Technical Support Document

ZIONSOLUTIONS LLC
An EnergySolutions Company

TSD 14-021

BFM Drilling Spoils and Alternate Exposure Scenarios

Revision 1

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Summary of Changes in this Revision:

- Rev. 1 – Changes in response to NRC Requests for additional information.

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1. PURPOSE

TSD 14-010 (1) and Chapter 6 of the Zion Station Restoration Project (ZSRP) License Termination Plan (LTP) provides the methods for compliance with the radiological criteria for license termination. A ‘Basement Fill Model’ (BFM) was developed to calculate the dose to the Average Member of the Critical Group (AMCG) from residual radioactivity remaining in the backfilled basements at Zion Nuclear Power Station (ZNPS). The AMCG assumed in the BFM is the Resident Farmer. The BFM conceptual model defines several exposure pathways under an assumption that the configuration of backfilled basements remains in the “as-left” geometry at the time of license termination. Because the residual radioactivity in the backfilled basements ranges from 15 to 39 feet below grade, depending on the basement, there are no exposure pathways other than through potentially contaminated water from the well that is assumed to be installed as a part of the Resident Farmer exposure scenario.

This technical support document (TSD) evaluates the potential doses of additional exposure scenarios resulting from disturbance of the “as-left’ geometry of the backfilled basements. The scenarios evaluated include:

- exposure to drilling spoils brought to the surface during installation of the resident farmer well,
- exposure resulting from the construction of a basement to the resident farmer house in the backfill material, and
- large scale excavation of backfilled structures at some time after license termination.

The drilling spoils exposure scenario is the result of a well being installed into the backfilled basement at the time of maximum BFM groundwater concentration as calculated in TSD 14-010 (1). The inadvertent intruder construction scenario uses the NUREG-1757 (7) Appendix J methodology to evaluate potential doses from a house placed in the fill material of the Auxiliary Building or Spent Fuel Building end state structures at the time of maximum groundwater concentrations. The Large Excavation scenario evaluates the potential exposures from potential worst case concentration in end state concrete and fill material 10 years after license termination. A final evaluation of the potential doses associated with a drill spoils scenario involving end state concrete at the open air demolition limit of 2 mrem/hr on contact is also made.

2. DISCUSSION

2.1. End State Basement Fill Model and Resident Farmer Scenario

As described in the Exelon and Zion*Solutions* Asset Sale Agreement (2), all structures above the 588 foot elevation will be removed in the site end state. The portions of the structures remaining below the 588 foot elevation will be remediated and surveyed to ensure the 10 CFR 20 Subpart E license termination criteria have been met. They will then be backfilled with clean material.

The results of concrete characterization core samples were evaluated separately for the Reactor Building Containments (3), Auxiliary Building (4) and the Turbine Building. (5). Cores were also obtained in the Crib House, but these were for the purpose of identifying background concentrations in clean, non-contaminated concrete. Only portions of the Spent Fuel Pool below the 588 foot elevation could potentially remain in the end state for the Spent Fuel Building. The rest of the building is above the 588 foot elevation. Since the Spent Fuel Pool is still in use, no characterization of end state concrete under the liner has been possible; however, allowable end state source terms that result in 25 millirem per year (mrem/yr) for each radionuclide of concern have been modeled. (1) The source terms from the concrete characterization data in the Containments and Auxiliary Building are summarized in the Radionuclides of Concern (ROC) TSD 14-019 (6). TSD 14-019 summarizes the calculated source terms from the concrete characterization core decay corrected to the earliest feasible license termination date of July 1, 2018. The TSD also provides the basis for considering the Auxiliary Building as the bounding end state structure relative to potential source term and dose consequences. (4) Since all concrete interior of the Containment liner is to be removed in the Reactor Buildings, the Auxiliary Building and Spent Fuel Pool alternate scenario exposures will bound all other potential doses from end state structures such as the Turbine Building, Waste Water Treatment Facility (WWTF), etc.

The resident farmer scenario, as described in NUREG-1757 Volume 2 Rev. 1 (7), Draft NUREG-1549 (8), and NUREG/CR-6697 (9), assumes a well is installed on a site after license termination and used for drinking, irrigation and livestock water. The resident framer scenario developed for the ZNPS assumes the well is drilled directly into a backfilled basement. The bulk of the Auxiliary Building source term will be in the basement floor at the 542 foot elevation. (4)

2.2. Alternate Scenarios Evaluated

Three alternate scenarios are evaluated for the Auxiliary Building End State and the Spent Fuel Pool End State, the “Well Installation”, “Construction” and “Large Scale Excavation” scenarios. The Well Installation Scenario evaluates potential dose from materials brought to the surface at the time of peak fill concentration. The alternate scenarios evaluated are summarized in Table 1.

Table 1 - Alternate Scenarios Evaluated

Scenario	Description
Well Installation	Peak fill material concentration
Construction	Peak fill material concentration
Large Scale Excavation	After ISFSI Decommissioning

The resident farmer scenario assumes a well is placed in the middle of the Auxiliary Building basement or the Spent Fuel Pool structure. This scenario evaluates dose to the resident farmer from soil and material brought to the surface in drilling spoils during the installation process and subsequently dispersed on the surface of the site.

