BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA
2. Page 1

3. System	4. Document Identifier
Monitored Geological Repository	000-00C-MGR0-03500-000-00B

5. Title

Source Terms for HLW Glass Canisters

6. Group

Nuclear and Radiological

7. Document Status Designation

☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

- No new ORIGEN-S calculations were run for this revision 00B.
- The changed values are in Attachment E, spreadsheet *Results.xls*, tabs *Tinv* and *Cinv*, spreadsheet *Input.xls*, reference to Ref. 2.2.1, Table B-1 and Table B-2 summation columns, Table 19, WVDP data, and other changes marked by *Change Bars*.
- Changes are identified by *Change Bars*.
- Affected pages are 1, 3-4, 6, 8-12, 14, 15, 17, 19-27, 29-37, 41-43, and 47-55.

Attachments	Total Number of Pages
Attachment A – List of the Files in the Electronic Attachment – One CD	1
Attachment B – Total HLW Radionuclide Inventory from All Sites (Tables)	6
Attachment C – HLW Decay Heat vs. Time (Figures)	1
Attachment D – Batch File for Running SCALE 4.4A.	1
Attachment E – Electronic attachment - One CD.	N/A

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial issue	52	52	Dorin Musat	Jeff Ryman Charlotta Sanders	Kevin Doody	Dave Darling 9/20/2007
00B	Correct errors found in various tables and referencing (see condition report 11575). Include HLW property overview.	57	57	Tanya Sloma [signature] 01/28/08	Charlotta Sanders [signature] 01/29/2008	Kevin Doody [signature] 1/29/08	Dave Darling [signature] 1/30/08

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

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ACRONYMS

DOE	U.S. Department of Energy
HLW	high-level (radioactive) waste
HS	Hanford Site
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MGR	monitored geologic repository
ORIGEN-S	Oak Ridge Isotope Generation – Version S (module of the SCALE code system)
SCALE	Standardized Computer Analysis for Licensing Evaluations (software code system)
SNF	spent nuclear fuel
SRS	Savannah River Site
SS	stainless steel
WP	waste package
WVDP	West Valley Demonstration Project

1. PURPOSE

The objective of this calculation is to determine the radionuclide inventory (*Curie* and *gram*) and source terms for the high-level radioactive waste (HLW) from the Hanford Site (HS), Savannah River Site (SRS), West Valley Demonstration Project (WVDP), and Idaho National Laboratory (INL). The source terms include decay heat (*Watt*), gamma (s^{-1} and $MeV \cdot s^{-1}$), and neutron (s^{-1}) radiation sources. The scope of this calculation is limited to the HLW types expected to be received and deposited at the proposed Yucca Mountain Monitored Geological Repository (MGR). The scope is also limited to radionuclide inventory source terms for a time period of one million years.

The work scope includes the following:

- The radionuclide inventory, decay heat, gamma, and neutron source terms per canister basis for the HS waste form.
- The total radionuclide inventory and decay heat for the HS HLW glass.
- The radionuclide inventory, decay heat, gamma, and neutron source terms per canister basis for the SRS waste form.
- The total radionuclide inventory and decay heat for the SRS HLW glass.
- The radionuclide inventory, decay heat, gamma, and neutron source terms per canister basis for the WVDP waste form.
- The total radionuclide inventory and decay heat for the WVDP HLW glass.
- The radionuclide inventory, decay heat, gamma, and neutron source terms per canister basis for the INL waste form.
- The total radionuclide inventory and decay heat for the INL HLW glass.

The results of this calculation will be used to carry out performance assessment of the proposed MGR and to evaluate radiation environments surrounding the HLW canisters, HLW casks, and co-disposal waste packages (WPs) including 5-HLW/DOE SNF short, 5-HLW/DOE SNF long, and 2-MCO/2-HLW. Also, the results presented here will be used as input in shielding design calculations, dose rate evaluations, and radionuclide inventory releases.

Revision 00B corrects value errors in various tables, along with referencing. Additionally, Section 6.3 has been added to present several HLW properties. Excel spreadsheets of Attachment E have been updated for transparency.

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Note: References 2.2.11, 2.2.20, 2.2.21, and 2.2.24 are QA:N/A sources. However, these are used as indirect inputs. References 2.2.12, 2.2.13, 2.2.14, 2.2.16, 2.2.17, and 2.2.23 are also QA; N/A sources. However, as they are DOE documents generated by the HLW custodian, they are considered the best available data on the subject and acceptable for the intended use. The referenced values are reliable and reasonable; therefore, based on engineering judgment, their use is justified. Similar justification is at the point of use.

2.3 DESIGN CONSTRAINTS

None.

2.4 DESIGN OUTPUTS

The results of this design calculation will be used as input in future calculations involving HLW total and per canister basis radionuclide inventories and source terms, which include thermal evaluations and WP loading, shielding, dose rate evaluations, radionuclide inventory releases, and performance assessment of the proposed MGR.

3 ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

This calculation does not use any assumption that requires verification.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

The following assumptions, used throughout Section 6 and its subsections, do not require further confirmation:

3.2.1 It is assumed that the glass chemical composition within canisters is homogenous.

Rationale: The HLW generators do not provide any data regarding the stratification of glass composition within the canister. The glass composition does not change the total gamma source terms per canister; however, non uniformities in glass composition may affect the total neutron source terms due to α-n reactions. Since neutron contribution to dose rates around HLW canisters is negligible (Ref. 2.2.18, [DIRS 166210], Section 6.1, Tables 23 and 27 through 29) this assumption is inconsequential.

Usage: This assumption is used in Table 2, Table 6, Table 10, and Table 14.

3.2.2 It is assumed that the radionuclide concentration within canisters is homogenous.

Rationale: The HLW generators do not provide any data regarding the preferential concentration of radionuclides within the canister. The concentration of radionuclides does not change the total gamma source terms per canister; however, non uniformities in concentration of actinide isotopes may affect the total neutron source terms due to α-n reactions. Since neutron contribution to dose rates around HLW canisters is negligible (Ref. 2.2.18, [DIRS 166210], Section 6.1, Tables 23 and 27 through 29) this assumption is inconsequential.

Usage: This assumption is used in Table 5, Table 8, Table 13, and Table 17.

4 METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037 (Ref. 2.1.1). The DOE and commercial WP is classified as a Safety Category item (important to safety and important to waste isolation) on the Q-List (Ref. 2.2.5, Table A-1, p. A-4). Therefore, the approved version is designated as QA: QA.

4.2 USE OF SOFTWARE

4.2.1 ORIGEN-S Functional Module of SCALE Version 4.4A Code System

The ORIGEN-S functional module of the SCALE 4.4A code system (Ref. 2.2.7) is used to decay the isotopic concentrations of the individual HLW forms in both the total quantity and a single canister. It is also used to generate HLW source terms based on the initial radionuclide inventories and the glass composition.

The software specifications are as follows:

- Program Name: SCALE
- Version/Revision Number: Version 4.4A
- Operating System: HP-UX B 10.20
- Software Tracking Number: 10129-4.4A-00
- Computer Type HP 9000/700 Series workstation

The ORIGEN-S module of the SCALE 4.4A code system (Ref. 2.2.7) is: (a) appropriate for spent nuclear fuel (SNF) depletion calculations, (b) used within the range of validation as documented in Ref. 2.2.8, *Validation Test Report (VTR) for SCALE-4.4A.*, and (c) obtained from Software Configuration Management in accordance with the appropriate procedure (Ref. 2.1.2 IT-PRO-0011, *Software Management*). Therefore, the ORIGEN-S module of SCALE Version 4.4A code system (Ref. 2.2.7) is suitable for use in this design calculation.

The batch file used to run the SCALE 4.4A code on the workstation and to stamp the user name, run date, shell, operating system, and computer name on the output file is presented in Attachment D.

The ORIGEN-S input and output files documented in this calculation are included in the Attachment E, folder *ORIGEN*.

4.2.2 Microsoft® Office Excel

The commercially available Microsoft® Office Excel 2003 spreadsheet code, which is a component of Microsoft® Office 2003 Professional, is used to calculate various input values (i.e., weight percentages, elements masses, radionuclide inventories, etc.) in Attachment E, folder *excel*, *Input.xls*. Standard functions of Excel are also used in this design calculation to display results (i.e. radionuclide inventories, decay heat generation rates, gamma, and neutron source terms) in tabular and graphic forms in Attachment E, folder *excel*, spreadsheet *Results.xls*. The user defined formulas, inputs, and results have been reproduced and checked by hand and are documented in sufficient detail to allow an independent repetition of the computations. Usage of Microsoft® Office 2003 Professional in this calculation constitutes Level 2 software usage, as defined in IT-PRO-0011 (Ref. 2.1.2, Attachment 12). Microsoft® Office 2003 Professional is listed in the current controlled Software Report, as well as the Repository Project Management Automation Plan (Ref. 2.1.3, Table 6-1). Microsoft® Office Excel 2003 was executed on a PC running the Microsoft® Windows XP Professional Version 2002 Service Pack 2 operating system.

The Excel spreadsheets used in this calculation are included in the Attachment E, folder *excel*.

4.3 HLW DECAY CALCULATION

The radionuclide inventory and source terms for the HLW from the four sites at various time steps of interest (see Table 1) are calculated using the ORIGEN-S module of the SCALE 4.4A code system (Ref. 2.2.7). For each HLW form, the initial isotopic concentration and the glass composition is input and decayed out for time periods which extend to one million years.

The source terms per HLW canister type computed by ORIGEN-S include the isotopic masses (*gram*), the radionuclide activities (*Curie*), the total and gamma decay heat (*Watt*), the neutron production rates (s^{-1}), and the gamma production rates (s^{-1} and $MeV \cdot s^{-1}$) generated by the HLW forms. The source terms per HLW canister are calculated by blending the radionuclide activities per canister (*Curie*) with the material composition of the HLW glass for each canister type (*gram*); this ensures correct evaluation of the α-n neutron source.

For total HLW glass from each site, only the isotopic masses (*gram*), the radionuclide activities (*Curie*), and the total and gamma decay heat (*Watt*) were calculated.

5 LIST OF ATTACHMENTS

6 BODY OF CALCULATION

Technical product inputs and sources of the inputs used in the development of this design calculation are documented in this section. The values cited herein and in the associated Microsoft® Excel spreadsheets referenced in this section may present numerical values with many significant digits. These values are the results of the calculations or unit transformations; consequently, the number of digits should not be interpreted as an indication of accuracy.

6.1 BACKGROUND

HLW is the highly radioactive material resulting from the reprocessing of SNF. The U.S. Department of Energy (DOE) stores its HLW at the HS, SRS, and INL. The commercially generated HLW is stored at the WVDP in New York state. The HLW from all four sites are destined for disposal in the proposed MGR at Yucca Mountain.

Before being shipped to Yucca Mountain, the HLW at the HS, SRS, and WVDP will be vitrified into borosilicate glass and poured into SS (stainless steel) canisters, whereas the HLW at the INL will be processed into glass, ceramic matrix, and metal matrix and placed in SS canisters. The process of vitrifying the HLW is already finished at WVDP, is ongoing at SRS, but have not yet started at INL and HS.

The INL ceramic and metal matrixes will not be disposed of at the MGR as these waste types do not meet the requirement in *Waste Acceptance System Requirements Document* (Ref. 2.2.9, Section 4.8.1[A]); hence, they will not be included in the *License Application* baseline and, consequently, will not be addressed in this revision. Also, the immobilized plutonium in borosilicate glass is not addressed in this revision because of the DOE cancellation of the immobilization portion of the disposition strategies (Ref. 2.2.2, Summary, Item 1). Therefore, this calculation evaluates a total of four waste forms: the borosilicate glass from HS, SRS, WVDP, and INL.

The following subsections present the detailed description of the characteristics of each HLW form used in calculation.

In order to generate the HLW source terms for each type of canister (i.e., waste form), the ORIGEN-S decay calculation was carried out by blending the radioactive nuclides with the nuclides present in the HLW glass in each canister. The actinide nuclides were included only as radioactive nuclides, so they were not accounted for twice. For the same reason, the masses of the fission products in the glass composition were adjusted (decreased by the mass of the radioactive nuclides considered).

6.2 DECAY TIME STEPS

The decay information for the whole HLW quantity and per canister basis was determined for the calendar years shown in Table 1. The time *zero* in the ORIGEN-S calculations corresponds to calendar years 2010, 2006, 1996, and 2035 for HLW from HS, SRS, WVDP, and INL, respectively. The reference for INL HLW provides the initial inventory at year 2035; thus, for this waste form, the decay times start from the year the initial inventory is provided (2035). For each time step, ORIGEN-S prints the nuclide inventory, heat generation rate, gamma, and neutron source terms.

Table 1. Calendar years of the Time Steps for Nuclide Inventories and Source Terms

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
2040	2041	2042	2043	2044	2045	2046	2047	2048	2049
2050	2051	2052	2053	2054	2055	2056	2057	2058	2059
2060	2061	2062	2063	2064	2065	2066	2067	2068	2069
2070	2071	2072	2073	2074	2075	2076	2077	2078	2079
2080	2081	2082	2083	2084	2085	2086	2087	2088	2089
2090	2091	2092	2093	2094	2095	2096	2097	2098	2099
2100	2101	2102	2103	2104	2105	2106	2107	2108	2109
2110	2111	2112	2113	2114	2115	2116	2117	2118	2119
2120	2121	2122	2123	2124	2125	2126	2127	2128	2129
2130	2131	2132	2133	2134	2135	2136	2137	2138	2139
2140	2150	2167	2217	2267	2317	2367	2417	2467	2517
3017	4017	7017	12017	22017	52017	102017	202017	502017	1002017

NOTE: For INL HLW the time steps start at 2035 - the year for which the initial inventory is provided

6.3 HLW PHYSICAL CHARACTERISTICS OVERVIEW

The HLW to be received at the repository would come in SS canisters. The waste has gone through a solidification process (vitrification) that yields a leach-resistant material, typically borosilicate glass. In this process, the HLW is mixed with glass-forming materials, heated and converted to a durable glass waste form, and then poured into SS canisters (Ref. 2.2.12, Attachment 4, p. 2). Once the material solidifies into glass, the canister is sealed, loaded into a transport cask and shipped to the repository.

Table 6.3-1 provides physical parameters of the standard canisters used for HLW.

Table 6.3-1. Physical Parameters of the Standard Canisters for HLW

Parameter	Hanford	SRS	INL [j]	WVDP
Length (cm)	450 [a]	300 [e]	300	300 [l]
Nominal Outer Diameter (cm)	61 [a]	61 [e]	61	61 [l]
Thickness (cm)	0.95 [a]	0.95 [e]	0.95	0.34 [l]
Material	304L SS [b]	304L SS [f]	304L SS	304L SS [l]
Canister Weight (kg)	715 [a]	~ 500 [g]	~ 500	181.4 [m]
Available Volume (m^3)	1.19 [c]	0.736 [g]	0.736	0.83 [n]
Nominal Fill Height (%)	87, 95, 100 [c]	90 [h]	90	91 [o]
Glass Volume (m^3)	1.04, 1.14, 1.19 [c]	0.66 [g]	0.66	0.76 [p]
Glass Mass (kg)	3,360 [d]	1,795 [i]	1560 [k]	2000 [q]

Source: Reference 2.2.12, [a] Table RL-3, [k] Table ID-1
Reference 2.2.20, [b] Section 3.4.3
Reference 2.2.10, [c] Table 3
Reference 2.2.6, [d] Table 7, [i] Table 14, [q] Section 6.14
Reference 2.2.11, [e] Sections 2.4.1, 2.4.2, and 4.3.3, [f] Section 3.1 and Table 1, [g] Section 5.5
Reference 2.2.16, [l] WQR-3.11 p. 2, [m] Table 1
Reference 2.2.24, [o] p. 6

Notes: [h] Calculated (based on data from this table) [(glass volume/available volume)*100]
[j] Per Reference 2.2.13, p.7 Data Type 9, INL canisters will be identical in design to the SRS canisters.
[n] Calculated (based on data from this table) [height to base of neck * (outer radius – thickness)^2 * π]. Base of neck = 115 in. (Reference 2.2.16, WQR-3.6, p. 2, item 3 and h_n definition)
[p] Calculated (based on data from this table) [available volume* (nominal fill(%)/100)]

<u>Mass and Volume</u>

The approximate mass of glass per waste canister for each HLW stream is provided in Table 6.3-1.

