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EVALUATION OF INADVERTENT INTRUDER EXTERNAL EXPOSURE FROM SALTSTONE DISPOSAL CELL WASTEFORM

Introduction

The Performance Assessment (PA) for the Saltstone Disposal Facility is currently undergoing revision. One of the performance objectives of both DOE Order 435.1 and 10CFR61 is the protection of a future inadvertent intruder who intrudes upon the disposal facility following 100 years of institutional control. One potential exposure pathway for the intruder is external exposure within the intruder's residence from building on top of the Saltstone disposal cells. This report provides the information on this potential exposure pathway necessary for inclusion in the PA revision.

Discussion

There are various factors that impact the potential exposure to the intruder including the initial radionuclide concentration in the waste form, shielding material between the waste form and the basement, and the radionuclide concentration in the waste form over time as individual radionuclides decay. The first step in this evaluation is to determine the external exposure rate from the initial radionuclide concentrations in the waste form at the time of facility closure. Table III.7 of EPA Federal Guidance Report 12 [EPA-402-R-93-081] provides dose conversion factors for contamination to an infinite depth in soil. The DCFs are used in column two of Tables 1, 2 and 3, with column three presenting the conversion of this data into appropriate units as provided on page 165 of Federal Guidance Report 12 [EPA-402-R-93-081]. These factors can be applied to the Saltstone disposal cells and provide conservative exposure rates as the saltstone grout would provide more self-shielding than soil.

Information contained in SRNS-J2100-2008-00004 was used to determine the radionuclide concentrations at the time of facility closure presented in column four of Tables 1, 2, and 3, with columns five and six presenting the conversion of this data into appropriate units. The concentrations were obtained using the radionuclide inventories stated in Table 4-1, 4-4, and 4-6 of SRNS-J2100-2008-00004, with the corresponding disposal unit volumes of 5,230,000 gallons (Vault 1), 20,700,000 gallons (Vault 4), and 2,900,000 gallons (FDC).

The DCFs and grout concentrations are then used in column seven of Tables 1, 2, and 3 to derive estimates of the unshielded dose rates above Vault 1, Vault 4, and a Future Disposal Cell, respectively. The maximum unshielded dose rate of 5.68E+06 mrem/yr is from Vault 4 and assumes a constant inventory (i.e., no decay) with a reference date of 10/1/2030 (per SRNS-J2100-2008-00004) and a basemat shielding factor of 0.7 as presented on page 190 of EPA Federal Guidance Report 12 [EPA-402-R-93-081]. Greater than 99% of the dose rate is due to Cs-137/Ba-137m, with other significant contributors being Sr-90/Y-90 and Sn-126/Sb-126m.

Between the top of the closure cap erosion barrier and the saltstone waste form there are several layers of shield materials including the clean grout cap, disposal unit roof, and the soil closure cap layers. Based on the information provided in the closure cap design report WSRC-STI-2008-00244 on pages 13 and 15, and confirmed with the report author, the minimum distance from the top of the saltstone waste form to the top of the closure cap erosion barrier is approximately 25 feet. The resident intruder is assumed to build a basement in their house that is 3 meters in depth (i.e., approximately 10 feet). Soil will be assumed to be the constant shield material, which is conservative compared to the materials expected to be available for shielding (i.e., the clean grout cap and disposal unit roof), because these materials would provide more shielding than the soil. Since the planned lower sand drainage layer would not provide more shielding than the soil, this one foot layer is ignored. Therefore, a 14 foot soil shield layer will be evaluated.

In order to determine the shielding effectiveness of the soil layer, it is necessary to develop an attenuation coefficient for the soil. The soil composition assumed is that of the reference soil on page 13 of EPA Federal Guidance Report 12 [EPA-402-R-93-081] that is used in the dose conversion factor development. The soil is assigned a bulk density of 1.6 g/cc, which is the density of SRS native soil used in Performance Assessment modeling [WSRC-STI-2006-00198]. The elemental mass attention coefficients can be found in Section 3 (Tabulation of Cross Sections for Elements and Compounds) of NSRDS-NBS 29 for various energies. Two different photon emission energies will be examined. The first is 0.8 MeV to reflect the Cs-137/Ba-137m and Sn-126/Sb-126m. The second energy is 1.5 MeV to evaluate nuclides such as Al-26 and K-40, which contribute a low dose rate compared to other nuclides at the time of closure, but have long half-lives and higher emission energies and may be significant contributors under shielded conditions. Columns four through seven of Table 4 present the derivation of the attention coefficients for soil for the two reference energies.