The source term for the drilling spoils scenario is the residual radioactivity in the concrete and fill (after leaching from the surface) at the time of peak water and fill concentrations. The release of source term from the concrete to the fill material is modeled for the full suite of potential ROCs using Brookhaven National Laboratory (BNL) code DUST MS as described in the building models provided in TSD 14-031 (10). The embedded source term in the Auxiliary Building and Spent Fuel Building are assumed to be a diffusion controlled release in very conservative models. The other buildings were modeled as instantaneous release of all concrete source term at t=0. The DUST MS model results for the ROCs determined in TSD 14-019 (6) are provided in Attachment 1. As shown in Equation 1, the value in the last column of the Attachment 1 tables for the Auxiliary and Spent Fuel Building diffusion model is the activity remaining in the concrete at the time of the peak concentration per mCi of original source term.

Equation 1 - Concrete Source Term @ t= Peak per mCi

$$C_p = \frac{A_{0\ e^{-\lambda t}} - A_w - A_f}{A_{0\ mCi}}$$

Where:

C_p = Concrete source term conversion factor in pCi per mCi. This is the total source term in all the concrete.

A_0 = DUST Model source term in pCi

λ = Decay Constant in years^{-1}

t = time to peak for ROCs from TSD 14-009 (11)

A_w = Peak Activity in Solution in pCi

A_f = Peal activity sorbed to full material in pCi

$A_{0\ mCi}$ = DUST Model source term in mCi

NUREG-1757 (7) Volume 2, Appendix J provides an example evaluation for the house construction scenario where radioactive material is brought to the surface during excavation for a house basement. This is commonly referred to as Inadvertent Intruder Construction Scenario. As described in NUREG-1757, the basement excavation is assumed to be about 10 feet deep (3 meters). As noted in the Conestoga-Rovers & Associates (CRA) final hydrology report for ZSRP decommissioning (12), the top grade is at the 591 foot elevation and the top of the water table is at the 579 foot elevation or 12 feet (i.e., 3.66 meters) below the surface. Since the excavation is only to 3 meters, it does not extend into the saturated zone and none of the excavated soil will contain the radioactivity released from the end state structure. However, there is a potential for direct radiation exposure to occupants in the basement from the source term in the saturated zone below the water table. The potential doses for the “Construction Scenario” at the Auxiliary Building and the Spent Fuel Pool end state areas is assumed to occur at the time of peak source term in basement fill.

3. ALTERNATE SCENARIO CALCULATIONS

3.1. BFM Drilling Spoils Scenario

Since the resident farmer scenario assumes a well is installed in the end state basements, the potential exposures from the well drill spoils are evaluated. The scenario assumes a well is drilled with an 8 inch bit and encounters rejection at the floor of the basements after removing a half inch of concrete. The drilling scenario is applied to the DUST MS Auxiliary Building and Spent Fuel Building model results which use diffusion controlled release and assumes each radionuclide is at it’s peak sorbed concentration simultaneously, even though these occur at different times for the ROCs as seen in Attachment 1. The instantaneous release model for the other buildings assumes there is no source term remaining in the concrete and the peak concentration in the fill material occures at t=0. The source term is in the fill saturated zone material below the water table (clean fill contains residual radioactivity as a result of leaching from concrete) and that the source term remaining in the concrete is mixed with the drill spoils from the vadose zone area above the water table and and spread at a 15 cm depth. Potential exposures are evaluated using site-specific surface soil Derived Concentration Guideline Levels (DCGLs) and area factors derived from RESRAD reports documented in TSD 14-010 (1).

Previous evaluations of exposures from this scenario have assumed a slurry pit was used and that the cuttings were further diluted by refilling the pit with the material excavated during its construction and that it was then later dispersed at the surface. Including a slurry pit results in much lower potential concentrations in the drill spoils spread on the surface. Earthen pits are commonly used adjacent to drilling pits to dispose of drilling mud and well cuttings for oil and gas wells. Installers vary in how they handle drilling fluids, muds and cuttings differently. Some use earthen pits, some use poly lined pits, some use tanks and the material is sometimes disposed of on-site by dumping it on the surface. As a conservative assumption, no dilution of the end state fill concentrations will be assumed from the drilling mud or in the process of disposing of the slurry.The bore hole will be assumed to be 8 inches in diameter to accommodate the installation of a standard 4 inch diameter casing. The well drilling scenario parameters for each end state building are shown in Table 2.