Vitrified DOE HLW is given a value of 0.5 MTHM/canister, which is based on the historical method (Ref. 2.2.22, p. 1 and Ref. 2.2.21, pp 1-8, and 1-9). DOE uses this conversion, of 0.5 MTHM per canister, of DOE HLW to establish the basis to meet the NWPA statutory repository limit (Ref. 2.2.9, Table 7.1).

The HLW from West Valley is classified as commercial HLW and not DOE HLW (Ref. 2.2.22, p. 1), and therefore is treated differently than DOE HLW. HLW from West Valley has been given a value of 2.3 MTHM/canister, which is based on dividing the total number of MTHM from SNF reprocessed by the total number of canisters filled. West Valley has 640 MTHM from SNF reprocessing filling 275 canisters; dividing 640 by 275 equals about 2.3 MTHM/canister (Ref. 2.2.22, p. 3 and Ref. 2.2.23, p. S-26, respectively).

Information included in the Ref. 2.2.23 is a DOE document generated by the HLW waste generator/custodian (West Valley Nuclear Services). The West Valley Nuclear Services is the most authoritative source of information and the data is unique and considered reliable. Therefore, the information provided is suitable for use in this calculation for nuclide inventories calculation and source terms generation.

6.4 HLW OF HANFORD SITE

The HLW at the HS consists of the liquid high-level radioactive waste and the strontium and cesium capsules. The two wastes would be vitrified together into borosilicate glass and poured into SS canisters (Ref. 2.2.6, Section 6.19). Each canister has a nominal height of 4.50 *meters* (15 *feet*) a nominal outside diameter of 0.61 *meter* (2 *feet*) and a 0.95 *centimeter* (3/8 in.) wall thickness (Ref. 2.2.12, Table RL-3). The estimated mass of the HLW in each canister is 3,360 *kg* (Ref. 2.2.6, Table 7); however, since the AZ-101 canister is bounding for all HLW canisters produced at Hanford (Ref. 2.2.10, Section 3.1, Item 1), the glass mass for this canister type (3,345 *kg* per Ref. 2.2.10, Table 4) is used in this calculation. The density of the Hanford HLW glass is 2.811 g/cm^3 (Ref. 2.2.10, Section 2.1, item 4). The estimated total HLW number of canisters, glass mass, and volume are 7,071-13,205 *canisters* (Ref. 2.2.10, Table 3), 23,700-38,500 *metric tons* (Ref. 2.2.10, Table 1) and 8,431-13,700 *cubic meters* , respectively.

Information included in the Ref. 2.2.10 was prepared by the waste generator/custodian (Office of River Protection Richland, WA), at DOE's request, to support analyses for the Yucca Mountain Project.

The Office of River Protection is the most authoritative source of information and the data is unique and considered reliable. Therefore, the information provided is suitable for use in this calculation for nuclide inventories calculation and source terms generation.

6.4.1 Chemical Composition of the AZ-101 HLW Glass

The bounding source terms for HS HLW canister is estimated to be from the waste reprocessed from the tank AZ-101 (Ref. 2.2.10, Section 3.1, item 1); therefore, the chemical composition of this waste type (Ref. 2.2.10, Table 4) is used in this calculation and presented in Table 2.

Table 2. Chemical Composition of the Hanford AZ-101 HLW Glass

Compound	wt%	Compound	wt%	Compound	wt%	Compound	wt%
AgO	0.05	CuO	0.05	NiO	0.97	SeO_2	0.06
As_2O_5	0.03	Cr_2O_3	1.92	PbO	0.05	Ta_2O_5	0.00
Al_2O_3	8.28	F	0.08	P_2O_5	0.11	TeO_2	0.02
B_2O_3	6.16	Fe_2O_3	19.53	PdO	0.00	ThO_2	0.05
BaO	0.12	K_2O	0.45	Pr_2O_3	0.08	TiO_2	0.02
BeO	0.01	La_2O_3	0.64	Rb_2O	0.01	Tl_2O_3	0.00
Bi_2O_3	0.01	Li_2O	2.33	Rh_2O_3	0.04	U_3O_8	1.40
CaO	0.53	MgO	0.28	Ru_2O_3	0.26	V_2O_5	0.01
Cl	0.01	MoO_3	0.44	SiO_2	31.63	WO_3	0.00
CdO	1.20	MnO_2	0.25	SO_3	0.49	Y_2O_3	0.00
CeO_2	0.16	Na_2O	15.72	SrO	0.07	ZnO	0.03
Co_2O_3	0.01	Nd_2O_3	0.51	Sb_2O_3	0.00	ZrO_2	5.92
						Total	100

Source: Ref. 2.2.10, Table 4 (Waste Oxides plus Glass Formers) and Assumption 3.2.1.

6.4.2 Elemental Composition

Based on the composition of AZ-101 of Hanford HLW glass (Table 2), the elemental composition is calculated in Attachment E, spreadsheet *Input.xls*, worksheet *HS* and presented in Table 3.

The uranium, thorium, strontium, and zirconium are included in the radionuclide inventory; therefore, their masses are adjusted so they will not be considered twice in the calculation. In the ORIGEN-S input they are accounted for in the radionuclide input and excluded from the HLW glass mass input.

Table 3. Elemental Composition by Mass of Hanford HLW Glass Canister

Element	Mass (*kg*)	Adjusted Mass (*kg*)	Element	Mass (*kg*)	Adjusted Mass (*kg*)	Element	Mass (*kg*)	Adjusted Mass (*kg*)
Ag	1.457	N/A	La	18.256	N/A	S	6.565	N/A
Al	146.599	N/A	Li	36.212	N/A	Sb	0.000	N/A
As	0.654	N/A	Mg	5.649	N/A	Se [a]	1.428	1.427
B	64.000	N/A	Mn	5.285	N/A	Si	494.607	N/A
Ba	3.596	N/A	Mo	9.811	N/A	Sr [a]	1.980	1.453
Be	0.121	N/A	Na	390.133	N/A	Ta	0.000	N/A
Bi	0.300	N/A	Nd	14.627	N/A	Te	0.535	N/A
Ca	12.672	N/A	Ni [a]	25.499	25.492	Th [a]	1.470	0.000
Cd	35.142	N/A	O	1344.462	N/A	Ti	0.401	N/A
Ce	4.357	N/A	P	1.606	N/A	Tl	0.000	N/A
Cl	0.335	N/A	Pb	1.553	N/A	U [a]	39.716	0.000
Co	0.238	N/A	Pd	0.000	N/A	V	0.187	N/A
Cr	43.947	N/A	Pr	2.287	N/A	W	0.000	N/A
Cu	1.336	N/A	Rb	0.306	N/A	Y	0.000	N/A
F	2.676	N/A	Rh	1.085	N/A	Zn	0.806	N/A
Fe	456.965	N/A	Ru	7.029	N/A	Zr [a]	146.615	144.311
K	12.497	N/A				Total	3345.000	3300.975

Source: Attachment E, Spreadsheet*Input.xls*, worksheet *HS*.
NOTE: [a] Mass of the element was adjusted to account for the nuclide inventory that was used as the second component of the blend. The adjusted mass is obtained by subtracting the mass of the isotopes specified as radionuclides from the calculated mass of the element.

6.4.3 Radionuclide Inventory

The recommended total radionuclide inventory of Hanford HLW glass as of 01/01/2010 is provided in Ref. 2.2.6, Table 8 and presented in Table 4.

Table 4. Total Radionuclide Inventory of Hanford HLW Glass at 01/01/2010

Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)
Ac227	9.80E+01	Nb93m	2.65E+03	Sm151	3.27E+06
Am241	1.43E+05	Ni59	1.37E+03	Sn126	5.79E+02
Am243	1.50E+01	Ni63	1.20E+05	Sr90	4.07E+07
Ba137m	3.51E+07	Np237	1.41E+02	Tc99	2.97E+04
Cd113m	1.03E+04	Pa231	2.72E+02	Th229	2.00E+00
Cm242	0.00E+00	Pu238	4.55E+03	Th232	8.00E+00
Cm243	1.10E+01	Pu239	6.91E+04	U232	4.00E+01
Cm244	2.09E+02	Pu240	1.23E+04	U233	5.10E+02
Co60	2.48E+03	Pu241	8.10E+04	U234	2.20E+02
Cs134	8.91E+02	Pu242	1.00E+00	U235	9.00E+00
Cs137	3.72E+07	Ra226	9.00E-02	U236	6.00E+00
Eu152	1.03E+03	Ra228	2.10E+01	U238	1.99E+02
Eu154	6.68E+04	Ru106	2.00E+00	Y90	4.07E+07
Eu155	2.42E+03	Sb125	2.47E+03	Zr93	4.81E+03
I129	4.80E+01	Se79	1.22E+02	Total	1.60E+08

Source: Ref. 2.2.6, Table 8

The bounding source terms for HS HLW canister is estimated to be from the waste reprocessed from the tank AZ-101 (Ref. 2.2.10, Section 3.1, item 1); therefore, the radionuclide inventory of this waste type (Ref. 2.2.10, Table 5) is used in this calculation and presented Table 5.

Table 5. Radionuclide Inventory of Hanford HLW Glass Canister at 01/01/2010

Nuclide	**Activity (*Ci/canister*)**	**Nuclide**	**Activity (*Ci/canister*)**	**Nuclide**	**Activity (*Ci/canister*)**
Ac227	1.09E-04	Nb93m	2.44E+00	Sm151	3.62E+03
Am241	4.65E+02	Ni59	4.96E-01	Sn126	5.74E-01
Am243	9.99E-02	Ni63	5.13E+01	Sr90	7.38E+04
Ba137m [a]	6.62E+04	Np237	2.50E-01	Tc99	2.31E+01
C14	1.06E-07	Pa231	4.24E-04	Th229	1.08E-07
Cd113m	2.69E+01	Pu238	2.29E+00	Th232	1.50E-04
Cm242	3.46E-01	Pu239	2.13E+01	U232	4.72E-04
Cm243	4.42E-02	Pu240	6.42E+00	U233	2.09E-03
Cm244	4.27E-01	Pu241	1.22E+02	U234	1.46E-02
Co60	1.04E+00	Pu242	9.91E-04	U235	5.56E-04
Cs134	2.23E+02	Ra226	1.29E-05	U236	1.18E-03
Cs137	7.00E+04	Ra228	1.93E-05	U238	1.01E-02
Eu152	4.96E+00	Ru106	1.61E-02	Y90 [b]	7.38E+04
Eu154	7.92E+00	Sb125	1.87E+01	Zr93	5.76E+00
Eu155	3.28E+02	Se79	9.15E-02	Total	2.89E+05

Source: Ref. 2.2.10, Table 5 and Assumption 3.2.2.

NOTE: [a] Secular equilibrium value calculated based on 0.946 branching factor for $^{137}Cs \rightarrow ^{137m}Ba$.

[b] Secular equilibrium value calculated based on 1.0 branching factor for $^{90}Sr \rightarrow ^{90}Y$.

[a, b] The justification for use of the secular equilibrium values is that the equilibrium is reached after few half-life times of the progeny nuclide; therefore, since HLW cooling time is very large compared with ^{137m}Ba ($T_{1/2}$=2.552 minutes) and ^{90}Y ($T_{1/2}$=64 hours) half-life times, both ^{137m}Ba and ^{90}Y, reached the secular equilibrium with their parents.

6.5 HLW OF SAVANNAH RIVER SITE

The SRS HLW consists of wastes generated from the treatment of irradiated nuclear fuels. The Defense Waste Processing Facility at SRS mixes the HLW with glass-forming materials, converts it to a durable borosilicate glass waste form, and pours it into SS canisters. An estimated 6,833 HLW glass canisters (Ref. 2.2.6, Table 10) would be generated at SRS. Each canister has a nominal height of 3 *meters* (10 *feet*), a nominal outside diameter of 61.0 *centimeter* (2 *feet*), and a 0.95 *centimeter* (3/8 *in.*) wall thickness (Ref. 2.2.11, Sections 2.4.1, 2.4.2, and 4.3.3). The estimated total HLW glass volume and mass are 4,600 *cubic meters* and 12,265 *metric tons*, respectively (Ref. 2.2.6, Table 9). The average mass of glass in each canister is 1,795 *kg* (Ref. 2.2.6, Table 14) and the density of SRS HLW glass is 2.64 g/cm^3 (Ref. 2.2.14, Section 3.0); however, in this calculation, the mass of 4000 lb (1814.4 kg) HLW glass per canister (Ref. 2.2.14, Table 2) was used to generate the maximum source terms per canister basis.

Information included in the Ref. 2.2.14 was prepared by the waste generator/custodian (Washington Savannah River Company) in accordance with the *DOE Quality Assurance Requirements and Description* (Ref. 2.2.14, p. 2).

The Washington Savannah River Company is the most authoritative source of information and the data is unique and considered reliable. Therefore, the information provided is suitable for use in this calculation for nuclide inventories calculation and source terms generation.

6.5.1 Chemical Composition

The recommended chemical composition of the SRS HLW glass to be used in source term generation is provided in Ref. 2.2.6, Table 4 and presented in Table 6.

Table 6. Chemical Composition of SRS HLW Glass

Compound	wt%	Compound	wt%	Compound	wt%
Al_2O_3	7.08	MgO	1.45	ThO_2	0.55
B_2O_3	6.94	MnO	2.07	TiO_2	0.55
BaO	0.12	Na_2O	8.24	U_3O_8	1.01
CaO	1.05	NiO	0.40	Y_2O_3	0.04
Cr_2O_3	0.09	P_2O_5	0.05	ZnO	0.02
Cs_2O	0.07	PbO	0.01	ZrO_2	0.37
CuO	0.25	PbS	0.06	[a] $(R.E.)_2O_3$	0.63
Fe_2O_3	7.38	PuO_2	0.06	Pd	0.03
K_2O	2.14	SiO_2	54.39	Rh	0.02
La_2O_3	0.09	SO_4	0.14	Ru	0.08
Li_2O	4.62	SrO	0.01	Total	100

Source: Ref. 2.2.6, Table 4 and Assumption 3.2.1.
NOTE: [a] $(R.E.)_2O_3$ represent the total wt% of the oxides of Pr, Ce, Nd, Sm, and Eu estimated from isotopics.

6.5.2 Elemental Composition

Based on the glass composition of SRS HLW glass (Table 6), the elemental composition is calculated in Attachment E, spreadsheet *Input.xls*, worksheet *SRS* and presented in Table 7.