Utilizing the 14 feet of soil coverage (t) and the derived attention coefficients (μ), Table 4 presents the number of mean free paths (μ*t) and the shielding reduction ($e^{-\mu t}$) provided by the soil coverage at the two reference energies. For 0.8 MeV the reduction is approximately 4.4E-22 and for 1.5 MeV the reduction is approximately 2.3E-16. After applying the minimum reduction factor to the maximum dose rate, the resulting dose rate is approximately 1E-9 mrem/yr. Even though a scattering buildup factor has not been applied, an infinite media buildup factor will not be greater than 1000 for the mean free paths involved.

In conclusion, the external dose rate is much less than 0.001 mrem/yr and is therefore an insignificant contributor to the all-pathways dose to the inadvertent intruder. One inherent conservatism in this evaluation is that any inventory decay is ignored. The inadvertent intruder dose as applied to the PA is not applicable until the end of a 100 year institutional control period, and many of the radionuclides of concern (e.g., Cs-137) have half-lives which are 30 years or less. In addition, the emission energy of 1.5 MeV conservatively bounds the most significant dose contributors, and as indicated in Table 4, is still an additional six orders of magnitude larger than energies of 0.8 MeV.

References

EPA-402-R-93-081, *Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil*, September 1993.

NSRDS-NBS 29, Hubbell, J. H., *Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV*, August 1969.

SRNS-J2100-2008-00004, Dean, W. B., *Estimated Closure Inventory for the Saltstone Disposal Facility*, Revision 2, June 2009.

WSRC-STI-2006-00198, Phifer, M. A, Millings, M. R. & Flach, G. P., *Hydraulic Property Data Package for the E-Area and Z-Area Soils, Cementitious Materials, and Waste Zones*, Revision 0, September 2006.

WSRC-STI-2008-00244, Jones, W. E. & Phifer, M. A., *Saltstone Disposal Facility Closure Cap Concept and Infiltration Estimates*, May 2008.

Distribution:

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Table 1: Vault 1 External Dose Rate at Time of Closure

Nuclide	Sv/Bq/s/m^3	mrem/yr/µCi/cm^3	Ci/gal	Ci/m^3	µCi/cm^3	mrem/yr
Ac-227	2.65E-21	3.10E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Al-26	9.32E-17	1.09E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am-241	2.34E-19	2.73E+04	8.99E-11	2.38E-08	2.38E-08	4.55E-04
Am-242m	9.04E-21	1.06E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am-243	7.60E-19	8.88E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-137m	1.93E-17	2.25E+06	7.85E-07	2.07E-04	2.07E-04	3.27E+02
Bk-249	2.49E-23	2.91E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	7.20E-23	8.41E+00	2.49E-07	6.57E-05	6.57E-05	3.87E-04
Ce-144	3.84E-19	4.49E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cf-249	9.91E-18	1.16E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cf-251	2.82E-18	3.29E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cf-252	9.41E-22	1.10E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cl-36	1.28E-20	1.50E+03	1.45E-10	3.84E-08	3.84E-08	4.02E-05
Cm-242	9.15E-22	1.07E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-243	3.12E-18	3.64E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-244	6.74E-22	7.87E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-245	1.82E-18	2.13E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-247	9.53E-18	1.11E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-248	4.70E-22	5.49E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	8.68E-17	1.01E+07	1.57E-11	4.16E-09	4.16E-09	2.95E-02
Cs-134	5.07E-17	5.92E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-135	2.05E-22	2.39E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	4.02E-21	4.70E+02	8.23E-07	2.17E-04	2.17E-04	7.15E-02
Eu-152	3.75E-17	4.38E+06	3.44E-10	9.10E-08	9.10E-08	2.79E-01
Eu-154	4.11E-17	4.80E+06	4.40E-11	1.16E-08	1.16E-08	3.91E-02
Eu-155	9.75E-19	1.14E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
H-3	0.00E+00	0.00E+00	1.17E-06	3.08E-04	3.08E-04	0.00E+00
I-129	6.93E-20	8.09E+03	2.11E-08	5.56E-06	5.56E-06	3.15E-02
K-40	5.57E-18	6.51E+05	1.45E-10	3.84E-08	3.84E-08	1.75E-02
Na-22	7.32E-17	8.55E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nb-93m	5.57E-22	6.51E+01	4.78E-08	1.26E-05	1.26E-05	5.76E-04
Nb-94	5.18E-17	6.05E+06	4.78E-10	1.26E-07	1.26E-07	5.35E-01
Ni-59	0.00E+00	0.00E+00	6.70E-09	1.77E-06	1.77E-06	0.00E+00
Ni-63	0.00E+00	0.00E+00	1.49E-07	3.94E-05	3.94E-05	0.00E+00
Np-237	4.17E-19	4.87E+04	8.61E-10	2.28E-07	2.28E-07	7.76E-03