Table 2 – End State Building Well Drilling Parameters

Parameter	**Aux** (4)	**Rx Bld CTMT** (3)	**Spent Fuel Pool/ Transfer Canals** (5)	**Turbine** (5)	**Crib House/ Forebay** (5)	**WWTF** (5)
Ground Surface Elevation ft	591	591	591	591	591	591
Water Table Elevation ft	579	579	579	579	579	579
Basement Floor Elevation ft	542	565	576	560	537	577
Vadose Zone Clean Fill Height ft	12	12	12	12	12	12
Sat Zone Contam Fill Height ft	37	14	3	19	42	2
8 inch Diameter Borehole Area (ft^2)	0.35	0.35	0.35	0.35	0.35	0.35
Concrete Cutting Depth inches	0.5	0.0	0.5	0.0	0.0	0.0
Concrete Cutting Depth ft	0.042	0.000	0.042	0.000	0.000	0.000
Drill Spoils Volumes						
Vadose Zone Clean Fill Volume m^3	0.119	0.119	0.119	0.119	0.119	0.119
Sat Zone Contam Fill Volume m^3	0.37	0.14	0.03	0.19	0.41	0.02
Density Corrected Concrete Cutting Volume m^3	6.59E-04	0.00E+00	6.59E-04	0.00E+00	0.00E+00	0.00E+00
Total Borehole Volume m^3	**0.48**	**0.26**	**0.15**	**0.31**	**0.53**	**0.14**
Spread area m^2 @ 0.15 m height	3.23	1.71	0.99	2.04	3.56	0.92
Drilling Spoils Mass						
Clean Vadose Zone Mass grams	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Saturated Zone Contam Bore Hole Mass g	5.48E+05	2.07E+05	4.45E+04	2.82E+05	6.22E+05	2.96E+04
Concrete Cut Mass grams	9.88E+02	0.00E+00	9.88E+02	0.00E+00	0.00E+00	0.00E+00
Total Borehole Mass grams	7.27E+05	3.85E+05	2.23E+05	4.59E+05	8.00E+05	2.07E+05
Saturated Zone Volume and Concrete Floor Areas						
Sat Zone Volume m^3	28445	6537	208	26135	30524	144
Modeled Sat Zone Void Space Volume ft^3	1.00E+06	2.31E+05	7.35E+03	9.23E+05	1.08E+06	5.09E+03
Modeled Floor Surface Area (ft^2)	27149	16489	2448	48576	25665	2543

The grade at the site is at the 591’ elevation and the water table is at the 579’ elevation. The drill spoils would have 12 feet of clean soil above the water table in the vadose zone. The saturated zone contaminated fill material length of the 8 inch diameter core would be from the floor elevation of each building to the water table at the 579’ elevation. Thus the Auxiliary Building would have 12 feet of clean soil from the vadose zone and 37 feet of contaminated soil below it in the saturated zone. The Spent Fuel Building would have 12 feet of clean soil in the vadose zone and 3 feet of contaminated soil in the saturated zone.

A hole diameter of 8 inches equals 0.35 square feet (ft^2) which results in the drill spoil volumes and masses shown in Table 2. The drilling spoils volume and mass calculation for the instaneous release buildings (Containments, Turbine, Crib House, and WWTF) take no credit for the mass of the ½ inch of concrete cutting drill spoils since the volumes and masses are not significant. The diffusion model buildings (Auxiliary and Spent Fuel) assume that an 8 inch diameter, ½ inch deep concrete cutting is removed with the fill material. The initial density of the concrete is assumed to be 2.40 g/cm^3 (3). The concrete drill cutting spoils are asumed to have a density of 1.5 g/cm^3, resulting in an increase in the volume by a factor of 1.6. The concrete source terms in the Auxiliary Building and Spent Fuel Building drill spoils are provided in Attachment 1 “Concrete Total at Peak pCi per mCi” values in the last column of the tables (e.g. Equation 1 *Cp*) divided by the floor surface area in Table 2, multiplied by the drill bit surface area of 0.35 ft^2.

Equation 2 Diffusion Model Buildings Saturated Zone Drill Spoils Concentration pCi/g per mCi

$$C_{sat\ zone}\ \frac{pCi/g}{mCi} = \frac{C_p\ pCi/mCi\ \times 0.35\ ft^2}{A_f\ ft^2\ \times\ M_{sat}} + C_{sorbed}\ \frac{pCi/g}{mCi}$$

Where

$C_{sat\ zone}$ = The concentration pCi/g per mCi of end state source term in the saturated zone drill spoils from the sorbed activity in the fill and the concrete cuttings.

C_p = The total activity pCi/mCi remaining in the concrete at the peak sorbed fill concentration time (t = peak) calculated using Equation 1.

A_f = Table 2 abstracted floor area ft^2 of the DUST MS model (e.g. Sat Zone Void Space divided by height of water table above floor).

M_{sat} = The Table 2 mass (grams) of the saturated zone drill spoils.

C_{sorbed} = The DUST MS sorbed concentration pCi/g per mCi from the Attachment 1 tables.

The estimated concrete cutting activity is very conservative because it assumes all of the activity is concentrated in the first half inch of the floor when actual core data indicates it is distributed at deeper depths.In addition, the first half-inch inventory calculations used for the drill spoils scenario included data from wall cores (4) (3). The total 8 inch diameter bore hole volumes in cubic meters (m^3) are shown in Table 2. The total drill spoils volumes spread to a 15 cm thickness result in areas of 0.92 to 3.56 m^2 as seen in Table 2. The area factors for the full suite of radionuclides are calculated based upon the DCGL(w) reported in the RESRAD single radionuclide guidelines G(i,tmin) calculated for the 64,500 m^2 contaminated zone of the site and the 0.3, 1, 3, and 10 m^2 contaminated zones. (1) The area factor is calculated by dividing the smaller single nuclide guideline (e.g., 0.3, 1, 3, 10 m^2 G(i,tmin)) by the 64,500 m^2 G(i,tmin) as provided in Table 3.