The uranium, thorium, plutonium, and some fission products are included in the radionuclide inventory; therefore, their masses are adjusted so they will not be considered twice in the calculation. In the ORIGEN-S input they are accounted for in the radionuclide input and excluded from the HLW glass mass input.

Table 7. Elemental Composition by Mass of SRS HLW Glass Canister

Element	Mass (*kg*)	Adjusted Mass (*kg*)	Element	Mass (*kg*)	Adjusted Mass (*kg*)	Element	Mass (*kg*)	Adjusted Mass (*kg*)
Al	67.987	N/A	Li	38.943	N/A	Rh	0.363	N/A
B	39.107	N/A	Mg	15.865	N/A	Ru	1.452	N/A
Ba	1.950	N/A	Mn	29.087	N/A	S	0.994	N/A
Ca	13.616	N/A	Na	110.913	N/A	Si	461.289	N/A
Co	0.000	N/A	Ni [a]	5.703	5.691	Sr [a]	0.154	0.000
Cr	1.117	N/A	O	844.935	N/A	Th [a]	8.770	0.000
Cs [a]	1.200	0.382	P	0.396	N/A	Ti	5.981	N/A
Cu	3.624	N/A	Pb	1.111	N/A	U [a]	15.540	0.000
Fe	93.655	N/A	Pd [a]	0.544	0.542	Y	0.571	N/A
K	32.233	N/A	Pu [a]	0.960	0.000	Zn	0.292	N/A
La	1.392	N/A	R.E. [a b]	9.868	0.000	Zr [a]	4.970	4.816
						Total	1,814.581	1,778.302

Source: Attachment E, Spreadsheet *Input.xls*, worksheet *SRS*. The adjusted mass is obtained by subtracting the mass of the isotopes specified as radionuclides from the calculated mass of the element.

NOTES: [a] the mass of the element was adjusted to account for the nuclide inventory that was used as the second component of the blend.

[b] $(R.E.)_2O_3$ represents the total wt% of the oxides of Pr, Ce, Nd, Sm, and Eu.

6.5.3 Radionuclide Inventory

A hypothetical maximum radiochemical loading per canister, as of 11/16/2006, is recommended in Ref. 2.2.6, Table 3 and presented in Table 8. This hypothetical inventory and the source terms derived from it are intended for use in shielding design and other applications which require the use of bounding radionuclide inventories/source terms, providing that the user found them suitable for the intended use.

Table 8. Radionuclide Inventory of the Projected Maximum SRS HLW Glass Canister at 11/16/2006

Nuclide	Activity (*Ci/canister*)	Nuclide	Activity (*Ci/canister*)	Nuclide	Activity (*Ci/canister*)
Co60	1.86E+02	Cs135	2.16E-01	U238	4.74E-02
Ni59	8.44E-01	Cs137	5.55E+04	Np237	2.88E-02
Ni63	8.01E+01	Ba137m	5.25E+04	Pu238	9.86E+02
Se79	5.34E-01	Ce144	3.83E+00	Pu239	1.74E+01
Sr90	3.43E+04	Pr144m	3.83E+00	Pu240	8.40E+00
Y90	3.43E+04	Pm147	2.22E+03	Pu241	8.44E+02
Zr93	3.86E-01	Sm151	1.61E+02	Pu242	2.14E-02
Nb93m	1.49E-01	Eu154	4.19E+02	Am241	3.33E+02
Tc99	9.16E+00	Eu155	6.79E-01	Am242m	7.77E-02
Ru106	4.36E+00	Th229	8.89E-05	Am243	1.37E+00
Pd107	1.31E-03	Th230	7.98E-06	Cm243	4.23E-01
Cd113	2.62E-11	Th232	1.40E-03	Cm244	4.37E+02
Sn121m	1.94E+00	U232	2.98E-04	Cm245	2.42E-02
Sn126	7.83E-01	U233	5.59E-02	Cm246	2.90E-02
Sb125	1.20E+02	U234	4.52E-02	Cm247	2.20E-02
I129	3.22E-04	U235	6.64E-04	Cf249	2.34E-02
Cs134	1.95E+02	U236	3.67E-03	Cf251	1.85E-02
				Total	1.83E+05

Source: Ref. 2.2.6, Table 3 and Assumption 3.2.2.

The projected maximum specific radionuclide inventory (*Curie/lb*) of SRS HLW glass, as of 11/16/2006, is provided in Ref. 2.2.14, Table 1. Based on these data, the total radionuclide inventory of SRS HLW is calculated in Attachment E, spreadsheet *Input.xls*, worksheet *SRS* and presented in Table 9.

Table 9. Total Radionuclide Inventory of SRS HLW Glass at 11/16/2006

Nuclide	**Activity (*Ci*)**	**Nuclide**	**Activity (*Ci*)**	**Nuclide**	**Activity (*Ci*)**
Co60	1.26E+06	Cs135	1.46E+03	U238	3.22E+02
Ni59	5.71E+03	Cs137	3.76E+08	Np237	1.94E+02
Ni63	5.41E+05	Ba137m	3.54E+08	Pu238	6.65E+06
Se79	3.60E+03	Ce144	2.59E+04	Pu239	1.18E+05
Sr90	2.31E+08	Pr144m	2.59E+04	Pu240	5.68E+04
Y90	2.31E+08	Pm147	1.50E+07	Pu241	5.71E+06
Zr93	2.61E+03	Sm151	1.09E+06	Pu242	1.44E+02
Nb93m	1.01E+03	Eu154	2.84E+06	Am241	2.25E+06
Tc99	6.19E+04	Eu155	4.60E+03	Am242m	5.25E+02
Ru106	2.95E+04	Th229	6.00E-01	Am243	9.25E+03
Pd107	8.84E+00	Th230	5.41E-02	Cm243	2.87E+03
Cd113	1.77E-07	Th232	9.49E+00	Cm244	2.95E+06
Sn121m	1.31E+04	U232	2.01E+00	Cm245	1.63E+02
Sn126	5.30E+03	U233	3.79E+02	Cm246	1.96E+02
Sb125	8.14E+05	U234	3.06E+02	Cm247	1.48E+02
I129	2.18E+00	U235	4.49E+00	Cf249	1.58E+02
Cs134	1.32E+06	U236	2.48E+01	Cf251	1.25E+02
				Total	1.23E+09

Source: Attachment E, spreadsheet *Input.xls*, worksheet *SRS*

6.6 HLW OF WEST VALLEY DEMONSTRATION PROJECT

The HLW produced at the WVDP comes from the commercial SNF reprocessing plant operated by Nuclear Fuel Services. The HLW has already been converted into borosilicate glass at WVDP and poured into 275 canisters (Ref. 2.2.6, Table 12) with nominal outside diameter of 0.61 *meter*, nominal height of 3 *meters*, and wall thickness of 0.34 cm (Ref. 2.2.16, WQR 3.11 p. 2). The total HLW glass volume and mass are 210 *cubic meters*, and 550 *metric tons*, respectively (Ref. 2.2.6, Table 11). The mass of the glass in each canister is approximately 2000 *kg* (Ref. 2.2.6, Section 6.14) and the density of WVDP HLW glass is 2.6 to 2.7 g/cm^3 (Ref. 2.2.12, Attachment 3, item 6).

Information included in the Ref. 2.2.16 and Ref. 2.2.17 is prepared directly by the waste generator/custodian (West Valley Nuclear Services).

The West Valley Nuclear Services is the most authoritative source of information and the data is unique and considered reliable. Therefore, the information provided is suitable for use in this calculation for nuclide inventories calculation and source terms generation.

6.6.1 Chemical Composition

The recommended chemical composition of the WVDP HLW glass is provided in Ref. 2.2.6, Table 5 and presented in Table 10.

Table 10. Chemical Composition of WVDP HLW Glass

Compound	wt%	Compound	wt%
Al_2O_3	6.04	Nd_2O_3	0.14
B_2O_3	12.97	NiO	0.25
BaO	0.16	P_2O_5	1.21
CaO	0.48	RuO_2	0.08
Ce_2O_3	0.31	SiO_2	41.22
Cr_2O_3	0.14	SrO	0.02
Fe_2O_3	12.09	ThO_2	3.58
K_2O	5.03	TiO_2	0.80
Li_2O	3.73	UO_3	0.63
MgO	0.90	ZnO	0.02
MnO	0.82	ZrO_2	1.33
Na_2O	8.05	Total	100

Source: Ref. 2.2.6, Table 5 and Assumption 3.2.1.

6.6.2 Elemental Composition

Based on the chemical composition of WVDP HLW glass (Table 10), the elemental composition is calculated in Attachment E spreadsheet *Input.xls*, worksheet *WV* and presented in Table 11.

The uranium, thorium, and some fission products are included in the radionuclide inventory; therefore, their masses are adjusted so they will not be considered twice in the calculation. In the ORIGEN-S input they are accounted for in the radionuclide input and excluded from the HLW glass mass input.

Table 11. Elemental Composition by Mass of WVDP HLW Glass Canister

Element	Mass (*kg*)	Adjusted Mass (*kg*)	Element	Mass (*kg*)	Adjusted Mass (*kg*)
Al	63.933	N/A	Nd	2.401	N/A
B	80.562	N/A	Ni [a]	3.929	3.915
Ba	2.866	N/A	O	901.459	N/A
Ca	6.861	N/A	P	10.561	N/A
Ce	5.293	N/A	Ru	1.229	N/A
Cr	1.916	N/A	Si	385.353	N/A
Fe	169.121	N/A	Sr [a]	0.340	0.140
K	83.513	N/A	Th [a]	62.923	0.000
Li	34.657	N/A	Ti	9.589	N/A
Mg	10.855	N/A	U [a]	10.485	0.000
Mn	12.701	N/A	Zn	0.321	N/A
Na	119.439	N/A	Zr [a]	19.692	18.660
			Total	2000.000	1925.346

Source: Attachment E, Spreadsheet*Input.xls*, worksheet *WV*. The adjusted mass is obtained by subtracting the mass of the isotopes specified as radionuclides from the calculated mass of the element.

NOTE: [a] the mass of the element was adjusted to account for the nuclide inventory that was used as the second component of the blend.

6.6.3 Radionuclide Inventory

The total radionuclide inventory of the WVDP HLW glass, as of year 1996, is provided in Ref. 2.2.6, Table 15 and presented in Table 12.

Table 12 Total Radionuclide Inventory per WVDP HLW Glass as of year 1996

Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)
^{3}H	5.87E+01	^{144}Pr	3.11E-03	^{230}Th	5.87E-02
^{14}C	1.37E+02	^{146}Pm	5.11E+00	^{232}Th	1.64E+00
^{55}Fe	1.42E+02	^{147}Pm	1.80E+04	^{231}Pa	1.52E+01
^{60}Co	3.49E+02	^{151}Sm	8.05E+04	^{232}U	6.87E+00
^{59}Ni	1.06E+02	^{152}Eu	2.69E+02	^{233}U	9.53E+00
^{63}Ni	8.17E+03	^{154}Eu	5.91E+04	^{234}U	4.61E+00
^{79}Se	6.02E+01	^{155}Eu	1.03E+04	^{235}U	1.01E-01
^{90}Sr	5.81E+06	^{207}Tl	9.40E+00	^{236}U	2.96E-01
^{90}Y	5.81E+06	^{208}Tl	3.09E+00	^{238}U	8.54E-01
^{93}Zr	2.72E+02	^{211}Pb	9.43E+00	^{236}Np	9.47E+00
^{93m}Nb	2.07E+02	^{212}Pb	8.62E+00	^{237}Np	2.35E+01
^{99}Tc	1.70E+03	^{211}Bi	9.43E+00	^{239}Np	3.47E+02
^{106}Ru	2.31E-01	^{212}Bi	8.62E+00	^{236}Pu	8.43E-01
^{106}Rh	2.31E-01	^{212}Po	5.52E+00	^{238}Pu	8.04E+03
^{107}Pd	1.10E+01	^{215}Po	9.43E+00	^{239}Pu	1.65E+03
^{113m}Cd	1.60E+03	^{216}Po	8.62E+00	^{240}Pu	1.22E+03
^{121m}Sn	1.61E+01	^{219}Rn	9.43E+00	^{241}Pu	6.13E+04
^{126}Sn	1.04E+02	^{220}Rn	8.62E+00	^{242}Pu	1.65E+00
^{125}Sb	1.62E+03	^{223}Fr	1.30E-01	^{241}Am	5.35E+04
^{126}Sb	1.46E+01	^{223}Ra	9.43E+00	^{242}Am	2.87E+02
^{126m}Sb	1.04E+02	^{224}Ra	8.62E+00	^{242m}Am	2.89E+02
^{125m}Te	3.97E+02	^{228}Ra	1.58E+00	^{243}Am	3.47E+02
^{129}I	2.10E-01	^{227}Ac	9.43E+00	^{242}Cm	2.38E+02
^{134}Cs	6.87E+02	^{228}Ac	1.58E+00	^{243}Cm	1.16E+02
^{135}Cs	1.61E+02	^{227}Th	9.30E+00	^{244}Cm	6.07E+03
^{137}Cs	6.29E+06	^{228}Th	8.62E+00	^{245}Cm	8.81E-01
^{137m}Ba	5.95E+06	^{229}Th	2.15E-01	^{246}Cm	1.01E-01
^{144}Ce	3.11E-03			Total	2.42E+07

Source: Ref. 2.2.6, Table 15

Ref. 2.2.16, WQR 1.2, Table 5, *High Curies*, provides the bounding radionuclide inventory for WV HLW canister, as of year 1996. Since not all radionuclides are provided, the inventory was updated as follows:

- The secular equilibrium activities of ^{90}Y and ^{137m}Ba were calculated based on 1.0 branching factor for ^{90}Sr→^{90}Y and 0.946 branching factor for ^{137}Cs→^{137m}Ba. The secular equilibrium is reached after few half-life times of the progeny nuclide; therefore, since HLW cooling time is very large compared with ^{90}Y ($T_{1/2}$=64 hours) and ^{137m}Ba ($T_{1/2}$=2.552 minutes) half-lives, both ^{90}Y and ^{137m}Ba, reached the secular equilibrium with their parents.

- The scaling factors for the year 1996 are provided for some nuclides (Ref. 2.2.17, WQR 1.2, Addendum 1, Table 5). Their activity was obtained multiplying these factors with the ^{90}Sr/^{137}Cs activities from Ref. 2.2.16, WQR 1.2, Table 5, *High Curies*.
- An average activity was calculated dividing the total radionuclide activities provided in Table 12 by the number of canisters poured at WV (Ref. 2.2.6, Table 12).
- The highest of the two values (scaled or averaged) was selected for each nuclide.

The calculated radionuclide inventory per WVDP HLW canister as of year 1996 (Attachment E, spreadsheet *Input.xls*, worksheet *WV*) is presented in Table 13.

