-03	2.52E-03	N/A	4.52E-02	3.93E-03	1.15E+01
Ra-226	1.33E-08	1.26E-06	1.57E-09	N/A	4.35E-07	2.99E-07	1.77E-07	N/A	2.19E-06	9.89E-01	2.21E-06
Ra-228	1.85E-08	1.76E-03	2.19E-09	N/A	3.89E-10	1.77E-08	1.49E-08	N/A	1.76E-03	2.72E+02	6.46E-06
Sr-90	2.38E+03	2.79E+03	2.81E+02	N/A	1.53E+03	2.25E+04	1.18E+04	N/A	4.13E+04	1.37E+02	3.01E+02
Tc-99	6.37E-01	5.07E-01	7.53E-02	N/A	5.70E-01	3.60E+00	2.30E+00	N/A	7.69E+00	1.70E-02	4.53E+02
Th-229	1.39E-08	5.25E-03	1.64E-09	N/A	3.53E-09	3.27E-07	2.78E-07	N/A	5.26E-03	2.14E-01	2.46E-02
Th-230	5.44E-07	2.00E-04	6.42E-08	N/A	3.87E-07	1.02E-04	5.82E-05	N/A	3.61E-04	2.06E-02	1.75E-02
Th-232	2.66E-09	1.52E-03	3.15E-10	N/A	4.57E-11	2.02E-08	1.85E-08	N/A	1.52E-03	1.10E-07	1.38E+04
U-232	1.05E-04	2.98E+00	1.24E-05	N/A	0.00E+00	1.72E-02	1.37E-02	N/A	3.02E+00	2.20E+01	1.37E-01
U-233	5.31E-06	1.91E+00	6.28E-07	N/A	2.16E-06	9.51E-05	8.36E-05	N/A	1.91E+00	9.66E-03	1.98E+02
U-234	3.99E-03	1.41E-01	4.72E-04	N/A	1.84E-01	8.92E-01	5.06E-01	N/A	1.73E+00	6.24E-03	2.77E+02
U-235	5.32E-03	3.57E-03	6.29E-04	N/A	7.01E-03	1.40E-02	7.06E-03	N/A	3.75E-02	2.16E-06	1.74E+04
U-236	9.72E-03	1.32E-02	1.15E-03	N/A	2.66E-02	1.78E-01	1.13E-01	N/A	3.41E-01	6.47E-05	5.27E+03
U-238	2.28E-03	9.79E-03	2.70E-04	N/A	1.45E-01	5.80E-05	3.46E-05	N/A	1.57E-01	3.36E-07	4.67E+05

Table I-7. Calculation of Radionuclide Inventory in Grams from DHLW in a Co-disposal Waste Package for TSPA-SR