Table 1: Vault 1 External Dose Rate at Time of Closure (continued)

Nuclide	Sv/Bq/s/m^3	mrem/yr/µCi/cm^3	Ci/gal	Ci/m^3	µCi/cm^3	mrem/yr
Pa-231	1.02E-18	1.19E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pd-107	0.00E+00	0.00E+00	3.64E-10	9.61E-08	9.61E-08	0.00E+00
Pm-147	2.68E-22	3.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pr-144	1.35E-18	1.58E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pt-193	3.03E-23	3.54E+00	7.08E-08	1.87E-05	1.87E-05	4.63E-05
Pu-238	8.10E-22	9.46E+01	1.49E-09	3.94E-07	3.94E-07	2.61E-05
Pu-239	1.58E-21	1.85E+02	2.30E-09	6.07E-07	6.07E-07	7.84E-05
Pu-240	7.85E-22	9.17E+01	2.30E-09	6.07E-07	6.07E-07	3.89E-05
Pu-241	3.16E-23	3.69E+00	1.88E-09	4.96E-07	4.96E-07	1.28E-06
Pu-242	6.85E-22	8.00E+01	1.72E-10	4.55E-08	4.55E-08	2.55E-06
Pu-244	4.04E-22	4.72E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra-226	1.70E-19	1.99E+04	1.22E-13	3.24E-11	3.24E-11	4.50E-07
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rh-106	6.91E-18	8.07E+05	2.87E-17	7.58E-15	7.58E-15	4.28E-09
Ru-106	0.00E+00	0.00E+00	2.87E-17	7.58E-15	7.58E-15	0.00E+00
Sb-125	1.31E-17	1.53E+06	3.06E-08	8.09E-06	8.09E-06	8.66E+00
Sb-126	9.16E-17	1.07E+07	2.68E-08	7.08E-06	7.08E-06	5.30E+01
Sb-126m	4.98E-17	5.82E+06	1.91E-07	5.04E-05	5.04E-05	2.05E+02
Se-79	9.96E-23	1.16E+01	5.74E-08	1.52E-05	1.52E-05	1.24E-04
Sm-151	5.27E-24	6.16E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn-126	7.89E-19	9.22E+04	1.91E-07	5.04E-05	5.04E-05	3.25E+00
Sr-90	3.77E-21	4.40E+02	1.32E-09	3.49E-07	3.49E-07	1.08E-04
Tc-99	6.72E-22	7.85E+01	2.11E-05	5.56E-03	5.56E-03	3.06E-01
Te-125m	8.11E-20	9.47E+03	7.27E-09	1.92E-06	1.92E-06	1.27E-02
Th-229	1.72E-18	2.01E+05	5.74E-08	1.52E-05	1.52E-05	2.13E+00
Th-230	6.47E-21	7.56E+02	7.85E-08	2.07E-05	2.07E-05	1.10E-02
Th-232	2.79E-21	3.26E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	4.83E-21	5.64E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-233	7.48E-21	8.74E+02	5.36E-08	1.42E-05	1.42E-05	8.66E-03
U-234	2.15E-21	2.51E+02	5.36E-08	1.42E-05	1.42E-05	2.49E-03
U-235	3.86E-18	4.51E+05	6.12E-10	1.62E-07	1.62E-07	5.11E-02
U-236	1.15E-21	1.34E+02	6.12E-10	1.62E-07	1.62E-07	1.52E-05
U-238	5.52E-22	6.45E+01	1.42E-09	3.74E-07	3.74E-07	1.69E-05
Y-90	1.28E-19	1.50E+04	1.32E-09	3.49E-07	3.49E-07	3.65E-03
Zr-93	0.00E+00	0.00E+00	4.78E-08	1.26E-05	1.26E-05	0.00E+00
					Total	6.01E+02