Table 13. Radionuclide Inventory per WVDP HLW Glass Canister as of year 1996

Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)
^{3}H [c]	2.13E-01	^{144}Pr [c]	1.13E-05	^{230}Th [c]	2.13E-04
^{14}C	1.30E+00	^{146}Pm [c]	1.86E-02	^{232}Th	1.55E-02
^{55}Fe [c]	5.16E-01	^{147}Pm [c]	6.55E+01	^{231}Pa	1.44E-01
^{60}Co [b]	1.05E+01	^{151}Sm	7.63E+02	^{232}U [c]	2.50E-02
^{59}Ni	1.00E+00	^{152}Eu [c]	9.78E-01	^{233}U	9.03E-02
^{63}Ni	7.74E+01	^{154}Eu [b]	2.57E+02	^{234}U	2.40E-02
^{79}Se	5.70E-01	^{155}Eu [c]	3.75E+01	^{235}U [b]	3.72E-04
^{90}Sr	2.80E+04	^{207}Tl [c]	3.42E-02	^{236}U [b]	1.08E-03
^{90}Y	2.80E+04	^{208}Tl [c]	1.12E-02	^{238}U [b]	3.33E-03
^{93}Zr	2.58E+00	^{211}Pb [c]	3.43E-02	^{236}Np	8.97E-02
^{93m}Nb	1.96E+00	^{212}Pb [c]	3.13E-02	^{237}Np	1.50E-01
^{99}Tc	8.72E+00	^{211}Bi [c]	3.43E-02	^{239}Np [c]	1.26E+00
^{106}Ru [c]	8.40E-04	^{212}Bi [c]	3.13E-02	^{236}Pu [b]	3.11E-01
^{106}Rh [c]	8.40E-04	^{212}Po [c]	2.01E-02	^{238}Pu	3.92E+01
^{107}Pd	1.04E-01	^{215}Po [c]	3.43E-02	^{239}Pu	8.75E+00
^{113m}Cd [c]	5.82E+00	^{216}Po [c]	3.13E-02	^{240}Pu	6.28E+00
^{121m}Sn [c]	5.85E-02	^{219}Rn [c]	3.43E-02	^{241}Pu	3.11E+02
^{126}Sn	9.85E-01	^{220}Rn [c]	3.13E-02	^{242}Pu	8.15E-03
^{125}Sb [c]	5.89E+00	^{223}Fr [c]	4.73E-04	^{241}Am	5.07E+02
^{126}Sb [c]	5.31E-02	^{223}Ra [c]	3.43E-02	^{242}Am [c]	1.04E+00
^{126m}Sb [c]	3.78E-01	^{224}Ra [c]	3.13E-02	^{242m}Am	2.74E+00
^{125m}Te [c]	1.44E+00	^{228}Ra [c]	5.75E-03	^{243}Am	3.28E+00
^{129}I [c]	7.64E-04	^{227}Ac	8.93E-02	^{242}Cm [b]	2.13E+01
^{134}Cs [b]	4.76E+00	^{228}Ac [c]	5.75E-03	^{243}Cm [c]	4.22E-01
^{135}Cs	1.09E+00	^{227}Th [c]	3.38E-02	^{244}Cm	5.75E+01
^{137}Cs	3.17E+04	^{228}Th [c]	3.13E-02	^{245}Cm [c]	3.20E-03
^{137m}Ba	3.00E+04	^{229}Th [c]	7.82E-04	^{246}Cm [c]	3.67E-04
^{144}Ce [c]	1.13E-05			Total	1.20E+05

Source: Attachment E, spreadsheet *Input.xls*, worksheet *WV* and Assumption 3.2.2.
NOTES: [a] Activity calculated based on secular equilibrium (parent's activity*branching factor).
[b] Activity calculated based on scaling factors (isotope activity*scaling factor).
[c] Activity calculated based on average of total inventory (total isotope activity/number of canisters).

6.7 HLW OF IDAHO NATIONAL LABORATORY

INL has proposed three different HLW stream matrices for disposal – glass, ceramic, and metal. The glass matrix waste stream would come from the Idaho Nuclear Technology and Engineering Center (INTEC). The Argonne National Laboratory-West (ANL-W) would generate both the ceramic and the metallic HLW matrices. However, the INL ceramic and metal waste forms are not expected to be disposed of at the Yucca Mountain MGR (Section 6.1); therefore, they are not a subject of this calculation. An estimated 1190 INL/INTEC HLW glass canisters will be poured at the INL and the mass of glass in each canister will be approximately 1,560 *kg* (Ref. 2.2.12,

Table ID-1). The estimated total HLW glass volume, mass, and density are 743 *cubic meters*, 1,860 *metric tons*, and 2.5 g/cm^3, respectively (Ref. 2.2.12, Table ID-1). Each canister has a nominal outside diameter of 0.61 *meter* (2 *feet*) and a nominal height of 3 *meters* (10 *feet*) (See Table 6.3-1).

Information regarding the INL HLW glass included in Ref. 2.2.12 and Ref. 2.2.13 was prepared by the waste generator/custodian (INL), at the Yucca Mountain Site Characterization Office request, to support analyses for the Yucca Mountain Project.

The INL is the most authoritative source of information and the data is unique and considered reliable. Therefore, the information provided is suitable for use in this calculation for nuclide inventories calculation and source terms generation.

6.7.1 Chemical Composition

The chemical composition of INL/INTEC HLW glass, recommended in Ref. 2.2.6, Table 2, is presented in Table 14.

Table 14. Chemical Composition of INL/INTEC HLW Glass

Compound/Metal	wt%	Compound/Metal	wt%
Al_2O_3	7.11	P_2O_5	0.05
$N_3H_{12}PMo_{12}O_{40}$	1.40	SiO_2	54.87
B_2O_3	10.94	ZrO_2	0.93
CaF_2	7.75	Cd	2.27
CaO	0.22	Cr	0.73
Cs_2O	0.01	Hg	0.01
Fe_2O_3	0.04	Ni	0.08
Na_2O	13.48	Pb	0.10
		Total	100

Source: Ref. 2.2.6, Table 2 and Assumption 3.2.1.

6.7.2 Elemental Composition

Based on the chemical composition of INL/INTEC HLW glass (Table 14), the elemental composition is calculated in Attachment E spreadsheet *Input.xls*, worksheet *INL* and presented in Table 15.

The cesium is included in the ORIGEN-S input as part of the radionuclide inventory and, hence, excluded from the HLW glass mass input.

Table 15. Elemental Composition of INL/INTEC HLW Glass per Canister

Element	Mass (*kg*)	Adjusted Mass (*kg*)	Element	Mass (*kg*)	Adjusted Mass (*kg*)
Al	58.702	N/A	Zr	10.741	N/A
N	0.489	N/A	O	692.851	N/A
B	53.003	N/A	Cd	35.412	N/A
Ca	64.514	N/A	Cr	11.388	N/A
H	0.141	N/A	Hg	0.156	N/A
Cs [a]	0.147	0.000	Ni	1.248	N/A
Fe	0.436	N/A	Pb	1.560	N/A
Na	156.004	N/A	Mo	13.400	N/A
P	0.701	N/A	F	58.839	N/A
Si	400.111	N/A	Total	1559.844 [b]	1559.697

Source: Attachment E, Spreadsheet *Input.xls*, worksheet *INL*.
NOTE: [a] the mass of the element was adjusted to account for the nuclide inventory that was used as the second component of the blend.
[b] the total mass per canister differs from 1560 kg (Section 6.7) due to rounding error.

6.7.3 Radionuclide Inventory

The total radionuclide inventory of the INL/INTEC HLW glass provided by the waste generator (Ref. 2.2.6, Table 17) for year 2035 is presented in Table 16.

Table 16. Total Radionuclide Inventory of INL/INTEC HLW Glass as of year 2035

Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)	Nuclide	Activity (*Ci*)
^{3}H	3.56E+03	^{137m}Ba	5.60E+06	^{239}Pu	1.81E+03
^{14}C	2.78E-02	^{147}Pm	2.67E+01	^{240}Pu	1.57E+03
^{60}Co	3.21E+01	^{154}Eu	5.98E+03	^{241}Pu	1.93E+04
^{90}Sr	7.04E+06	^{155}Eu	7.55E+00	^{242}Pu	3.42E+00
^{90}Y	7.04E+06	^{226}Ra	9.69E-03	^{241}Am	1.27E+04
^{93m}Nb	4.74E+02	^{230}Th	3.95E-01	^{242}Am	1.50E-02
^{94}Nb	5.36E-03	^{232}Th	9.89E-08	^{243}Am	1.39E-02
^{99}Tc	3.41E+03	^{232}U	4.63E-03	^{242}Cm	1.24E-02
^{102}Rh	1.99E-05	^{233}U	1.33E-03	^{243}Cm	4.70E-04
^{125}Sb	1.03E+00	^{234}U	9.95E+01	^{244}Cm	1.03E-02
^{126}Sn	8.91E+01	^{235}U	5.90E-01	^{245}Cm	3.69E-06
^{129}I	5.64E+00	^{236}U	1.54E+00	^{246}Cm	8.66E-08
^{134}Cs	3.28E-02	^{238}U	2.94E-02	^{247}Cm	3.09 E-14
^{135}Cs	1.63E+02	^{237}Np	6.26E+00	^{248}Cm	9.35 E-15
^{137}Cs	5.95E+06	^{238}Pu	8.98E+04	Total	2.58E+07

Source: Ref. 2.2.6, Table 17

Based on Ref. 2.2.13 (p. 5, item 2 and Table ID-II), the bounding radionuclide inventory per canister is calculated in Attachment E, spreadsheet *Input.xls*, worksheet *INL* and presented in Table 17.

Table 17. Radionuclide Inventory of INL/INTEC HLW Canister as of year 2035

Nuclide	Activity (*Ci/canister*)	Nuclide	Activity (*Ci/canister*)	Nuclide	Activity (*Ci/canister*)
^{3}H	4.30E+00	^{137m}Ba	1.16E+04	^{239}Pu	2.01E+00
^{14}C	8.26E-05	^{147}Pm	2.97E-02	^{240}Pu	1.75E+00
^{60}Co	3.57E-02	^{154}Eu	6.65E+00	^{241}Pu	2.15E+01
^{90}Sr	1.16E+04	^{155}Eu	3.75E-02	^{242}Pu	3.80E-03
^{90}Y	1.16E+04	^{226}Ra	7.16E-05	^{241}Am	1.41E+01
^{93m}Nb	1.43E+00	^{230}Th	2.75E-03	^{242}Am	9.37E-05
^{94}Nb	1.60E-05	^{232}Th	4.96 E-10	^{243}Am	1.05E-04
^{99}Tc	9.92E+00	^{232}U	6.15E-06	^{242}Cm	7.71E-05
^{102}Rh	2.21E-08	^{233}U	6.06E-06	^{243}Cm	3.36E-06
^{125}Sb	1.14E-03	^{234}U	1.11E-01	^{244}Cm	7.71E-05
^{126}Sn	2.59E-01	^{235}U	6.57E-04	^{245}Cm	2.81E-08
^{129}I	1.65E-02	^{236}U	1.71E-03	^{246}Cm	6.61 E-10
^{134}Cs	3.64E-05	^{238}U	3.27E-05	^{247}Cm	2.37 E-16
^{135}Cs	2.53E-01	^{237}Np	2.75E-02	^{248}Cm	7.16 E-17
^{137}Cs	1.21E+04	^{238}Pu	9.99E+01	Total	4.71E+04

Source: Attachment E, spreadsheet *Input.xls*, worksheet *INL* and Assumption 3.2.2.

7 RESULTS AND CONCLUSIONS

The source terms of the HLW have been calculated using the ORIGEN-S module of the SCALE 4.4 computer code system (Ref. 2.2.7). The radionuclide inventory (*gram* and *Curie*), the gamma (s^{-1} and $MeV \cdot s^{-1}$) and neutron (s^{-1}) production rates, and the decay heat (*Watt*) were calculated for each of the four HLW canister types. The radionuclide inventory (*gram* and *Curie*) and decay heat (*Watt*) as well as the grand totals have been determined for the entire HLW glass amount from each site. The time period for which the waste characteristics were determined extends to 1,000,000 years (see Table 1).

An extract of the decay calculations results is presented in the following subsections and attachments. However, complete radionuclide inventories and source terms are available on the ORIGEN-S output files which are provided in Attachment E, folder *ORIGEN*.

7.1 RESULTS

7.1.1 HLW Information

For each HLW type the following information is requested during the ORIGEN-S runs for each time step of interest (Table 1):

- nuclide mass for total inventory and per canister basis - *g*
- nuclide radioactivity for total inventory and per canister basis - *Ci*
- nuclide thermal (total) power (heat generation rate) for total inventory and per canister basis - *W*
- nuclide gamma power for total inventory and per canister basis - *W*
- total (α-n and spontaneous fission) neutron source term on standard 27 energy groups per canister basis – *neutrons/s*
- gamma source term on standard 18 energy groups per canister basis - *photons/s* and *MeV/s*.

7.1.2 Radionuclide Inventory

Table 18 and Table 19 present the radionuclide inventory per canister for each HLW type at years 2017 and 2067, respectively.

Table 18 Maximum Radionuclide Inventory per HLW Glass Canister at 2017

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	SRS	WVDP	INL [a]
Ac225	1.40E-06	1.39E-04	9.47E-04	4.26E-17
Ac227	1.72E-04	2.09E-08	1.16E-01	1.85E-17
Ac228	9.38E-05	9.87E-04	1.47E-02	2.33E-14
Am241	4.61E+02	3.38E+02	4.97E+02	1.41E+01
Am242	—	7.36E-02	2.46E+00	6.32E-05
Am242m	—	7.39E-02	2.47E+00	—

Table 18 Maximum Radionuclide Inventory per HLW Glass Canister at 2017

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	SRS	WVDP	INL [a]
Am243	9.98E-02	1.37E+00	3.27E+00	1.05E-04
At217	1.40E-06	1.39E-04	9.47E-04	4.26E-17
Ba137m	5.62E+04	4.15E+04	1.84E+04	1.14E+04
Bi210	2.51E-06	5.99E-09	5.17E-07	1.17E-12
Bi211	1.72E-04	2.09E-08	1.16E-01	1.69E-21
Bi212	4.85E-04	1.07E-03	4.74E-02	9.20E-12
Bi213	1.40E-06	1.39E-04	9.47E-04	4.26E-17
Bi214	1.29E-05	4.60E-08	1.95E-06	4.76E-06
C14	1.06E-07	—	1.30E+00	8.26E-05
Cd113	1.47E-09	2.62E-11	—	1.48E-09
Cd113m	1.91E+01	—	2.07E+00	—
Ce142	1.17E-05	—	1.43E-05	—
Ce144	—	4.74E-04	8.90E-14	—
Cf249	—	2.29E-02	—	—
Cf251	—	1.84E-02	—	—
Cm242	6.54E-06	6.10E-02	2.04E+00	7.71E-05
Cm243	3.73E-02	3.31E-01	2.53E-01	3.36E-06
Cm244	3.27E-01	2.97E+02	2.57E+01	7.71E-05
Cm245	—	2.42E-02	3.19E-03	2.81E-08
Cm246	—	2.90E-02	3.66E-04	6.61E-10
Cm247	—	2.20E-02	—	2.37E-16
Cm248	—	—	—	7.16E-17
Co60	4.14E-01	4.91E+01	6.63E-01	3.57E-02
Cs134	2.12E+01	6.48E+00	4.09E-03	3.64E-05
Cs135	—	2.16E-01	1.09E+00	2.53E-01
Cs137	5.95E+04	4.39E+04	1.95E+04	1.21E+04
Eu152	3.45E+00	—	3.28E-01	—
Eu154	4.50E+00	1.85E+02	4.72E+01	6.65E+00
Eu155	1.16E+02	1.52E-01	1.67E+00	3.75E-02
Fe55	—	—	2.49E-03	—
Fr221	1.40E-06	1.39E-04	9.47E-04	4.26E-17
Fr223	2.37E-06	2.88E-10	1.60E-03	2.55E-19
Gd152	5.22E-14	—	2.24E-14	—
H3	—	—	6.54E-02	4.30E+00
I129	—	3.22E-04	7.64E-04	1.65E-02
K40	1.07E-05	2.77E-05	7.17E-05	—
La138	3.98E-07	3.04E-08	—	—
Nb93m	3.30E+00	2.33E-01	2.33E+00	1.43E+00
Nb94	—	—	—	1.60E-05
Nd144	4.12E-09	1.43E-15	6.77E-10	—
Ni59	4.96E-01	8.44E-01	1.00E+00	—
Ni63	4.89E+01	7.47E+01	6.69E+01	—