Table 3 - Single Nuclide Guidelines and Area Factors Bounding Drill Spoils at 0.15 m Thick

Nuclide	RESRAD Report 64,500 m^2 pCi/g	0.3 m^2 G(i,tmin) pCi/g	1 m^2 G(i,tmin) pCi/g	3 m^2 G(i,tmin) pCi/g	10 m^2 G(i,tmin) pCi/g	0.3 m^2 Area Factors	1 m^2 Area Factors	3 m^2 Area Factors	10 m^2 Area Factors
Ag-108m	7.401E+00	2.783E+02	8.349E+01	3.601E+01	1.706E+01	3.76E+01	1.13E+01	4.87E+00	2.31E+00
Am-241	1.872E+02	1.416E+04	7.207E+03	4.132E+03	2.212E+03	7.56E+01	3.85E+01	2.21E+01	1.18E+01
Am-243	5.572E+01	2.176E+03	6.964E+02	3.178E+02	1.539E+02	3.91E+01	1.25E+01	5.70E+00	2.76E+00
C-14	1.196E+02	1.689E+07	4.902E+06	1.710E+06	5.128E+05	1.41E+05	4.10E+04	1.43E+04	4.29E+03
Cm-243	8.561E+01	3.494E+03	1.127E+03	5.064E+02	2.437E+02	4.08E+01	1.32E+01	5.92E+00	2.85E+00
Cm-244	3.966E+02	3.985E+04	3.284E+04	2.565E+04	1.663E+04	1.00E+02	8.28E+01	6.47E+01	4.19E+01
Co-60	4.762E+00	1.947E+02	5.840E+01	2.494E+01	1.177E+01	4.09E+01	1.23E+01	5.24E+00	2.47E+00
Cs-134	7.614E+00	3.366E+02	1.010E+02	4.363E+01	2.068E+01	4.42E+01	1.33E+01	5.73E+00	2.72E+00
Cs-137	1.608E+01	8.012E+02	2.404E+02	1.038E+02	4.920E+01	4.98E+01	1.50E+01	6.46E+00	3.06E+00
Eu-152	1.074E+01	4.168E+02	1.250E+02	5.361E+01	2.534E+01	3.88E+01	1.16E+01	4.99E+00	2.36E+00
Eu-154	9.969E+00	3.917E+02	1.175E+02	5.034E+01	2.378E+01	3.93E+01	1.18E+01	5.05E+00	2.39E+00
Eu-155	3.911E+02	1.140E+04	3.420E+03	1.591E+03	7.783E+02	2.91E+01	8.74E+00	4.07E+00	1.99E+00
Fe-55	3.412E+04	1.166E+09	4.273E+08	1.536E+08	4.754E+07	3.42E+04	1.25E+04	4.50E+03	1.39E+03
H-3	4.817E+03	3.965E+07	1.189E+07	3.964E+06	1.260E+06	8.23E+03	2.47E+03	8.23E+02	2.62E+02
Nb-94	7.510E+00	2.885E+02	8.656E+01	3.726E+01	1.764E+01	3.84E+01	1.15E+01	4.96E+00	2.35E+00
Ni-59	1.175E+04	2.977E+08	9.423E+07	3.198E+07	9.666E+06	2.53E+04	8.02E+03	2.72E+03	8.23E+02
Ni-63	4.289E+03	1.101E+08	3.457E+07	1.170E+07	3.532E+06	2.57E+04	8.06E+03	2.73E+03	8.24E+02
Np-237	8.304E-01	1.268E+03	3.924E+02	1.382E+02	4.578E+01	1.53E+03	4.73E+02	1.66E+02	5.51E+01
Pu-238	2.324E+02	2.491E+04	2.056E+04	1.607E+04	1.042E+04	1.07E+02	8.85E+01	6.91E+01	4.48E+01
Pu-239	2.093E+02	2.265E+04	1.867E+04	1.455E+04	9.390E+03	1.08E+02	8.92E+01	6.95E+01	4.49E+01
Pu-240	2.094E+02	2.268E+04	1.872E+04	1.462E+04	9.462E+03	1.08E+02	8.94E+01	6.98E+01	4.52E+01
Pu-241	9.196E+03	7.451E+05	3.805E+05	2.125E+05	1.118E+05	8.10E+01	4.14E+01	2.31E+01	1.22E+01
Sb-125	3.362E+01	1.259E+03	3.777E+02	1.630E+02	7.726E+01	3.74E+01	1.12E+01	4.85E+00	2.30E+00
Sr-90	2.157E+01	6.204E+04	1.915E+04	6.728E+03	2.215E+03	2.88E+03	8.88E+02	3.12E+02	1.03E+02
Tc-99	1.372E+02	9.305E+05	2.791E+05	9.303E+04	2.956E+04	6.78E+03	2.03E+03	6.78E+02	2.15E+02