Table 2: Vault 4 External Dose Rate at Time of Closure

Nuclide	Sv/Bq/s/m^3	mrem/yr/µCi/cm^3	Ci/gal	Ci/m^3	µCi/cm^3	mrem/yr
Ac-227	2.65E-21	3.10E+02	7.73E-13	2.04E-10	2.04E-10	4.43E-08
Al-26	9.32E-17	1.09E+07	1.64E-08	4.34E-06	4.34E-06	3.31E+01
Am-241	2.34E-19	2.73E+04	6.28E-06	1.66E-03	1.66E-03	3.18E+01
Am-242m	9.04E-21	1.06E+03	3.24E-09	8.55E-07	8.55E-07	6.32E-04
Am-243	7.60E-19	8.88E+04	8.70E-08	2.30E-05	2.30E-05	1.43E+00
Ba-137m	1.93E-17	2.25E+06	1.35E-02	3.58E+00	3.58E+00	5.64E+06
Bk-249	2.49E-23	2.91E+00	8.70E-36	2.30E-33	2.30E-33	4.68E-33
C-14	7.20E-23	8.41E+00	1.31E-06	3.45E-04	3.45E-04	2.03E-03
Ce-144	3.84E-19	4.49E+04	8.70E-17	2.30E-14	2.30E-14	7.22E-10
Cf-249	9.91E-18	1.16E+06	3.14E-20	8.30E-18	8.30E-18	6.72E-12
Cf-251	2.82E-18	3.29E+05	5.80E-08	1.53E-05	1.53E-05	3.53E+00
Cf-252	9.41E-22	1.10E+02	8.70E-26	2.30E-23	2.30E-23	1.77E-21
Cl-36	1.28E-20	1.50E+03	1.45E-10	3.83E-08	3.83E-08	4.01E-05
Cm-242	9.15E-22	1.07E+02	3.24E-09	8.55E-07	8.55E-07	6.40E-05
Cm-243	3.12E-18	3.64E+05	1.02E-08	2.68E-06	2.68E-06	6.84E-01
Cm-244	6.74E-22	7.87E+01	6.28E-06	1.66E-03	1.66E-03	9.15E-02
Cm-245	1.82E-18	2.13E+05	4.45E-08	1.17E-05	1.17E-05	1.75E+00
Cm-247	9.53E-18	1.11E+06	1.89E-13	4.98E-11	4.98E-11	3.88E-05
Cm-248	4.70E-22	5.49E+01	5.80E-21	1.53E-18	1.53E-18	5.89E-17
Co-60	8.68E-17	1.01E+07	2.22E-08	5.87E-06	5.87E-06	4.17E+01
Cs-134	5.07E-17	5.92E+06	2.51E-08	6.64E-06	6.64E-06	2.75E+01
Cs-135	2.05E-22	2.39E+01	2.61E-07	6.90E-05	6.90E-05	1.16E-03
Cs-137	4.02E-21	4.70E+02	1.45E-02	3.83E+00	3.83E+00	1.26E+03
Eu-152	3.75E-17	4.38E+06	4.69E-09	1.24E-06	1.24E-06	3.80E+00
Eu-154	4.11E-17	4.80E+06	5.80E-07	1.53E-04	1.53E-04	5.15E+02
Eu-155	9.75E-19	1.14E+05	3.29E-08	8.68E-06	8.68E-06	6.92E-01
H-3	0.00E+00	0.00E+00	1.26E-05	3.32E-03	3.32E-03	0.00E+00
I-129	6.93E-20	8.09E+03	1.35E-08	3.58E-06	3.58E-06	2.03E-02
K-40	5.57E-18	6.51E+05	1.45E-10	3.83E-08	3.83E-08	1.74E-02
Na-22	7.32E-17	8.55E+06	7.25E-09	1.92E-06	1.92E-06	1.15E+01
Nb-93m	5.57E-22	6.51E+01	4.06E-07	1.07E-04	1.07E-04	4.88E-03
Nb-94	5.18E-17	6.05E+06	4.21E-09	1.11E-06	1.11E-06	4.70E+00
Ni-59	0.00E+00	0.00E+00	1.93E-08	5.11E-06	5.11E-06	0.00E+00
Ni-63	0.00E+00	0.00E+00	1.06E-06	2.81E-04	2.81E-04	0.00E+00
Np-237	4.17E-19	4.87E+04	2.95E-08	7.79E-06	7.79E-06	2.66E-01