Table 18 Maximum Radionuclide Inventory per HLW Glass Canister at 2017

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	SRS	WVDP	INL [a]
Np236	—	—	8.97E-02	
Np237	2.51E-01	2.99E-02	1.53E-01	2.75E-02
Np238	—	3.33E-04	1.11E-02	—
Np239	9.98E-02	1.37E+00	3.27E+00	1.11E-05
Pa231	4.24E-04	1.43E-07	1.44E-01	1.65E-12
Pa233	2.51E-01	2.99E-02	1.53E-01	2.66E-04
Pa234	1.31E-05	6.16E-05	4.33E-06	1.62E-10
Pa234m	1.01E-02	4.74E-02	3.33E-03	3.55E-07
Pb209	1.40E-06	1.39E-04	9.47E-04	1.27E-17
Pb210	2.51E-06	5.99E-09	5.16E-07	6.77E-11
Pb211	1.72E-04	2.09E-08	1.16E-01	1.69E-21
Pb212	4.85E-04	1.07E-03	4.74E-02	1.40E-11
Pb214	1.29E-05	4.60E-08	1.95E-06	4.76E-06
Pd107	—	1.31E-03	1.04E-01	—
Pm146	—	—	1.34E-03	—
Pm147	—	1.53E+02	2.55E-01	2.97E-02
Po210	2.31E-06	5.29E-09	4.87E-07	5.61E-16
Po211	4.74E-07	5.74E-11	3.20E-04	4.65E-24
Po212	3.11E-04	6.87E-04	3.04E-02	5.90E-12
Po213	1.37E-06	1.36E-04	9.27E-04	4.17E-17
Po214	1.29E-05	4.60E-08	1.95E-06	4.75E-06
Po215	1.72E-04	2.09E-08	1.16E-01	1.69E-21
Po216	4.85E-04	1.07E-03	4.74E-02	8.11E-11
Po218	1.29E-05	4.60E-08	1.95E-06	4.76E-06
Pr144	—	4.74E-04	8.90E-14	—
Pr144m	—	6.63E-06	1.25E-15	—
Pu236	—	—	9.98E-03	—
Pu238	2.17E+00	9.10E+02	3.36E+01	9.99E+01
Pu239	2.13E+01	1.74E+01	8.75E+00	2.01E+00
Pu240	6.42E+00	8.78E+00	6.35E+00	1.75E+00
Pu241	8.70E+01	5.17E+02	1.13E+02	2.15E+01
Pu242	9.91E-04	2.14E-02	8.17E-03	3.80E-03
Pu243	—	2.20E-02	—	1.71E-16
Ra223	1.72E-04	2.09E-08	1.16E-01	1.69E-21
Ra224	4.85E-04	1.07E-03	4.74E-02	8.11E-11
Ra225	1.40E-06	1.39E-04	9.47E-04	4.89E-15
Ra226	1.29E-05	4.60E-08	1.95E-06	7.16E-05
Ra228	9.38E-05	9.87E-04	1.47E-02	6.21E-14
Rb87	7.42E-06	—	—	—
Rh102	—	—	—	2.21E-08
Rh106	1.37E-04	4.40E-03	5.14E-10	—
Rn219	1.72E-04	2.09E-08	1.16E-01	1.69E-21

Table 18 Maximum Radionuclide Inventory per HLW Glass Canister at 2017

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	SRS	WVDP	INL [a]
Rn220	4.85E-04	1.07E-03	4.74E-02	8.11E-11
Rn222	1.29E-05	4.60E-08	1.95E-06	4.76E-06
Ru106	1.37E-04	4.40E-03	5.14E-10	—
Sb125	3.16E+00	9.17E+00	2.85E-02	1.14E-03
Sb126	8.04E-02	1.10E-01	1.38E-01	7.61E-04
Sb126m	5.74E-01	7.83E-01	9.85E-01	2.59E-01
Se79	9.15E-02	5.34E-01	5.70E-01	—
Sm146	—	—	3.14E-10	—
Sm147	—	5.12E-08	1.61E-09	2.02E-16
Sm151	3.43E+03	1.49E+02	6.49E+02	—
Sn121	—	1.33E+00	3.48E-02	—
Sn121m	—	1.71E+00	4.49E-02	—
Sn126	5.74E-01	7.83E-01	9.85E-01	2.59E-01
Sr90	6.21E+04	2.67E+04	1.67E+04	1.16E+04
Tc99	2.31E+01	9.16E+00	8.72E+00	9.92E+00
Te123	1.07E-09	—	—	—
Te125m	7.72E-01	2.24E+00	6.95E-03	1.19E-06
Th227	1.70E-04	2.06E-08	1.15E-01	6.47E-20
Th228	4.84E-04	1.07E-03	4.72E-02	2.31E-09
Th229	1.40E-06	1.39E-04	9.47E-04	5.53E-13
Th230	9.41E-07	1.35E-05	2.18E-04	1.06E-09
Th231	5.56E-04	6.64E-04	3.72E-04	1.44E-04
Th232	1.50E-04	1.40E-03	1.55E-02	4.96E-10
Th234	1.01E-02	4.74E-02	3.33E-03	3.55E-07
Tl206	3.32E-12	—	6.82E-13	1.55E-18
Tl207	1.72E-04	2.08E-08	1.16E-01	1.69E-21
Tl208	1.74E-04	3.85E-04	1.70E-02	3.31E-12
Tl209	2.93E-08	2.91E-06	1.99E-05	8.94E-19
U232	4.40E-04	2.69E-04	3.24E-02	6.15E-06
U233	2.10E-03	5.59E-02	9.03E-02	6.06E-06
U234	1.46E-02	7.23E-02	2.62E-02	1.11E-01
U235	5.56E-04	6.64E-04	3.72E-04	6.57E-04
U236	1.18E-03	3.67E-03	1.08E-03	1.71E-03
U237	2.08E-03	1.24E-02	2.70E-03	1.96E-05
U238	1.01E-02	4.74E-02	3.33E-03	3.27E-05
V50	2.35E-14	—	—	—
Y90	6.21E+04	2.67E+04	1.67E+04	1.16E+04
Zr93	5.76E+00	3.86E-01	2.58E+00	—
Total	2.44E+05	1.42E+05	7.28E+04	4.69E+04

Source: Attachment E, spreadsheet *Results.xls*, worksheet *Cinv*
NOTES: [a] Radionuclide inventory for INL HLW canister is provided for year 2035

Table 19 Maximum Radionuclide Inventory per HLW Glass Canister at 2067

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	SRS	WVDP	INL
Ac225	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Ac227	3.73E-04	4.71E-07	1.38E-01	1.66E-07
Ac228	1.50E-04	1.40E-03	1.55E-02	4.88E-10
Am241	4.28E+02	3.27E+02	4.62E+02	1.39E+01
Am242	—	5.76E-02	1.92E+00	—
Am242m	—	5.78E-02	1.93E+00	—
Am243	9.94E-02	1.36E+00	3.26E+00	1.05E-04
At217	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Ba137m	1.77E+04	1.31E+04	5.80E+03	5.45E+03
Bi210	1.06E-05	3.68E-07	3.98E-06	4.48E-05
Bi211	3.74E-04	4.72E-07	1.38E-01	1.67E-07
Bi212	4.27E-04	1.57E-03	3.89E-02	4.62E-06
Bi213	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Bi214	1.27E-05	8.83E-07	6.71E-06	7.08E-05
C14	1.05E-07	—	1.29E+00	8.23E-05
Cd113	1.47E-09	2.62E-11	—	1.48E-09
Cd113m	1.63E+00	—	1.77E-01	—
Ce142	1.17E-05	—	1.43E-05	—
Ce144	—	—	—	—
Cf249	—	2.08E-02	—	—
Cf251	—	1.77E-02	—	—
Cm242	—	4.77E-02	1.59E+00	—
Cm243	1.10E-02	9.80E-02	7.50E-02	1.54E-06
Cm244	4.81E-02	4.37E+01	3.79E+00	2.26E-05
Cm245	—	2.42E-02	3.18E-03	2.80E-08
Cm246	—	2.87E-02	3.63E-04	6.58E-10
Cm247	—	2.20E-02	—	—
Cm248	—	—	—	—
Co60	5.76E-04	6.83E-02	9.23E-04	5.30E-04
Cs134	1.06E-06	3.25E-07	2.05E-10	7.74E-10
Cs135	—	2.16E-01	1.09E+00	2.53E-01
Cs137	1.88E+04	1.38E+04	6.15E+03	5.78E+03
Eu152	2.56E-01	—	2.44E-02	—
Eu154	7.97E-02	3.27E+00	8.35E-01	5.03E-01
Eu155	7.07E-02	9.21E-05	1.02E-03	3.28E-04
Fe55	—	—	7.64E-09	—
Fr221	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Fr223	5.14E-06	6.50E-09	1.91E-03	2.30E-09
Gd152	1.62E-13	—	3.29E-14	—
H3	—	—	3.93E-03	7.11E-01
I129	—	3.22E-04	7.64E-04	1.65E-02
K40	1.07E-05	2.77E-05	7.17E-05	—
La138	3.98E-07	3.04E-08	—	—
Nb93m	5.47E+00	3.68E-01	2.55E+00	3.61E-01
Nb94	—	—	—	1.60E-05
Nd144	4.12E-09	1.43E-15	6.77E-10	—

Table 19 Maximum Radionuclide Inventory per HLW Glass Canister at 2067

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	SRS	WVDP	INL
Ni59	4.96E-01	8.44E-01	9.99E-01	—
Ni63	3.46E+01	5.28E+01	4.73E+01	—
Np236	—	—	8.97E-02	—
Np237	2.58E-01	3.53E-02	1.61E-01	2.76E-02
Np238	—	2.60E-04	8.70E-03	—
Np239	9.94E-02	1.36E+00	3.26E+00	1.05E-04
Pa231	4.24E-04	8.49E-07	1.44E-01	4.46E-07
Pa233	2.58E-01	3.53E-02	1.61E-01	2.76E-02
Pa234	1.31E-05	6.16E-05	4.33E-06	4.25E-08
Pa234m	1.01E-02	4.74E-02	3.33E-03	3.27E-05
Pb209	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Pb210	1.06E-05	3.68E-07	3.98E-06	4.48E-05
Pb211	3.74E-04	4.72E-07	1.38E-01	1.67E-07
Pb212	4.27E-04	1.57E-03	3.89E-02	4.62E-06
Pb214	1.27E-05	8.83E-07	6.71E-06	7.08E-05
Pd107	—	1.31E-03	1.04E-01	—
Pm146	—	—	2.53E-06	—
Pm147	—	2.80E-04	4.66E-07	6.32E-06
Po210	1.04E-05	3.55E-07	3.88E-06	4.38E-05
Po211	1.03E-06	1.30E-09	3.81E-04	4.59E-10
Po212	2.73E-04	1.01E-03	2.49E-02	2.96E-06
Po213	1.05E-05	3.75E-04	1.31E-03	2.25E-08
Po214	1.27E-05	8.83E-07	6.71E-06	7.08E-05
Po215	3.74E-04	4.72E-07	1.38E-01	1.67E-07
Po216	4.27E-04	1.57E-03	3.89E-02	4.62E-06
Po218	1.27E-05	8.83E-07	6.71E-06	7.08E-05
Pr144	—	—	—	—
Pr144m	—	—	—	—
Pu236	—	—	7.98E-03	—
Pu238	1.46E+00	6.13E+02	2.32E+01	7.76E+01
Pu239	2.13E+01	1.74E+01	8.74E+00	2.01E+00
Pu240	6.38E+00	9.43E+00	6.38E+00	1.74E+00
Pu241	7.77E+00	4.62E+01	1.01E+01	4.58E+00
Pu242	9.91E-04	2.14E-02	8.20E-03	3.80E-03
Pu243	—	2.20E-02	—	—
Ra223	3.74E-04	4.72E-07	1.38E-01	1.67E-07
Ra224	4.27E-04	1.57E-03	3.89E-02	4.62E-06
Ra225	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Ra226	1.27E-05	8.83E-07	6.71E-06	7.08E-05
Ra228	1.50E-04	1.40E-03	1.55E-02	4.88E-10
Rb87	7.42E-06	—	—	—
Rh102	—	—	—	1.05E-11
Rh106	—	—	—	—
Rn219	3.74E-04	4.72E-07	1.38E-01	1.67E-07
Rn220	4.27E-04	1.57E-03	3.89E-02	4.62E-06
Rn222	1.27E-05	8.83E-07	6.71E-06	7.08E-05

Table 19 Maximum Radionuclide Inventory per HLW Glass Canister at 2067

Nuclide	Radioactivity (*Ci/Canister*)			
	HS	**SRS**	**WVDP**	**INL**
Ru106	—	—	—	—
Sb125	9.68E-06	2.81E-05	8.72E-08	3.37E-07
Sb126	8.03E-02	1.10E-01	1.38E-01	3.63E-02
Sb126m	5.74E-01	7.83E-01	9.85E-01	2.59E-01
Se79	9.15E-02	5.34E-01	5.70E-01	—
Sm146	—	—	3.39E-10	—
Sm147	—	5.49E-08	1.62E-09	7.35E-13
Sm151	2.33E+03	1.01E+02	4.42E+02	—
Sn121	—	7.06E-01	1.86E-02	—
Sn121m	—	9.09E-01	2.39E-02	—
Sn126	5.74E-01	7.83E-01	9.85E-01	2.59E-01
Sr90	1.81E+04	7.80E+03	4.87E+03	5.27E+03
Tc99	2.31E+01	9.16E+00	8.72E+00	9.92E+00
Te123	1.07E-09	—	—	—
Te125m	2.36E-06	6.86E-06	2.13E-08	8.24E-08
Th227	3.68E-04	4.65E-07	1.37E-01	1.65E-07
Th228	4.25E-04	1.57E-03	3.88E-02	4.60E-06
Th229	1.07E-05	3.83E-04	1.34E-03	2.30E-08
Th230	7.73E-06	7.27E-05	2.31E-04	3.39E-05
Th231	5.57E-04	6.65E-04	3.73E-04	6.57E-04
Th232	1.50E-04	1.40E-03	1.55E-02	4.99E-10
Th234	1.01E-02	4.74E-02	3.33E-03	3.27E-05
Tl206	1.40E-11	4.86E-13	5.26E-12	5.91E-11
Tl207	3.73E-04	4.71E-07	1.38E-01	1.66E-07
Tl208	1.53E-04	5.65E-04	1.40E-02	1.66E-06
Tl209	2.25E-07	8.05E-06	2.81E-05	4.83E-10
U232	2.68E-04	1.64E-04	2.29E-02	4.48E-06
U233	2.16E-03	5.59E-02	9.03E-02	1.03E-05
U234	1.49E-02	1.78E-01	3.01E-02	1.19E-01
U235	5.57E-04	6.65E-04	3.73E-04	6.57E-04
U236	1.19E-03	3.69E-03	1.09E-03	1.71E-03
U237	1.86E-04	1.11E-03	2.41E-04	1.10E-04
U238	1.01E-02	4.74E-02	3.33E-03	3.27E-05
V50	2.35E-14	—	—	—
Y90	1.81E+04	7.80E+03	4.87E+03	5.28E+03
Zr93	5.76E+00	3.86E-01	2.58E+00	—
Total	7.56E+04	4.37E+04	2.27E+04	2.19E+04

Source: Attachment E, spreadsheet *Results.xls*, worksheet *Cinv*

The total HLW radionuclide inventory for each site at years 2017 and 2067 are provided in Attachment B.