Table 4 - End State Building Interpolated Drill Soils Area Factors

Drill Spoils m^2		3.23	1.71	0.99	2.04	3.56	0.92
Nuclide	**0.15 meter Soil DCGL pCi/g**	**Aux**	**Containment**	**Spent Fuel**	**Turbine**	**Crib House**	**WWTF**
Ag-108m	7.40E+00	4.78	9.00	11.57	7.94	4.66	14.21
Am-241	1.34E+02	21.73	32.65	38.91	29.94	21.26	42.64
Am-243	4.98E+01	5.61	10.08	12.79	8.96	5.47	15.46
C-14	8.96E+01	13966.77	31481.56	42096.81	27087.41	13502.17	52155.67
Cm-243	7.61E+01	5.81	10.58	13.47	9.39	5.67	16.25
Cm-244	2.71E+02	63.92	76.35	83.00	73.36	62.87	84.77
Co-60	4.73E+00	5.15	9.76	12.58	8.60	5.02	15.45
Cs-134	7.52E+00	5.63	10.58	13.61	9.34	5.49	16.71
Cs-137	1.58E+01	6.34	11.92	15.34	10.53	6.19	18.84
Eu-152	1.07E+01	4.90	9.27	11.94	8.18	4.78	14.67
Eu-154	9.97E+00	4.96	9.39	12.09	8.28	4.84	14.85
Eu-155	3.91E+02	4.00	7.08	8.97	6.31	3.90	11.02
Fe-55	3.37E+04	4399.01	9666.59	12763.24	8345.87	4254.73	14935.90
H-3	4.58E+03	804.36	1882.34	2532.17	1611.43	778.31	3110.50
I-129	0.00E+00						
Nb-94	7.51E+00	4.88	9.19	11.82	8.11	4.75	14.52
Ni-59	1.09E+04	2658.93	6132.78	8211.37	5260.52	2570.79	9949.16
Ni-63	3.97E+03	2664.96	6161.12	8255.20	5283.20	2576.57	10022.45
Np-237	8.01E-01	162.75	363.52	484.22	313.12	157.58	590.04
Pu-238	1.62E+02	68.34	81.59	88.68	78.41	67.22	90.55
Pu-239	1.46E+02	68.70	82.19	89.41	78.95	67.56	91.32
Pu-240	1.46E+02	69.00	82.43	89.61	79.20	67.86	91.51
Pu-241	6.52E+03	22.75	34.87	41.82	31.86	22.24	45.79
Sb-125	3.36E+01	4.76	8.96	11.52	7.91	4.65	14.16
Sr-90	1.34E+01	305.00	682.71	909.83	587.89	295.29	1109.37
Tc-99	1.28E+02	662.77	1551.26	2086.84	1327.97	641.30	2563.30

The building specific drill spoils area factors are interpolated from Table 3 using the Table 2 surface area at 0.15 m thick to provide building specific area factors as shown in Table 4 along with the ZSRP 15 cm soil DCGL(w) calculated in TSD 14-010. (1)

Drill spoils dose factors (mrem/yr per mCi) are calculated from the saturated zone concentrations ($C_{sat\ zone}$) calculated in Equation 2 and the Table 4 area factors and DCGLs using equation 3.

Equation 3 - Calculation of Nuclide Specific Drill Spoils Dose Factors mrem/yr per mCi

$$DF_{spoils} mrem\ yr^{-1} mCi^{-1} = \frac{C_{sat\ zone} \frac{pCi}{g\ mCi} \times \frac{V_{sat}\ m^3}{V_{total} m^3} \times 25\ mrem\ yr^{-1}}{AF\ \times\ DCGL(w)\ pCi/g}$$

Where;

DF $_{spoils}$ = The mrem/yr per mCi dose factor (DF) of the BFM Drill Spoils pathway.

$C_{sat\ zone}$ = The concentration (pCi/g per mCi) in the saturated zone from the concrete cutting and the sorbed contamination of the fill material calculated in Equation 2.

V_{sat} = The volume m^3 of the saturated zone core material in Table 2.

V_{total} = The total volume m^3 of the core material in Table 2.

AF = The area factor in Table 4.

DCGL(w) = the Soil DCGL pCi/g from Table 4.

25 mrem/yr = The annual dose at the DCGL(w) concentration.

The BFM Drill Spoils dose factors (DF_{spoils}) calculated using Equation 3 are provided in Table 5.

Table 5 - Drill Spoils Dose Factors mrem/yr per mCi

Nuclide	Aux Building Drill Spoils mrem/yr per mCi	CTMT Drill Spoils mrem per mCi	SFB Drill Spoils mrem/yr per mCi	Turbine Drill Spoils mrem/yr per mCi	Crib House Drill Spoils mrem/yr per mCi	WWTF Drill Spoils mrem/yr per mCi
Ag-108m	1.23E-02	2.05E-02	1.85E-01	6.61E-03	1.23E-02	1.57E-01
Am-241	1.51E-04	3.14E-04	3.06E-03	9.76E-05	1.49E-04	2.91E-03
Am-243	1.58E-03	2.73E-03	2.51E-02	8.75E-04	1.55E-03	2.16E-02
C-14	3.08E-07	4.27E-07	3.72E-06	1.42E-07	3.08E-07	3.11E-06
Cm-243	9.93E-04	1.70E-03	1.56E-02	5.47E-04	9.87E-04	1.34E-02
Cm-244	2.55E-05	6.63E-05	7.09E-04	1.97E-05	2.50E-05	7.21E-04
Co-60	1.07E-02	2.97E-02	1.58E-01	9.58E-03	1.78E-02	2.26E-01
Cs-134	6.29E-03	1.72E-02	9.41E-02	5.54E-03	1.02E-02	1.31E-01
Cs-137	3.22E-03	7.27E-03	4.83E-02	2.35E-03	4.34E-03	5.57E-02
Eu-152	5.02E-03	1.38E-02	7.46E-02	4.45E-03	8.24E-03	1.05E-01
Eu-154	5.57E-03	1.46E-02	8.25E-02	4.73E-03	8.77E-03	1.12E-01
Eu-155	2.83E-04	4.95E-04	4.55E-03	1.58E-04	2.77E-04	3.84E-03