Table 2: Vault 4 External Dose Rate at Time of Closure (continued)

Nuclide	Sv/Bq/s/m^3	mrem/yr/μCi/cm^3	Ci/gal	Ci/m^3	μCi/cm^3	mrem/yr
Pa-231	1.02E-18	1.19E+05	4.50E-12	1.19E-09	1.19E-09	9.90E-05
Pd-107	0.00E+00	0.00E+00	2.42E-09	6.38E-07	6.38E-07	0.00E+00
Pm-147	2.68E-22	3.13E+01	1.98E-08	5.24E-06	5.24E-06	1.15E-04
Pr-144	1.35E-18	1.58E+05	8.70E-17	2.30E-14	2.30E-14	2.54E-09
Pt-193	3.03E-23	3.54E+00	4.83E-07	1.28E-04	1.28E-04	3.16E-04
Pu-238	8.10E-22	9.46E+01	4.40E-04	1.16E-01	1.16E-01	7.70E+00
Pu-239	1.58E-21	1.85E+02	1.84E-05	4.85E-03	4.85E-03	6.27E-01
Pu-240	7.85E-22	9.17E+01	5.80E-06	1.53E-03	1.53E-03	9.83E-02
Pu-241	3.16E-23	3.69E+00	1.16E-04	3.06E-02	3.06E-02	7.92E-02
Pu-242	6.85E-22	8.00E+01	3.92E-08	1.03E-05	1.03E-05	5.79E-04
Pu-244	4.04E-22	4.72E+01	7.73E-10	2.04E-07	2.04E-07	6.75E-06
Ra-226	1.70E-19	1.99E+04	1.98E-07	5.24E-05	5.24E-05	7.28E-01
Ra-228	0.00E+00	0.00E+00	7.73E-14	2.04E-11	2.04E-11	0.00E+00
Rh-106	6.91E-18	8.07E+05	4.40E-14	1.16E-11	1.16E-11	6.56E-06
Ru-106	0.00E+00	0.00E+00	4.40E-14	1.16E-11	1.16E-11	0.00E+00
Sb-125	1.31E-17	1.53E+06	2.76E-07	7.28E-05	7.28E-05	7.80E+01
Sb-126	9.16E-17	1.07E+07	4.35E-08	1.15E-05	1.15E-05	8.61E+01
Sb-126m	4.98E-17	5.82E+06	3.09E-07	8.17E-05	8.17E-05	3.33E+02
Se-79	9.96E-23	1.16E+01	2.22E-06	5.87E-04	5.87E-04	4.78E-03
Sm-151	5.27E-24	6.16E-01	2.03E-06	5.36E-04	5.36E-04	2.31E-04
Sn-126	7.89E-19	9.22E+04	3.09E-07	8.17E-05	8.17E-05	5.27E+00
Sr-90	3.77E-21	4.40E+02	1.16E-02	3.06E+00	3.06E+00	9.45E+02
Tc-99	6.72E-22	7.85E+01	2.80E-05	7.41E-03	7.41E-03	4.07E-01
Te-125m	8.11E-20	9.47E+03	6.77E-08	1.79E-05	1.79E-05	1.19E-01
Th-229	1.72E-18	2.01E+05	1.21E-06	3.19E-04	3.19E-04	4.49E+01
Th-230	6.47E-21	7.56E+02	3.63E-07	9.58E-05	9.58E-05	5.07E-02
Th-232	2.79E-21	3.26E+02	1.55E-11	4.09E-09	4.09E-09	9.32E-07
U-232	4.83E-21	5.64E+02	2.13E-09	5.62E-07	5.62E-07	2.22E-04
U-233	7.48E-21	8.74E+02	1.16E-06	3.06E-04	3.06E-04	1.87E-01
U-234	2.15E-21	2.51E+02	1.26E-06	3.32E-04	3.32E-04	5.84E-02
U-235	3.86E-18	4.51E+05	2.27E-08	6.00E-06	6.00E-06	1.89E+00
U-236	1.15E-21	1.34E+02	3.72E-08	9.83E-06	9.83E-06	9.24E-04
U-238	5.52E-22	6.45E+01	2.85E-08	7.53E-06	7.53E-06	3.40E-04
Y-90	1.28E-19	1.50E+04	1.16E-02	3.06E+00	3.06E+00	3.21E+04
Zr-93	0.00E+00	0.00E+00	4.06E-07	1.07E-04	1.07E-04	0.00E+00
					Total	5.68E+06