7.1.3 Radiation Production Rates

Gamma and neutron production rates from each of the four HLW canister types were calculated for the time steps provided in Table 1 that extend to year 1,002,017. The source terms are provided in the SCALE standard 18 gamma energy groups and 27 neutron energy groups.

7.1.3.1 Gamma Source Terms

The energy spectrum and intensities of gamma production rates of the maximum canister for each site at years 2017 and 2067 are presented in Table 20 and Table 21, respectively.

Table 20. Maximum Gamma Source Spectrum for HLW Canisters at year 2017

Higher Energy Boundary (MeV)	HS		SRS		WVDP		INL [a]	
	Photon Source							
	(s^{-1})	(MeV/s)	(s^{-1})	(MeV/s)	(s^{-1})	(MeV/s)	(s^{-1})	(MeV/s)
5.00E-02	1.29E+15	3.88E+13	6.51E+14	1.95E+13	3.66E+14	1.10E+13	2.46E+14	7.37E+12
1.00E-01	3.87E+14	2.90E+13	1.78E+14	1.33E+13	1.10E+14	8.23E+12	7.18E+13	5.38E+12
2.00E-01	2.58E+14	3.87E+13	1.18E+14	1.76E+13	7.07E+13	1.06E+13	4.83E+13	7.25E+12
3.00E-01	8.23E+13	2.06E+13	3.67E+13	9.17E+12	2.24E+13	5.61E+12	1.54E+13	3.85E+12
4.00E-01	5.91E+13	2.07E+13	2.57E+13	9.01E+12	1.59E+13	5.58E+12	1.10E+13	3.86E+12
6.00E-01	4.01E+13	2.01E+13	1.80E+13	8.99E+12	1.08E+13	5.39E+12	7.38E+12	3.69E+12
8.00E-01	1.79E+15	1.25E+15	1.31E+15	9.19E+14	5.84E+14	4.09E+14	3.63E+14	2.54E+14
1.00E+00	7.98E+12	7.18E+12	5.37E+12	4.83E+12	2.55E+12	2.30E+12	1.49E+12	1.34E+12
1.33E+00	4.63E+12	5.40E+12	8.39E+12	9.77E+12	2.16E+12	2.52E+12	9.65E+11	1.12E+12
1.66E+00	9.03E+11	1.35E+12	1.35E+12	2.03E+12	2.85E+11	4.26E+11	1.65E+11	2.46E+11
2.00E+00	1.52E+11	2.77E+11	6.55E+10	1.20E+11	4.08E+10	7.47E+10	2.83E+10	5.18E+10
2.50E+00	7.75E+09	1.74E+10	3.36E+09	7.57E+09	2.08E+09	4.69E+09	1.45E+09	3.26E+09
3.00E+00	6.14E+06	1.69E+07	1.84E+07	5.07E+07	5.99E+08	1.65E+09	4.99E+03	1.37E+04
4.00E+00	1.23E+04	4.29E+04	4.35E+06	1.52E+07	3.78E+05	1.32E+06	4.13E+03	1.44E+04
5.00E+00	3.76E+03	1.69E+04	1.47E+06	6.59E+06	1.27E+05	5.73E+05	1.31E+03	5.89E+03
6.50E+00	1.42E+03	8.15E+03	5.88E+05	3.38E+06	5.10E+04	2.93E+05	5.03E+02	2.89E+03
8.00E+00	2.62E+02	1.90E+03	1.15E+05	8.36E+05	9.99E+03	7.24E+04	9.47E+01	6.86E+02
1.00E+01	5.32E+01	4.79E+02	2.45E+04	2.20E+05	2.12E+03	1.91E+04	1.95E+01	1.76E+02
Total	3.92E+15	1.43E+15	2.36E+15	1.01E+15	1.19E+15	4.61E+14	7.65E+14	2.88E+14

Source: Attachment E, spreadsheet *Results.xls*, worksheets *HScan*, *SRScan*, *WVcan*, and *INLcan*.
NOTES: [a] Source spectrum for the INL HLW canister is provided for year 2035.

Table 21. Maximum Gamma Source Spectrum for HLW Canisters at year 2067

Higher Energy Boundary (MeV)	HS		SRS		WVDP		INL	
	Photon Source							
	(s^{-1})	(MeV/s)	(s^{-1})	(MeV/s)	(s^{-1})	(MeV/s)	(s^{-1})	(MeV/s)
5.00E-02	3.85E+14	1.15E+13	1.96E+14	5.87E+12	1.10E+14	3.31E+12	1.13E+14	3.39E+12
1.00E-01	1.16E+14	8.73E+12	5.48E+13	4.11E+12	3.57E+13	2.68E+12	3.29E+13	2.47E+12
2.00E-01	7.54E+13	1.13E+13	3.39E+13	5.09E+12	2.06E+13	3.09E+12	2.20E+13	3.30E+12
3.00E-01	2.41E+13	6.02E+12	1.06E+13	2.66E+12	6.56E+12	1.64E+12	7.02E+12	1.75E+12
4.00E-01	1.73E+13	6.04E+12	7.52E+12	2.63E+12	4.66E+12	1.63E+12	5.03E+12	1.76E+12
6.00E-01	1.15E+13	5.76E+12	5.01E+12	2.50E+12	3.13E+12	1.56E+12	3.36E+12	1.68E+12
8.00E-01	5.62E+14	3.93E+14	4.13E+14	2.89E+14	1.84E+14	1.29E+14	1.73E+14	1.21E+14
1.00E+00	2.22E+12	1.99E+12	9.89E+11	8.90E+11	6.06E+11	5.46E+11	6.49E+11	5.84E+11
1.33E+00	1.31E+12	1.52E+12	6.29E+11	7.33E+11	3.68E+11	4.28E+11	3.89E+11	4.53E+11
1.66E+00	2.49E+11	3.72E+11	1.10E+11	1.65E+11	6.75E+10	1.01E+11	7.22E+10	1.08E+11
2.00E+00	4.42E+10	8.09E+10	1.90E+10	3.48E+10	1.19E+10	2.18E+10	1.29E+10	2.35E+10
2.50E+00	2.26E+09	5.09E+09	9.75E+08	2.19E+09	6.08E+08	1.37E+09	6.58E+08	1.48E+09
3.00E+00	5.39E+06	1.48E+07	2.07E+07	5.68E+07	4.91E+08	1.35E+09	6.59E+04	1.81E+05
4.00E+00	7.89E+03	2.76E+04	7.29E+05	2.55E+06	6.44E+04	2.25E+05	4.31E+03	1.51E+04
5.00E+00	2.36E+03	1.06E+04	2.45E+05	1.10E+06	2.14E+04	9.65E+04	1.12E+03	5.03E+03
6.50E+00	8.58E+02	4.94E+03	9.83E+04	5.65E+05	8.51E+03	4.89E+04	4.30E+02	2.47E+03
8.00E+00	1.53E+02	1.11E+03	1.93E+04	1.40E+05	1.65E+03	1.20E+04	8.12E+01	5.89E+02
1.00E+01	3.03E+01	2.73E+02	4.09E+03	3.68E+04	3.48E+02	3.14E+03	1.68E+01	1.51E+02
Total	1.19E+15	4.47E+14	7.22E+14	3.14E+14	3.66E+14	1.44E+14	3.58E+14	1.37E+14

Source: Attachment E, spreadsheet *Results.xls*, worksheets *HScan*, *SRScan*, *WVcan*, and *INLcan*.

7.1.3.2 Neutron Source Terms

The energy spectrum and intensities of neutron production rates of the maximum canister for each site at years 2017 and 2067 are presented in Table 22 and Table 23, respectively.

Table 22. Maximum Neutron Source Spectrum for HLW Canisters at year 2017

Energy (MeV)		HS	SRS	WVDP	INL [a]
Lower Boundary	Higher Boundary	Neutron Source (s^{-1})			
6.43E+00	2.00E+01	5.74E+03	8.07E+05	7.64E+04	2.27E+03
3.00E+00	6.43E+00	6.56E+06	3.08E+07	1.28E+07	2.72E+06
1.85E+00	3.00E+00	4.96E+06	2.48E+07	9.75E+06	2.05E+06
1.40E+00	1.85E+00	9.06E+05	8.30E+06	2.10E+06	3.75E+05
9.00E-01	1.40E+00	9.19E+05	1.04E+07	2.30E+06	3.80E+05
4.00E-01	9.00E-01	7.43E+05	1.05E+07	2.03E+06	3.07E+05
1.00E-01	4.00E-01	2.85E+05	2.51E+06	6.53E+05	1.18E+05
1.70E-02	1.00E-01	4.24E+04	1.35E+05	7.73E+04	1.76E+04
1.00E-11	1.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total		1.44E+07	8.83E+07	2.98E+07	5.97E+06

Source: Attachment E, spreadsheet *Results.xls*, worksheets *HScan*, *SRScan*, *WVcan*, and *INLcan*.
NOTES: The last 19 neutron energy groups are collapsed since all source terms are zeroes.
[a] Source spectrum for INL HLW canister is provided for year 2035

Table 23. Maximum Neutron Source Spectrum for HLW Canisters at year 2067

Energy (MeV)		HS	SRS	WVDP	INL
Lower Boundary	Higher Boundary	Neutron Source (s^{-1})			
6.43E+00	2.00E+01	4.71E+03	1.41E+05	1.79E+04	1.86E+03
3.00E+00	6.43E+00	6.09E+06	1.47E+07	1.06E+07	2.19E+06
1.85E+00	3.00E+00	4.60E+06	1.14E+07	8.02E+06	1.66E+06
1.40E+00	1.85E+00	8.38E+05	2.70E+06	1.51E+06	3.03E+05
9.00E-01	1.40E+00	8.49E+05	3.06E+06	1.55E+06	3.07E+05
4.00E-01	9.00E-01	6.84E+05	2.82E+06	1.28E+06	2.48E+05
1.00E-01	4.00E-01	2.64E+05	8.32E+05	4.74E+05	9.54E+04
1.70E-02	1.00E-01	3.95E+04	8.45E+04	6.78E+04	1.42E+04
1.00E-11	1.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total		1.34E+07	3.57E+07	2.35E+07	4.82E+06

Source: Attachment E, spreadsheet *Results.xls*, worksheets *HScan*, *SRScan*, *WVcan*, and *INLcan*.
NOTES: The last 19 neutron energy groups are collapsed since all source terms are zeroes.

7.1.4 Decay Heat Generation

Similar to the radiation production rates, the gamma and total decay heat from each of the four HLW canister types were calculated for the time steps provided in Table 1. The total decay heat of the individual canister types and for the total HLW inventory are presented in Table 24 and Table 25, respectively.

Table 24. Decay Heat for Maximum HLW Canisters

Decay Heat (*Watts/Canister*)							
2017				**2067**			
HS	**SRS**	**WVDP**	**INL** [a]	**HS**	**SRS**	**WVDP**	**INL**
7.20E+02	4.46E+02	2.25E+02	1.40E+02	2.27E+02	1.53E+02	7.94E+01	6.64E+01

Source: Attachment E, spreadsheet *Results.xls*, worksheets *HScan*, *SRScan*, *WVcan*, and *INLcan*.
NOTE: [a] Decay heat for INL HLW canister is provided for year 2035

Table 25. Total Decay Heat for HLW Glass Types

Decay Heat (*Watts*)									
2017					**2067**				
HS	**SRS**	**WVDP**	**INL** [a]	**Total** [a]	**HS**	**SRS**	**WVDP**	**INL**	**Total**
3.91E+05	3.01E+06	4.42E+04	7.94E+04	3.52E+06	1.22E+05	1.03E+06	1.46E+04	3.79E+04	1.20E+06

Source: Attachment E, spreadsheet *Results.xls*, worksheets *HSinv*, *SRSinv*, *WVinv*, and *INLinv*.
NOTE: [a] Decay heat for INL HLW canister is provided for year 2035

Graphic representations of decay heat vs. time, for total inventory and per canister basis, are presented in Attachment C Figure C-1 and Figure C-2, respectively.

7.2 CONCLUSIONS AND RECOMMENDATIONS

The HLW glass generators updated the total radionuclide inventories and also the inventories for the maximum canisters. The comparison of the new canister based radionuclide inventories with the old ones shows that the total and per canisters basis HLW source terms are higher than previously evaluated. This is particularly true for the Hanford HLW long canister.

- The INL HLW glass inventory is provided by the waste generator for the year 2035 time frame. However, since the INL HLW radionuclide inventory per canister basis is lower than the SRS canister inventory (used as bounding) at the same time frame (Attachment E, folder *ORIGEN*, file *srsc.out*), additional evaluations are not required.

- The radionuclide inventories (Table 18), the gamma source spectrum (Table 20), and the neutron source spectrum (Table 22) per canister basis show that the SRS HLW canister is bounding for all HLW short canisters (SRS, WVDP, and INL).

- The radionuclide inventories (Table 18) and the gamma source spectra (Table 20) per canister basis suggest that the SRS HLW glass may not be bounding for the HS HLW canister.

A dose rate evaluation of the SRS and HS HLW canisters was performed in the *Initial Handling Facility Shielding Requirements Calculation* (Ref. 2.2.25) to determine the bounding HLW glass canister for shielding design and direct radiation analyses. The calculation results demonstrate the SRS HLW canister produces higher dose rates on the radial and bottom axial surfaces than the HS HLW canister (Ref. 2.2.25, Figures 18 and 20, respectively), while the top axial surface dose rates of the HS HLW canister is higher than that of the SRS HLW canister (Ref. 2.2.25, Figure 19). However, when additional shielding is present around the canisters, differences in the spectrums exist, which may cause the bounding HLW glass canister to vary determined by the total dose rates outside the shielding. Therefore, depending on the purpose of the engineering study/design calculation the appropriate bounding HLW canister should be utilized.

ATTACHMENT A – LIST OF THE FILES IN THE ELECTRONIC ATTACHMENT – ONE CD

```
 Volume in drive D is 080128_1447
 Volume Serial Number is 7A44-EECC

 Directory of D:\

01/24/2008  11:08 AM    <DIR>          excel
01/11/2008  12:32 PM    <DIR>          ORIGEN
               0 File(s)              0 bytes

 Directory of D:\excel

01/24/2008  11:08 AM    <DIR>          .
01/28/2008  02:49 PM    <DIR>          ..
01/21/2008  02:01 PM           216,064 Input.xls
01/24/2008  11:08 AM           241,664 Results.xls
               2 File(s)        457,728 bytes

 Directory of D:\ORIGEN

01/11/2008  12:32 PM    <DIR>          .
01/28/2008  02:49 PM    <DIR>          ..
08/03/2007  06:40 PM            13,897 hsc
08/03/2007  06:40 PM         2,346,194 hsc.out
08/07/2007  07:28 AM             8,399 hsi
08/07/2007  07:29 AM           924,106 hsi.out
08/06/2007  08:49 AM            12,090 inlc
08/06/2007  08:49 AM         1,898,962 inlc.out
08/06/2007  11:55 AM             7,328 inli
08/06/2007  11:55 AM           871,534 inli.out
08/03/2007  06:41 PM            13,822 srsc
08/03/2007  06:41 PM         2,356,389 srsc.out
08/03/2007  06:41 PM             8,592 srsi
08/03/2007  06:41 PM         1,069,372 srsi.out
08/06/2007  03:32 PM            14,301 wvc
08/06/2007  03:32 PM         2,407,999 wvc.out
08/03/2007  06:41 PM             9,128 wvi
08/03/2007  06:41 PM         1,113,822 wvi.out
              16 File(s)     13,075,935 bytes

     Total Files Listed:
              18 File(s)     13,533,663 bytes
               6 Dir(s)               0 bytes free
```

ATTACHMENT B – TOTAL HLW RADIONUCLIDE INVENTORY FROM ALL SITES (TABLES)

The total radionuclide inventory for each of the four HLW forms and the grand total radionuclide inventories for years 2017 and 2067 are presented in Table B-1 and Table B-2, respectively.