Fe-55	2.97E-09	4.20E-09	3.71E-08	1.39E-09	2.97E-09	3.29E-08
H-3	0.00E+00	0.00E+00	1.45E-09	0.00E+00	0.00E+00	0.00E+00
Nb-94	1.20E-02	1.98E-02	1.79E-01	6.40E-03	1.19E-02	1.52E-01
Ni-59	1.51E-08	2.04E-08	1.77E-07	6.77E-09	1.50E-08	1.52E-07
Ni-63	3.23E-08	5.61E-08	3.78E-07	1.86E-08	4.14E-08	4.16E-07
Np-237	2.91E-03	4.04E-03	3.53E-02	1.34E-03	2.89E-03	3.01E-02
Pu-238	3.97E-05	1.04E-04	1.11E-03	3.08E-05	3.89E-05	1.13E-03
Pu-239	4.41E-05	1.15E-04	1.23E-03	3.40E-05	4.30E-05	1.25E-03
Pu-240	4.38E-05	1.14E-04	1.22E-03	3.38E-05	4.28E-05	1.24E-03
Pu-241	2.97E-06	6.03E-06	5.85E-05	1.88E-06	2.92E-06	5.56E-05
Sb-125	2.75E-03	4.52E-03	4.11E-02	1.46E-03	2.69E-03	3.45E-02
Sr-90	6.26E-05	1.39E-04	7.60E-04	4.61E-05	9.96E-05	1.04E-03
Tc-99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

= Activated Concrete ROC

= Basement Fill and Soil ROC

The dose significance of the radionuclides and potential dose contribution from the drill spoils pathway can be assessed using the Table 5 dose factors and the estimated July 1, 2018 Auxiliary Building (4), Unit 1 Containment Buildings (3) estimated activities based 1000 dpm/100 cm^2 concrete dust on the liner and using the U1/U2 Containment composite mix calculated based on the TSD 13-006 (3) Table 74 averages of Unit 1 and 2 Total Activities. There are minor differences in the Auxiliary Building July 1, 2018 nuclides due to changes in the NRC Radiological Toolbox half lives for radionuclides such as Fe-55 which was 2.70 years when TSD 14-013 calculations were made but changed to 2.737 years when TSD 14-019 and this TSD was done. Likewise the Ni-63 half-life was 96 years for TSD 14-013 versus 100.1 years for TSD 14-019 and this TSD. The source terms in Table 6 are consistent with TSD-14-019 which uses the current NRC Radiological Toolbox half-lives. In addition, the revision 0 Containment composite source term was from TSD 14-019 Table 18 which is a normalized 1 Ci source term. The other source terms in Table 6 are actual estimates of the end state source terms. For consistency, the composite mix was recalculated as the average of the Unit 1 and Unit 2 estimated total activities in Table 70 of TSD 13-006.

Table 6 - Estimated Drill Spoils Dose for Auxiliary Building and Containment Buildings Estimated End State Bounding Source Terms