Table 3: Future Disposal Cell External Dose Rate at Time of Closure

Nuclide	Sv/Bq/s/m^3	mrem/yr/μCi/cm^3	Ci/gal	Ci/m^3	μCi/cm^3	mrem/yr
Ac-227	2.65E-21	3.10E+02	5.86E-14	1.55E-11	1.55E-11	3.36E-09
Al-26	9.32E-17	1.09E+07	6.55E-08	1.73E-05	1.73E-05	1.32E+02
Am-241	2.34E-19	2.73E+04	4.83E-07	1.28E-04	1.28E-04	2.44E+00
Am-242m	9.04E-21	1.06E+03	2.03E-10	5.38E-08	5.38E-08	3.97E-05
Am-243	7.60E-19	8.88E+04	1.28E-08	3.37E-06	3.37E-06	2.09E-01
Ba-137m	1.93E-17	2.25E+06	7.59E-06	2.00E-03	2.00E-03	3.16E+03
Bk-249	2.49E-23	2.91E+00	6.21E-35	1.64E-32	1.64E-32	3.34E-32
C-14	7.20E-23	8.41E+00	6.90E-07	1.82E-04	1.82E-04	1.07E-03
Ce-144	3.84E-19	4.49E+04	1.24E-16	3.28E-14	3.28E-14	1.03E-09
Cf-249	9.91E-18	1.16E+06	2.31E-19	6.10E-17	6.10E-17	4.95E-11
Cf-251	2.82E-18	3.29E+05	7.93E-21	2.10E-18	2.10E-18	4.83E-13
Cf-252	9.41E-22	1.10E+02	6.21E-25	1.64E-22	1.64E-22	1.26E-20
Cl-36	1.28E-20	1.50E+03	1.45E-10	3.83E-08	3.83E-08	4.00E-05
Cm-242	9.15E-22	1.07E+02	2.17E-25	5.74E-23	5.74E-23	4.29E-21
Cm-243	3.12E-18	3.64E+05	7.24E-11	1.91E-08	1.91E-08	4.88E-03
Cm-244	6.74E-22	7.87E+01	3.28E-07	8.66E-05	8.66E-05	4.77E-03
Cm-245	1.82E-18	2.13E+05	8.28E-11	2.19E-08	2.19E-08	3.25E-03
Cm-247	9.53E-18	1.11E+06	2.45E-20	6.47E-18	6.47E-18	5.04E-12
Cm-248	4.70E-22	5.49E+01	2.55E-20	6.74E-18	6.74E-18	2.59E-16
Co-60	8.68E-17	1.01E+07	1.86E-08	4.92E-06	4.92E-06	3.49E+01
Cs-134	5.07E-17	5.92E+06	5.17E-12	1.37E-09	1.37E-09	5.66E-03
Cs-135	2.05E-22	2.39E+01	4.48E-11	1.18E-08	1.18E-08	1.99E-07
Cs-137	4.02E-21	4.70E+02	7.93E-06	2.10E-03	2.10E-03	6.89E-01
Eu-152	3.75E-17	4.38E+06	3.38E-08	8.93E-06	8.93E-06	2.74E+01
Eu-154	4.11E-17	4.80E+06	6.21E-07	1.64E-04	1.64E-04	5.51E+02
Eu-155	9.75E-19	1.14E+05	4.48E-08	1.18E-05	1.18E-05	9.44E-01
H-3	0.00E+00	0.00E+00	1.03E-05	2.73E-03	2.73E-03	0.00E+00
I-129	6.93E-20	8.09E+03	1.31E-07	3.46E-05	3.46E-05	1.96E-01
K-40	5.57E-18	6.51E+05	1.45E-10	3.83E-08	3.83E-08	1.74E-02
Na-22	7.32E-17	8.55E+06	2.38E-08	6.29E-06	6.29E-06	3.76E+01
Nb-93m	5.57E-22	6.51E+01	1.28E-07	3.37E-05	3.37E-05	1.54E-03
Nb-94	5.18E-17	6.05E+06	1.31E-09	3.46E-07	3.46E-07	1.47E+00
Ni-59	0.00E+00	0.00E+00	2.90E-08	7.65E-06	7.65E-06	0.00E+00
Ni-63	0.00E+00	0.00E+00	8.28E-07	2.19E-04	2.19E-04	0.00E+00
Np-237	4.17E-19	4.87E+04	1.72E-08	4.56E-06	4.56E-06	1.55E-01