Table B-1. Total Radionuclide Inventory for each HLW Glass Type at 2017

Nuclide	Radioactivity (Ci)				
	HS	SRS	WVDP	INL [a]	Total [a]
Ac225	2.31E+00	9.37E-01	2.32E-01	9.35E-15	3.48E+00
Ac227	1.33E+02	1.41E-04	1.22E+01	1.66E-14	1.45E+02
Ac228	1.36E+01	6.69E+00	1.64E+00	4.64E-12	2.19E+01
Am241	1.42E+05	2.22E+06	5.30E+04	1.27E+04	2.43E+06
Am242	—	4.97E+02	2.59E+02	1.01E-02	7.56E+02
Am242m	—	5.00E+02	2.61E+02	—	7.61E+02
Am243	1.50E+01	9.24E+03	3.46E+02	1.39E-02	9.60E+03
At217	2.31E+00	9.37E-01	2.32E-01	9.35E-15	3.48E+00
Ba137m	2.99E+07	2.81E+08	3.66E+06	5.62E+06	3.20E+08
Bi210	1.75E-02	4.06E-05	1.42E-04	1.59E-10	1.77E-02
Bi211	1.33E+02	1.41E-04	1.23E+01	1.52E-18	1.45E+02
Bi212	4.95E+01	7.26E+00	7.53E+00	6.93E-09	6.43E+01
Bi213	2.31E+00	9.37E-01	2.32E-01	9.35E-15	3.48E+00
Bi214	8.97E-02	3.12E-04	5.36E-04	6.44E-04	9.12E-02
C14	—	—	1.37E+02	2.78E-02	1.37E+02
Cd113	6.37E-15	1.77E-07	2.19E-15	—	1.77E-07
Cd113m	7.30E+03	—	5.70E+02	—	7.87E+03
Ce144	—	3.20E+00	2.45E-11	—	3.20E+00
Cf249	—	1.55E+02	—	—	1.55E+02
Cf251	—	1.24E+02	—	—	1.24E+02
Cm242	—	4.12E+02	2.15E+02	1.24E-02	6.27E+02
Cm243	9.28E+00	2.24E+03	6.96E+01	4.70E-04	2.32E+03
Cm244	1.60E+02	2.00E+06	2.72E+03	1.03E-02	2.00E+06
Cm245	—	1.63E+02	8.79E-01	3.69E-06	1.64E+02
Cm246	—	1.96E+02	1.01E-01	8.66E-08	1.96E+02
Cm247	—	1.48E+02	—	3.09E-14	1.48E+02
Cm248	—	—	—	9.35E-15	9.35E-15
Co60	9.88E+02	3.33E+05	2.20E+01	3.21E+01	3.34E+05
Cs134	8.47E+01	4.39E+04	5.90E-01	3.28E-02	4.40E+04
Cs135		1.46E+03	1.61E+02	1.63E+02	1.78E+03
Cs137	3.16E+07	2.98E+08	3.87E+06	5.95E+06	3.39E+08
Eu152	7.16E+02	—	9.02E+01	—	8.06E+02
Eu154	3.80E+04	1.25E+06	1.09E+04	5.98E+03	1.30E+06
Eu155	8.58E+02	1.03E+03	4.59E+02	7.55E+00	2.35E+03
Fe55	—	—	6.86E-01	—	6.86E-01
Fr221	2.31E+00	9.37E-01	2.32E-01	9.35E-15	3.48E+00
Fr223	1.83E+00	1.95E-06	1.69E-01	2.29E-16	2.00E+00
Gd152	1.08E-11	—	6.16E-12	—	1.70E-11
H3	—	—	1.80E+01	3.56E+03	3.58E+03

Table B-1. Total Radionuclide Inventory for each HLW Glass Type at 2017

Nuclide	Radioactivity (Ci)				
	HS	SRS	WVDP	INL [a]	Total [a]
I129	4.80E+01	2.18E+00	2.10E-01	5.64E+00	5.60E+01
K40	—	—	—	—	—
La138	—	—	—	—	—
Nb93m	3.21E+03	1.57E+03	2.46E+02	4.74E+02	5.50E+03
Nb94	—	—	—	5.36E-03	5.36E-03
Nd144	—	9.66E-12	—	—	9.66E-12
Ni59	1.37E+03	5.71E+03	1.06E+02	—	7.19E+03
Ni63	1.14E+05	5.04E+05	7.06E+03	—	6.25E+05
Np236	—	—	9.47E+00	—	9.47E+00
Np237	1.41E+02	2.01E+02	2.39E+01	6.26E+00	3.72E+02
Np238	—	2.25E+00	1.17E+00	—	3.42E+00
Np239	1.50E+01	9.24E+03	3.46E+02	1.47E-03	9.60E+03
Pa231	2.72E+02	9.69E-04	1.52E+01	1.48E-09	2.87E+02
Pa233	1.41E+02	2.01E+02	2.39E+01	6.06E-02	3.66E+02
Pa234	2.59E-01	4.19E-01	1.11E-03	1.46E-07	6.79E-01
Pa234m	1.99E+02	3.22E+02	8.54E-01	3.19E-04	5.22E+02
Pb209	2.31E+00	9.37E-01	2.32E-01	2.80E-15	3.48E+00
Pb210	1.75E-02	4.06E-05	1.42E-04	9.16E-09	1.77E-02
Pb211	1.33E+02	1.41E-04	1.23E+01	1.52E-18	1.45E+02
Pb212	4.95E+01	7.26E+00	7.53E+00	1.05E-08	6.43E+01
Pb214	8.97E-02	3.12E-04	5.36E-04	6.44E-04	9.12E-02
Pd107	—	8.84E+00	1.10E+01	—	1.98E+01
Pm146	—	—	3.67E-01	—	3.67E-01
Pm147	—	1.03E+06	7.01E+01	2.67E+01	1.03E+06
Po210	1.61E-02	3.58E-05	1.34E-04	7.59E-14	1.63E-02
Po211	3.66E-01	3.88E-07	3.37E-02	4.18E-21	4.00E-01
Po212	3.17E+01	4.65E+00	4.83E+00	4.44E-09	4.12E+01
Po213	2.26E+00	9.17E-01	2.27E-01	9.15E-15	3.40E+00
Po214	8.97E-02	3.12E-04	5.36E-04	6.43E-04	9.12E-02
Po215	1.33E+02	1.41E-04	1.23E+01	1.52E-18	1.45E+02
Po216	4.95E+01	7.26E+00	7.53E+00	6.11E-08	6.43E+01
Po218	8.97E-02	3.12E-04	5.36E-04	6.44E-04	9.12E-02
Pr144	—	3.20E+00	2.45E-11	—	3.20E+00
Pr144m	—	4.49E-02	3.43E-13	—	4.49E-02
Pu236	—	—	8.43E-01	—	8.43E-01
Pu238	4.31E+03	6.14E+06	6.85E+03	8.98E+04	6.24E+06
Pu239	6.91E+04	1.18E+05	1.65E+03	1.81E+03	1.91E+05
Pu240	1.23E+04	5.94E+04	1.23E+03	1.57E+03	7.45E+04
Pu241	5.78E+04	3.50E+05	2.22E+04	1.93E+04	4.49E+05
Pu242	1.00E+00	1.44E+02	1.65E+00	3.42E+00	1.50E+02
Pu243	—	1.48E+02	—	2.22E-14	1.48E+02
Ra223	1.33E+02	1.41E-04	1.23E+01	1.52E-18	1.45E+02
Ra224	4.95E+01	7.26E+00	7.53E+00	6.11E-08	6.43E+01
Ra225	2.31E+00	9.37E-01	2.32E-01	1.07E-12	3.48E+00
Ra226	8.97E-02	3.12E-04	5.36E-04	9.69E-03	1.00E-01
Ra228	1.36E+01	6.69E+00	1.64E+00	1.24E-11	2.19E+01

Table B-1. Total Radionuclide Inventory for each HLW Glass Type at 2017

Nuclide	Radioactivity (Ci)				
	HS	SRS	WVDP	INL [a]	Total [a]
Rh102	—	—	—	1.99E-05	1.99E-05
Rh106	1.70E-02	2.98E+01	1.41E-07	—	2.98E+01
Rn219	1.33E+02	1.41E-04	1.23E+01	1.52E-18	1.45E+02
Rn220	4.95E+01	7.26E+00	7.53E+00	6.11E-08	6.43E+01
Rn222	8.97E-02	3.12E-04	5.36E-04	6.44E-04	9.12E-02
Ru106	1.70E-02	2.98E+01	1.41E-07	—	2.98E+01
Sb125	4.18E+02	6.22E+04	7.83E+00	1.03E+00	6.26E+04
Sb126	8.11E+01	7.42E+02	1.46E+01	2.62E-01	8.38E+02
Sb126m	5.79E+02	5.30E+03	1.04E+02	8.91E+01	6.07E+03
Se79	1.22E+02	3.60E+03	6.02E+01	—	3.78E+03
Sm146	—	—	8.63E-08	—	8.63E-08
Sm147	—	3.46E-04	4.44E-07	1.81E-13	3.46E-04
Sm151	3.10E+06	1.01E+06	6.85E+04	—	4.18E+06
Sn121	—	8.95E+03	9.59E+00	—	8.96E+03
Sn121m	—	1.15E+04	1.24E+01	—	1.15E+04
Sn126	5.79E+02	5.30E+03	1.04E+02	8.91E+01	6.07E+03
Sr90	3.43E+07	1.80E+08	3.46E+06	7.04E+06	2.25E+08
Tc99	2.97E+04	6.19E+04	1.70E+03	3.41E+03	9.67E+04
Te125m	1.02E+02	1.52E+04	1.91E+00	1.07E-03	1.53E+04
Th227	1.31E+02	1.39E-04	1.21E+01	5.81E-17	1.43E+02
Th228	4.93E+01	7.23E+00	7.51E+00	1.74E-06	6.40E+01
Th229	2.31E+00	9.37E-01	2.32E-01	1.21E-10	3.48E+00
Th230	1.42E-02	9.12E-02	5.96E-02	9.50E-07	1.65E-01
Th231	9.00E+00	4.49E+00	1.01E-01	1.29E-01	1.37E+01
Th232	8.00E+00	9.49E+00	1.64E+00	9.89E-08	1.91E+01
Th234	1.99E+02	3.22E+02	8.54E-01	3.19E-04	5.22E+02
Tl206	2.32E-08	5.36E-11	1.88E-10	2.10E-16	2.34E-08
Tl207	1.33E+02	1.41E-04	1.22E+01	1.52E-18	1.45E+02
Tl208	1.78E+01	2.61E+00	2.71E+00	2.49E-09	2.31E+01
Tl209	4.86E-02	1.97E-02	4.88E-03	1.96E-16	7.32E-02
U232	3.73E+01	1.82E+00	5.74E+00	4.63E-03	4.49E+01
U233	5.10E+02	3.79E+02	9.53E+00	1.33E-03	8.99E+02
U234	2.20E+02	4.89E+02	5.05E+00	9.95E+01	8.14E+02
U235	9.00E+00	4.49E+00	1.01E-01	5.90E-01	1.42E+01
U236	6.00E+00	2.48E+01	2.97E-01	1.54E+00	3.26E+01
U237	1.38E+00	8.38E+00	5.32E-01	1.76E-02	1.03E+01
U238	1.99E+02	3.22E+02	8.54E-01	2.94E-02	5.22E+02
Y90	3.43E+07	1.80E+08	3.46E+06	7.04E+06	2.25E+08
Zr93	4.81E+03	2.61E+03	2.72E+02	—	7.69E+03
Total	1.34E+08	9.54E+08	1.46E+07	2.58E+07	1.13E+09

Source: Attachment E, spreadsheet *Results.xls*, worksheet *Tinv*.
NOTE: [a] Radionuclide inventory for INL HLW canister is provided for year 2035

Table B-2. Total Radionuclide Inventory for each HLW Glass Type at 2067

Nuclide	Radioactivity (Ci)				
	HS	SRS	WVDP	INL	Total
Ac225	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Ac227	2.43E+02	3.18E-03	1.46E+01	1.50E-04	2.58E+02
Ac228	8.01E+00	9.48E+00	1.64E+00	9.86E-08	1.91E+01
Am241	1.33E+05	2.06E+06	4.96E+04	1.26E+04	2.26E+06
Am242	—	3.89E+02	2.03E+02	—	5.92E+02
Am242m	—	3.91E+02	2.04E+02	—	5.95E+02
Am243	1.49E+01	9.20E+03	3.45E+02	1.39E-02	9.56E+03
At217	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Ba137m	9.41E+06	8.85E+07	1.15E+06	2.68E+06	1.02E+08
Bi210	7.41E-02	2.49E-03	1.09E-03	6.11E-03	8.38E-02
Bi211	2.44E+02	3.19E-03	1.46E+01	1.50E-04	2.59E+02
Bi212	3.15E+01	1.07E+01	5.56E+00	3.48E-03	4.78E+01
Bi213	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Bi214	8.92E-02	5.97E-03	1.83E-03	9.76E-03	1.07E-01
C14	—	—	1.36E+02	2.77E-02	1.36E+02
Cd113	2.05E-14	1.77E-07	3.29E-15	—	1.77E-07
Cd113m	6.25E+02	—	4.88E+01	—	6.74E+02
Ce144	—	—	—	—	—
Cf249	—	1.40E+02	—	—	1.40E+02
Cf251	—	1.19E+02	—	—	1.19E+02
Cm242	—	3.22E+02	1.68E+02	—	4.90E+02
Cm243	2.75E+00	6.65E+02	2.06E+01	2.16E-04	6.88E+02
Cm244	2.36E+01	2.95E+05	4.00E+02	3.02E-03	2.95E+05
Cm245	—	1.63E+02	8.76E-01	3.68E-06	1.64E+02
Cm246	—	1.94E+02	1.00E-01	8.62E-08	1.94E+02
Cm247	—	1.48E+02	—	3.09E-14	1.48E+02
Cm248	—	—	—	9.35E-15	9.35E-15
Co60	1.37E+00	4.63E+02	3.07E-02	4.77E-01	4.65E+02
Cs134	4.24E-06	2.20E-03	2.96E-08	6.98E-07	2.20E-03
Cs135	—	1.46E+03	1.61E+02	1.63E+02	1.78E+03
Cs137	9.97E+06	9.37E+07	1.22E+06	2.84E+06	1.08E+08
Eu152	5.31E+01	—	6.70E+00	—	5.98E+01
Eu154	6.72E+02	2.22E+04	1.92E+02	4.52E+02	2.35E+04
Eu155	5.22E-01	6.24E-01	2.79E-01	6.60E-02	1.49E+00
Fe55	—	—	2.10E-06	—	2.10E-06
Fr221	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Fr223	3.36E+00	4.39E-05	2.01E-01	2.06E-06	3.56E+00
Gd152	3.37E-11	—	9.04E-12	—	4.27E-11
H3	—	—	1.08E+00	5.89E+02	5.90E+02
I129	4.80E+01	2.18E+00	2.10E-01	5.64E+00	5.60E+01
K40	—	—	—	—	—
La138	—	—	—	—	—
Nb93m	4.62E+03	2.49E+03	2.69E+02	1.20E+02	7.50E+03