Nuclide	Aux Building Drill Spoils mrem per mCi	Aux Profile Ci	Aux Profile Drill Spoils mrem	CTMT Drill Spoils mrem per mCi	U1 CTMT 565' Liner Dust Ci	U1 CTMT Liner Dust mrem	U1 CTMT Liner Incore Dust Ci	U1 CTMT Liner Incore Dust mrem	TSD 14-019 Comp CTMT Mix Ci	TSD 14-019 Comp CTMT Mix mrem
H-3	0.00E+00	1.46E-03	0.00E+00	0.00E+00	2.92E-05	0.00E+00	2.83E-05	0.00E+00	1.58E-05	0.00E+00
C-14	3.08E-07	3.69E-04	1.14E-07	4.27E-07	5.96E-07	2.54E-10	***4.78E-07***	2.04E-10	3.27E-07	1.40E-10
Fe-55	2.97E-09	***8.85E-04***	2.63E-09	4.20E-09	***9.95E-07***	4.18E-12	***8.04E-07***	3.38E-12	***2.26E-06***	9.49E-12
Ni-59	1.51E-08	***4.17E-03***	6.32E-08	2.04E-08	***6.18E-06***	1.26E-10	***6.01E-06***	1.23E-10	***6.18E-06***	1.26E-10
Co-60	1.07E-02	7.60E-03	8.15E-02	2.97E-02	6.33E-05	1.88E-03	4.74E-05	1.41E-03	7.28E-05	2.16E-03
Ni-63	3.23E-08	1.97E-01	6.36E-06	5.61E-08	6.36E-05	3.57E-09	4.13E-05	2.31E-09	2.86E-04	1.60E-08
Sr-90	6.26E-05	4.27E-04	2.67E-05	1.39E-04	5.91E-07	8.24E-08	8.90E-08	1.24E-08	3.17E-07	4.42E-08
Nb-94	1.20E-02	***1.07E-04***	1.28E-03	1.98E-02	***1.02E-06***	2.03E-05	8.70E-07	1.72E-05	2.20E-06	4.36E-05
Tc-99	0.00E+00	1.34E-04	0.00E+00	0.00E+00	3.20E-07	0.00E+00	***1.77E-07***	0.00E+00	1.66E-07	0.00E+00
Ag-108m	1.23E-02	***1.44E-04***	1.78E-03	2.05E-02	**1.12E-06**	2.30E-05	8.42E-07	1.73E-05	3.85E-06	7.90E-05
Sb-125	2.75E-03	***1.46E-04***	4.01E-04	4.52E-03	***5.76E-07***	2.60E-06	***2.81E-07***	1.27E-06	***3.92E-07***	1.77E-06
Cs-134	6.29E-03	8.63E-05	5.43E-04	1.72E-02	8.23E-07	1.41E-05	***7.73E-07***	1.33E-05	5.23E-07	8.98E-06
Cs-137	3.22E-03	6.25E-01	2.01E+00	7.27E-03	1.23E-03	8.93E-03	2.86E-04	2.08E-03	8.08E-04	5.88E-03
Eu-152	5.02E-03	***1.46E-04***	7.35E-04	1.38E-02	***4.67E-04***	6.43E-03	4.65E-04	6.41E-03	2.90E-04	3.99E-03
Eu-154	5.57E-03	***7.89E-05***	4.39E-04	1.47E-02	***2.24E-05***	3.28E-04	2.17E-05	3.18E-04	1.40E-05	2.05E-04
Eu-155	2.83E-04	***6.48E-05***	1.83E-05	4.95E-04	7.44E-06	3.69E-06	7.27E-06	3.60E-06	4.45E-06	2.20E-06
Np-237	2.91E-03	***3.66E-06***	1.07E-05	4.04E-03	***1.23E-08***	4.97E-08	***1.09E-08***	4.39E-08	6.70E-09	2.71E-08
Pu-238	3.97E-05	***1.08E-05***	4.29E-07	1.04E-04	2.82E-08	2.93E-09	***1.85E-08***	1.92E-09	1.46E-08	1.52E-09
Pu-239	4.41E-05	***4.47E-06***	1.97E-07	1.15E-04	1.21E-08	1.39E-09	***8.60E-09***	9.85E-10	6.33E-09	7.25E-10
Pu-240	4.38E-05	***4.47E-06***	1.96E-07	1.14E-04	1.21E-08	1.38E-09	***8.59E-09***	9.81E-10	6.32E-09	7.22E-10
Pu-241	2.97E-06	***2.36E-04***	7.02E-07	6.03E-06	7.45E-07	4.50E-09	***6.49E-07***	3.91E-09	***4.10E-07***	2.47E-09
Am-241	1.51E-04	***1.06E-05***	1.61E-06	3.14E-04	1.53E-07	4.81E-08	***2.91E-08***	9.15E-09	8.13E-08	2.55E-08
Am-243	1.58E-03	7.95E-06	1.26E-05	2.73E-03	1.62E-08	4.42E-08	***1.38E-08***	3.77E-08	8.96E-09	2.45E-08
Cm-243	9.93E-04	***2.80E-06***	2.78E-06	1.70E-03	2.17E-08	3.69E-08	***1.07E-08***	1.82E-08	1.14E-08	1.95E-08
Cm-244	2.55E-05	***2.58E-06***	6.58E-08	6.63E-05	2.00E-08	1.33E-09	***9.82E-09***	6.51E-10	1.06E-08	7.01E-10

Nuclide	Aux Building Drill Spoils mrem per mCi	Aux Profile Ci	Aux Profile Drill Spoils mrem	CTMT Drill Spoils mrem per mCi	U1 CTMT 565' Liner Dust Ci	U1 CTMT Liner Dust mrem	U1 CTMT Liner Incore Dust Ci	U1 CTMT Liner Incore Dust mrem	TSD 14-019 Comp CTMT Mix Ci	TSD 14-019 Comp CTMT Mix mrem
	Total	**8.37E-01**	**2.10E+00**		**1.89E-03**	**1.76E-02**	**9.08E-04**	**1.03E-02**	**1.51E-03**	**1.24E-02**
	Missed mrem		4.68E-03			4.97E-05		3.95E-05		1.27E-04
	% Missed		**0.22%**			**0.28%**		**0.39%**		**1.02%**

= Activated Concrete ROC

= ROC

Bold Italic **= MDA**

Table 7 - Groundwater Pathway Dose for Auxiliary Building and Containment Buildings End State Mixes