Table 3: Future Disposal Cell External Dose Rate at Time of Closure (continued)

Nuclide	Sv/Bq/s/m^3	mrem/yr/µCi/cm^3	Ci/gal	Ci/m^3	µCi/cm^3	mrem/yr
Pa-231	1.02E-18	1.19E+05	3.38E-13	8.93E-11	8.93E-11	7.45E-06
Pd-107	0.00E+00	0.00E+00	1.93E-09	5.10E-07	5.10E-07	0.00E+00
Pm-147	2.68E-22	3.13E+01	2.66E-08	7.02E-06	7.02E-06	1.54E-04
Pr-144	1.35E-18	1.58E+05	1.24E-16	3.28E-14	3.28E-14	3.62E-09
Pt-193	3.03E-23	3.54E+00	3.79E-07	1.00E-04	1.00E-04	2.48E-04
Pu-238	8.10E-22	9.46E+01	5.86E-05	1.55E-02	1.55E-02	1.03E+00
Pu-239	1.58E-21	1.85E+02	5.17E-06	1.37E-03	1.37E-03	1.77E-01
Pu-240	7.85E-22	9.17E+01	1.41E-06	3.74E-04	3.74E-04	2.40E-02
Pu-241	3.16E-23	3.69E+00	1.45E-05	3.83E-03	3.83E-03	9.89E-03
Pu-242	6.85E-22	8.00E+01	1.35E-09	3.55E-07	3.55E-07	1.99E-05
Pu-244	4.04E-22	4.72E+01	5.52E-12	1.46E-09	1.46E-09	4.81E-08
Ra-226	1.70E-19	1.99E+04	2.69E-13	7.11E-11	7.11E-11	9.88E-07
Ra-228	0.00E+00	0.00E+00	3.00E-11	7.93E-09	7.93E-09	0.00E+00
Rh-106	6.91E-18	8.07E+05	4.14E-13	1.09E-10	1.09E-10	6.18E-05
Ru-106	0.00E+00	0.00E+00	4.14E-13	1.09E-10	1.09E-10	0.00E+00
Sb-125	1.31E-17	1.53E+06	8.28E-08	2.19E-05	2.19E-05	2.34E+01
Sb-126	9.16E-17	1.07E+07	4.14E-07	1.09E-04	1.09E-04	8.19E+02
Sb-126m	4.98E-17	5.82E+06	2.83E-06	7.47E-04	7.47E-04	3.04E+03
Se-79	9.96E-23	1.16E+01	4.83E-07	1.28E-04	1.28E-04	1.04E-03
Sm-151	5.27E-24	6.16E-01	2.03E-05	5.38E-03	5.38E-03	2.32E-03
Sn-126	7.89E-19	9.22E+04	2.83E-06	7.47E-04	7.47E-04	4.82E+01
Sr-90	3.77E-21	4.40E+02	1.28E-05	3.37E-03	3.37E-03	1.04E+00
Tc-99	6.72E-22	7.85E+01	1.86E-04	4.92E-02	4.92E-02	2.70E+00