Table B-2. Total Radionuclide Inventory for each HLW Glass Type at 2067

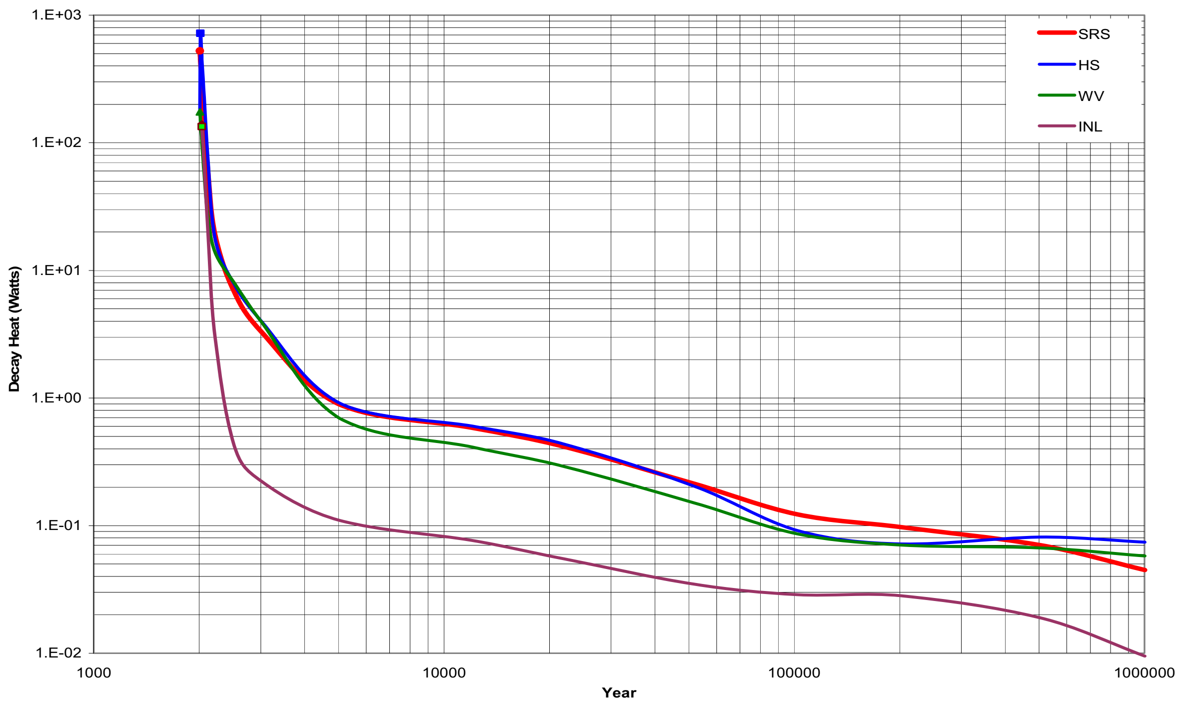
Nuclide	Radioactivity (Ci)				
	HS	SRS	WVDP	INL	Total
Nb94	—	—	—	5.35E-03	5.35E-03
Nd144	—	9.66E-12	—	—	9.66E-12
Ni59	1.37E+03	5.71E+03	1.06E+02	—	7.19E+03
Ni63	8.09E+04	3.57E+05	5.00E+03	—	4.43E+05
Np236	—	—	9.47E+00	—	9.47E+00
Np237	1.44E+02	2.36E+02	2.47E+01	6.39E+00	4.11E+02
Np238	—	1.76E+00	9.17E-01	—	2.68E+00
Np239	1.49E+01	9.20E+03	3.45E+02	1.39E-02	9.56E+03
Pa231	2.72E+02	5.74E-03	1.52E+01	4.01E-04	2.87E+02
Pa233	1.44E+02	2.36E+02	2.47E+01	6.39E+00	4.11E+02
Pa234	2.59E-01	4.19E-01	1.11E-03	3.82E-05	6.79E-01
Pa234m	1.99E+02	3.22E+02	8.54E-01	2.94E-02	5.22E+02
Pb209	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Pb210	7.40E-02	2.49E-03	1.09E-03	6.11E-03	8.37E-02
Pb211	2.44E+02	3.19E-03	1.46E+01	1.50E-04	2.59E+02
Pb212	3.15E+01	1.07E+01	5.56E+00	3.48E-03	4.78E+01
Pb214	8.92E-02	5.97E-03	1.83E-03	9.76E-03	1.07E-01
Pd107	—	8.84E+00	1.10E+01	—	1.98E+01
Pm146	—	—	6.96E-04	—	6.96E-04
Pm147	—	1.89E+00	1.28E-04	5.68E-03	1.90E+00
Po210	7.29E-02	2.40E-03	1.06E-03	5.97E-03	8.23E-02
Po211	6.71E-01	8.78E-06	4.02E-02	4.12E-07	7.11E-01
Po212	2.02E+01	6.83E+00	3.56E+00	2.23E-03	3.06E+01
Po213	4.44E+00	2.54E+00	2.67E-01	4.99E-06	7.25E+00
Po214	8.92E-02	5.97E-03	1.83E-03	9.76E-03	1.07E-01
Po215	2.44E+02	3.19E-03	1.46E+01	1.50E-04	2.59E+02
Po216	3.15E+01	1.07E+01	5.56E+00	3.48E-03	4.78E+01
Po218	8.92E-02	5.97E-03	1.83E-03	9.76E-03	1.07E-01
Pr144	—	—	—	—	—
Pr144m	—	—	—	—	—
Pu236	—	—	8.42E-01	—	8.42E-01
Pu238	2.90E+03	4.13E+06	4.67E+03	6.97E+04	4.21E+06
Pu239	6.90E+04	1.18E+05	1.65E+03	1.81E+03	1.90E+05
Pu240	1.22E+04	6.37E+04	1.23E+03	1.56E+03	7.87E+04
Pu241	5.16E+03	3.14E+04	1.99E+03	4.11E+03	4.27E+04
Pu242	1.00E+00	1.44E+02	1.66E+00	3.42E+00	1.50E+02
Pu243	—	1.48E+02	—	3.09E-14	1.48E+02
Ra223	2.44E+02	3.19E-03	1.46E+01	1.50E-04	2.59E+02
Ra224	3.15E+01	1.07E+01	5.56E+00	3.48E-03	4.78E+01
Ra225	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Ra226	8.92E-02	5.97E-03	1.83E-03	9.76E-03	1.07E-01
Ra228	8.01E+00	9.48E+00	1.64E+00	9.86E-08	1.91E+01

Table B-2. Total Radionuclide Inventory for each HLW Glass Type at 2067

Nuclide	Radioactivity (Ci)				
	HS	SRS	WVDP	INL	Total
Rh102	—	—	—	9.48E-09	9.48E-09
Rh106	2.73E-17	4.79E-14	—	—	4.79E-14
Rn219	2.44E+02	3.19E-03	1.46E+01	1.50E-04	2.59E+02
Rn220	3.15E+01	1.07E+01	5.56E+00	3.48E-03	4.78E+01
Rn222	8.92E-02	5.97E-03	1.83E-03	9.76E-03	1.07E-01
Ru106	2.73E-17	4.79E-14	—	—	4.79E-14
Sb125	1.28E-03	1.91E-01	2.40E-05	3.05E-04	1.93E-01
Sb126	8.10E+01	7.42E+02	1.46E+01	1.25E+01	8.50E+02
Sb126m	5.79E+02	5.30E+03	1.04E+02	8.91E+01	6.07E+03
Se79	1.22E+02	3.60E+03	6.02E+01	—	3.78E+03
Sm146	—	—	9.30E-08	—	9.30E-08
Sm147	—	3.71E-04	4.46E-07	6.61E-10	3.71E-04
Sm151	2.11E+06	6.86E+05	4.66E+04	—	2.84E+06
Sn121	—	4.77E+03	5.11E+00	—	4.78E+03
Sn121m	—	6.14E+03	6.58E+00	—	6.15E+03
Sn126	5.79E+02	5.30E+03	1.04E+02	8.91E+01	6.07E+03
Sr90	1.00E+07	5.25E+07	1.01E+06	3.20E+06	6.67E+07
Tc99	2.97E+04	6.19E+04	1.70E+03	3.41E+03	9.67E+04
Te125m	3.12E-04	4.65E-02	5.85E-06	7.44E-05	4.69E-02
Th227	2.41E+02	3.15E-03	1.44E+01	1.48E-04	2.55E+02
Th228	3.14E+01	1.06E+01	5.54E+00	3.46E-03	4.75E+01
Th229	4.54E+00	2.60E+00	2.73E-01	5.10E-06	7.41E+00
Th230	1.15E-01	4.91E-01	6.21E-02	3.04E-02	6.99E-01
Th231	9.00E+00	4.50E+00	1.01E-01	5.90E-01	1.42E+01
Th232	8.00E+00	9.49E+00	1.64E+00	1.01E-07	1.91E+01
Th234	1.99E+02	3.22E+02	8.54E-01	2.94E-02	5.22E+02
Tl206	9.78E-08	3.28E-09	1.44E-09	8.07E-09	1.11E-07
Tl207	2.43E+02	3.18E-03	1.46E+01	1.49E-04	2.58E+02
Tl208	1.13E+01	3.83E+00	2.00E+00	1.25E-03	1.71E+01
Tl209	9.53E-02	5.45E-02	5.73E-03	1.07E-07	1.56E-01
U232	2.27E+01	1.11E+00	3.82E+00	3.37E-03	2.76E+01
U233	5.10E+02	3.79E+02	9.54E+00	2.30E-03	8.99E+02
U234	2.21E+02	1.20E+03	5.85E+00	1.07E+02	1.53E+03
U235	9.00E+00	4.50E+00	1.01E-01	5.90E-01	1.42E+01
U236	6.02E+00	2.49E+01	2.99E-01	1.54E+00	3.28E+01
U237	1.23E-01	7.52E-01	4.75E-02	9.84E-02	1.02E+00
U238	1.99E+02	3.22E+02	8.54E-01	2.94E-02	5.22E+02
Y90	1.00E+07	5.26E+07	1.01E+06	3.20E+06	6.68E+07
Zr93	4.81E+03	2.61E+03	2.72E+02	—	7.69E+03
Total	4.18E+07	2.95E+08	4.51E+06	1.20E+07	3.53E+08

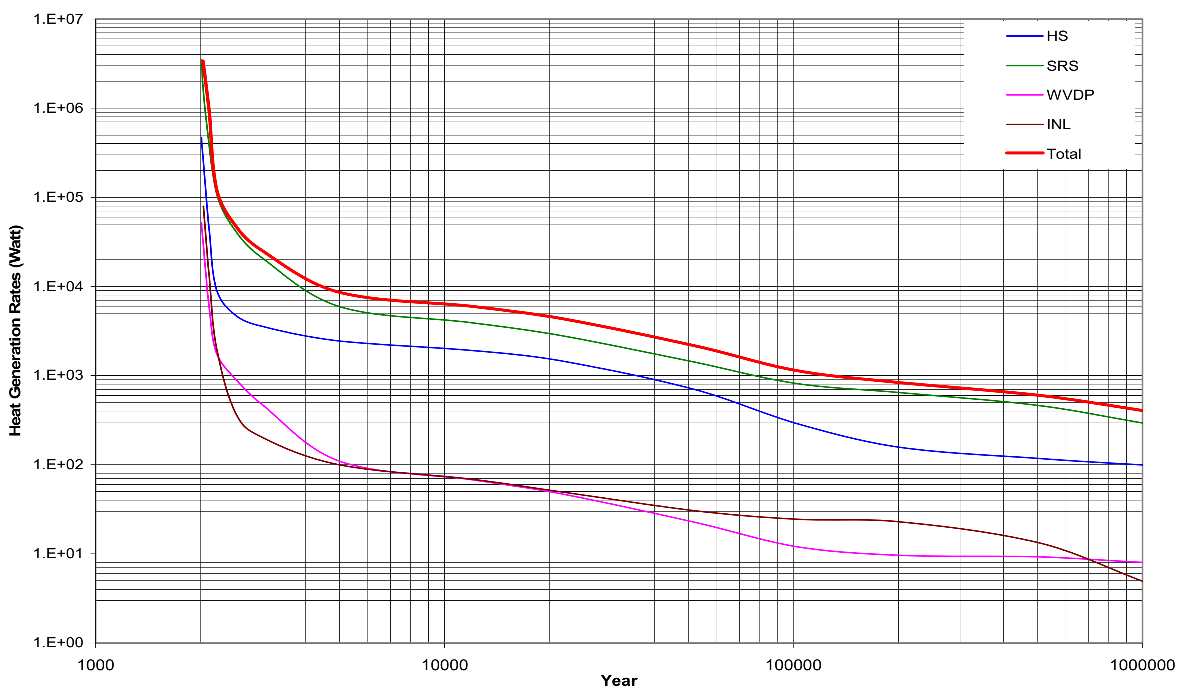
Source: Attachment E, spreadsheet *Results.xls*, worksheet *Tinv.*

ATTACHMENT C – DECAY HEAT VS. TIME (FIGURES)



Source: Attachment E, spreadsheet *Results.xls*, worksheet *Wc*

Figure C-1. Decay Heat vs. Time for Single HLW Canister



Source: Attachment E, spreadsheet *Results.xls*, worksheet *Wi*

Figure C-2. HLW Decay Heat vs. Time for the Total Inventory

ATTACHMENT D – BATCH FILE FOR RUNNING SCALE 4.4A

```
#!/bin/ksh
banner $USER
banner SCALE4.4
echo shell: $SHELL
if [ "" = "${SCALE}" ]
then
    SCALE=/opt/neut/scale4.4a; export SCALE
fi
CMDS=${SCALE}/cmds; export CMDS
pid=`$CMDS/ppid`
TMPDIR=/usr/tmp/${LOGNAME}.${pid}; export TMPDIR
mkdir $TMPDIR
if [ -f "$1.inp" ]
 then
   input="$1.inp"
   output="$1.out"
   msgs="$1.msg"
elif [ -f "$1.input" ]
 then
   input="$1.input"
   output="$1.output"
   msgs="$1.msgs"
elif [ -f $1 ]
 then
   input="$1"
   output="${1%.*}.out"
   msgs="${1%.*}.msg"
else
  echo ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
  echo          "the input file you specified does not exist"
  echo ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
  exit
fi
if [ `uname -s` != 'HP-UX' ]; then ulimit -sS `ulimit -sH`; fi
$CMDS/scale44 $input $output > $msgs 2>&1
banner $USER >>"$output"
date >>"$output"
echo $SHELL >>"$output"
uname -a >>"$output"
banner END
rm -r $TMPDIR
```