Configuration	6	7	8	9	10	11	12	13			
	Number Of Waste Packages								Curies from DHLW In a Co-disposal Waste Package	Specific Activity Ci/gram	Grams from DHLW In a Co-disposal Waste Package
	1100	1500	130	600	160	210	110	100			
	Fraction of Waste Packages										
	0.28	0.38	0.03	0.15	0.04	0.05	0.03	0.03			
Isotope	Weighted Value Of Curies Per Waste Package Configuration										
Ac-227	3.11E-03	1.86E-02	1.61E-03	7.44E-03	7.94E-04	N/A	N/A	4.67E-08	3.16E-02	7.24E+01	4.36E-04
Am-241	6.99E+01	9.44E+00	8.18E-01	3.77E+00	4.03E-01	N/A	N/A	1.02E+02	1.87E+02	3.44E+00	5.43E+01
Am-243	2.86E-01	1.23E-03	1.07E-04	4.92E-04	5.25E-05	N/A	N/A	2.08E-02	3.09E-01	2.00E-01	1.55E+00
C-14	3.17E-02	1.26E-05	1.10E-06	5.06E-06	5.39E-07	N/A	N/A	0.00E+00	3.17E-02	4.46E+00	7.11E-03
Cs-137	2.48E+04	5.12E+03	4.44E+02	2.05E+03	2.19E+02	N/A	N/A	2.34E+03	3.50E+04	8.65E+01	4.04E+02
I-129	1.16E-03	4.24E-03	3.67E-04	1.70E-03	1.81E-04	N/A	N/A	0.00E+00	7.65E-03	1.73E-04	4.41E+01
Ni-63	4.19E+00	8.84E+00	7.66E-01	3.54E+00	3.77E-01	N/A	N/A	2.80E-01	1.80E+01	5.68E+01	3.17E-01
Np-237	8.80E-02	1.88E-02	1.63E-03	7.51E-03	8.01E-04	N/A	N/A	8.71E-03	1.25E-01	7.05E-04	1.78E+02
Pa-231	3.44E-03	2.07E-02	1.80E-03	8.29E-03	8.84E-04	N/A	N/A	1.51E-07	3.51E-02	4.72E-02	7.44E-01
Pb-210	3.60E-07	6.33E-06	5.49E-07	2.53E-06	2.70E-07	N/A	N/A	3.44E-09	1.00E-05	7.64E+01	1.31E-07
Pu-238	8.76E+02	2.55E-01	2.21E-02	1.02E-01	1.09E-02	N/A	N/A	9.81E+01	9.75E+02	1.71E+01	5.69E+01
Pu-239	1.50E+01	5.18E+00	4.49E-01	2.07E+00	2.21E-01	N/A	N/A	1.96E+02	2.19E+02	6.21E-02	3.52E+03
Pu-240	8.52E+00	1.18E+00	1.02E-01	4.70E-01	5.02E-02	N/A	N/A	6.68E+01	7.71E+01	2.27E-01	3.39E+02
Pu-242	1.16E-02	1.53E-04	1.33E-05	6.14E-05	6.55E-06	N/A	N/A	1.28E-02	2.46E-02	3.93E-03	6.25E+00
Ra-226	2.27E-06	8.36E-06	7.25E-07	3.35E-06	3.57E-07	N/A	N/A	1.43E-08	1.51E-05	9.89E-01	1.52E-05
Ra-228	1.15E-03	3.74E-04	3.24E-05	1.50E-04	1.60E-05	N/A	N/A	4.86E-05	1.77E-03	2.72E+02	6.51E-06
Sr-90	2.77E+04	4.14E+03	3.59E+02	1.66E+03	1.77E+02	N/A	N/A	2.62E+03	3.66E+04	1.37E+02	2.67E+02
Tc-99	4.90E+00	4.32E+00	3.74E-01	1.73E+00	1.84E-01	N/A	N/A	3.87E-01	1.19E+01	1.70E-02	7.01E+02
Th-229	5.71E-05	4.93E-04	4.27E-05	1.97E-04	2.10E-05	N/A	N/A	9.72E-10	8.11E-04	2.14E-01	3.79E-03
Th-230	1.12E-04	1.94E-05	1.68E-06	7.75E-06	8.27E-07	N/A	N/A	2.44E-06	1.44E-04	2.06E-02	7.00E-03
Th-232	1.19E-03	3.36E-04	2.91E-05	1.34E-04	1.43E-05	N/A	N/A	5.12E-05	1.75E-03	1.10E-07	1.59E+04
U-232	1.08E-03	1.03E-02	8.93E-04	4.12E-03	4.39E-04	N/A	N/A	0.00E+00	1.68E-02	2.20E+01	7.64E-04
U-233	2.17E-03	6.29E-02	5.45E-03	2.52E-02	2.68E-03	N/A	N/A	8.99E-07	9.84E-02	9.66E-03	1.02E+01
U-234	1.29E-01	4.58E-02	3.97E-03	1.83E-02	1.96E-03	N/A	N/A	1.20E-02	2.12E-01	6.24E-03	3.39E+01
U-235	1.55E-04	1.92E-03	1.66E-04	7.67E-04	8.18E-05	N/A	N/A	2.88E-04	3.38E-03	2.16E-06	1.56E+03
U-236	3.76E-04	1.27E-03	1.10E-04	5.07E-04	5.41E-05	N/A	N/A	4.95E-05	2.36E-03	6.47E-05	3.65E+01
U-238	2.69E-02	1.52E-01	1.32E-02	6.08E-02	6.48E-03	N/A	N/A	5.15E-03	2.64E-01	3.36E-07	7.86E+05

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