Te-125m	8.11E-20	9.47E+03	2.00E-08	5.28E-06	5.28E-06	3.50E-02
Th-229	1.72E-18	2.01E+05	1.35E-08	3.55E-06	3.55E-06	5.00E-01
Th-230	6.47E-21	7.56E+02	6.55E-08	1.73E-05	1.73E-05	9.16E-03
Th-232	2.79E-21	3.26E+02	4.83E-10	1.28E-07	1.28E-07	2.91E-05
U-232	4.83E-21	5.64E+02	1.07E-10	2.82E-08	2.82E-08	1.12E-05
U-233	7.48E-21	8.74E+02	1.28E-08	3.37E-06	3.37E-06	2.06E-03
U-234	2.15E-21	2.51E+02	4.48E-08	1.18E-05	1.18E-05	2.08E-03
U-235	3.86E-18	4.51E+05	1.03E-09	2.73E-07	2.73E-07	8.63E-02
U-236	1.15E-21	1.34E+02	5.52E-09	1.46E-06	1.46E-06	1.37E-04
U-238	5.52E-22	6.45E+01	3.45E-08	9.11E-06	9.11E-06	4.11E-04
Y-90	1.28E-19	1.50E+04	1.28E-05	3.37E-03	3.37E-03	3.53E+01
Zr-93	0.00E+00	0.00E+00	1.28E-07	3.37E-05	3.37E-05	0.00E+00
					Total	7.92E+03

Table 4: Attenuation Coefficient Derivation and Soil Attenuation

			0.8 MeV	0.8 MeV	1.5 MeV	1.5 MeV
	Fraction	g/cc	μ/ρ	μ (cm^{-1})	μ/ρ	μ (cm^{-1})
H	0.021	0.0336	1.40E-01	4.70E-03	1.03E-01	3.46E-03
C	0.016	0.0256	7.09E-02	1.82E-03	5.19E-02	1.33E-03
O	0.577	0.9232	7.08E-02	6.54E-02	5.18E-02	4.78E-02
Al	0.05	0.08	6.83E-02	5.46E-03	5.00E-02	4.00E-03
Si	0.271	0.4336	7.06E-02	3.06E-02	5.18E-02	2.25E-02
K	0.013	0.0208	6.90E-02	1.44E-03	5.06E-02	1.05E-03
Ca	0.041	0.0656	7.09E-02	4.65E-03	5.20E-02	3.41E-03
Fe	0.011	0.0176	6.65E-02	1.17E-03	4.87E-02	8.57E-04
Totals	1	1.6		1.15E-01		8.44E-02

Minimum coverage of disposal cell		
Feet	cm	
14	426.72	
mfp =	4.92E+01	at 0.8 MeV
mfp =	3.60E+01	at 1.5 MeV
$e^{-\mu t}$ =	4.45E-22	at 0.8 MeV
$e^{-\mu t}$ =	2.29E-16	at 1.5 MeV