Nuclide	Aux Profile Ci	Aux GW DF mrem/mCi	Aux GW mrem	U1 CTMT 565' Liner Dust Ci	CTMT GW DF mrem/mCi	U1 CTMT Liner Dust GW mrem	U1 CTMT Liner Incore Dust Profile Ci	Incore GW mrem	TSD 14-019 Comp CTMT Mix Ci	TSD 14-019 Comp CTMT Mix GW mrem
H-3	1.46E-03	6.21E-03	9.05E-03	2.92E-05	2.72E-02	7.92E-04	2.83E-05	7.70E-04	1.58E-05	4.28E-04
C-14	3.69E-04	6.49E-02	2.39E-02	5.96E-07	2.84E-01	1.69E-04	***4.78E-07***	1.36E-04	3.27E-07	9.28E-05
Fe-55	8.85E-04	***8.06E-07***	7.14E-07	9.95E-07	***1.51E-05***	1.50E-08	***8.04E-07***	1.21E-08	***2.26E-06***	3.40E-08
Ni-59	4.17E-03	***1.35E-04***	5.62E-04	6.18E-06	***5.87E-04***	3.62E-06	***6.01E-06***	3.53E-06	***6.18E-06***	3.63E-06
Co-60	7.60E-03	1.00E-04	7.61E-04	6.33E-05	1.14E-02	7.24E-04	4.74E-05	5.42E-04	7.28E-05	8.33E-04
Ni-63	1.97E-01	2.86E-04	5.62E-02	6.36E-05	1.61E-03	1.02E-04	4.13E-05	6.63E-05	2.86E-04	4.59E-04
Sr-90	4.27E-04	3.29E-01	1.40E-01	5.91E-07	4.51E+00	2.67E-03	8.90E-08	4.02E-04	3.17E-07	1.43E-03
Nb-94	1.07E-04	***2.03E-03***	2.17E-04	1.02E-06	***8.84E-03***	9.05E-06	8.70E-07	7.68E-06	2.20E-06	1.94E-05
Tc-99	1.34E-04	1.48E-01	1.98E-02	3.20E-07	6.44E-01	2.06E-04	***1.77E-07***	1.14E-04	1.66E-07	1.07E-04
Ag-108m	1.44E-04	***5.47E-03***	7.88E-04	1.12E-06	**2.56E-02**	2.87E-05	8.42E-07	2.16E-05	3.85E-06	9.86E-05
Sb-125	1.46E-04	***1.04E-02***	1.52E-03	5.76E-07	***1.94E-01***	1.12E-04	***2.81E-07***	5.45E-05	***3.92E-07***	7.60E-05
Cs-134	8.63E-05	9.27E-03	8.00E-04	8.23E-07	1.98E-01	1.63E-04	***7.73E-07***	1.53E-04	5.23E-07	1.03E-04
Cs-137	6.25E-01	2.64E-02	1.65E+01	1.23E-03	1.57E-01	1.93E-01	2.86E-04	4.48E-02	8.08E-04	1.27E-01
Eu-152	1.46E-04	***5.95E-05***	8.70E-06	4.67E-04	***3.87E-03***	1.81E-03	4.65E-04	1.80E-03	2.90E-04	1.12E-03
Eu-154	7.89E-05	***6.77E-05***	5.34E-06	2.24E-05	***5.62E-03***	1.26E-04	2.17E-05	1.22E-04	1.40E-05	7.88E-05
Eu-155	6.48E-05	***8.01E-06***	5.19E-07	7.44E-06	8.72E-04	6.49E-06	7.27E-06	6.34E-06	4.45E-06	3.88E-06
Np-237	3.66E-06	***4.92E+01***	1.80E-01	1.23E-08	***2.13E+02***	2.62E-03	***1.09E-08***	2.32E-03	6.70E-09	1.43E-03
Pu-238	1.08E-05	***2.11E-01***	2.28E-03	2.82E-08	1.03E+00	2.89E-05	***1.85E-08***	1.90E-05	1.46E-08	1.50E-05
Pu-239	4.47E-06	***2.61E-01***	1.17E-03	1.21E-08	1.14E+00	1.38E-05	***8.60E-09***	9.79E-06	6.33E-09	7.21E-06
Pu-240	4.47E-06	***2.61E-01***	1.16E-03	1.21E-08	1.14E+00	1.38E-05	***8.59E-09***	9.79E-06	6.32E-09	7.20E-06
Pu-241	2.36E-04	***4.57E-03***	1.08E-03	7.45E-07	3.65E-02	2.72E-05	***6.49E-07***	2.37E-05	***4.10E-07***	1.50E-05
Am-241	1.06E-05	***2.58E-01***	2.73E-03	1.53E-07	1.15E+00	1.75E-04	***2.91E-08***	3.34E-05	8.13E-08	9.32E-05
Am-243	7.95E-06	2.63E-01	2.09E-03	1.62E-08	1.14E+00	1.85E-05	***1.38E-08***	1.58E-05	8.96E-09	1.03E-05
Cm-243	2.80E-06	***2.59E-02***	7.26E-05	2.17E-08	1.55E-01	3.37E-06	***1.07E-08***	1.65E-06	1.14E-08	1.78E-06
Cm-244	2.58E-06	***1.74E-02***	4.50E-05	2.00E-08	1.24E-01	2.49E-06	***9.82E-09***	1.22E-06	1.06E-08	1.31E-06

Nuclide	Aux Profile Ci	Aux GW DF mrem/mCi	Aux GW mrem	U1 CTMT 565' Liner Dust Ci	CTMT GW DF mrem/mCi	U1 CTMT Liner Dust GW mrem	U1 CTMT Liner Incore Dust Profile Ci	Incore GW mrem	TSD 14-019 Comp CTMT Mix Ci	TSD 14-019 Comp CTMT Mix GW mrem
GW Totals	**8.37E-01**		**1.69E+01**	**1.89E-03**		**2.02E-01**		**5.14E-02**		**1.33E-01**
Spoils Total			**2.10E+00**			**1.76E-02**		**1.03E-02**		**1.24E-02**
Total Dose			**1.90E+01**			**2.20E-01**		**6.17E-02**		**1.46E-01**
Spoils %			**12%**			**9%**		**20%**		**9%**

| | = Activated Concrete ROC | | = ROC | ***Bold Italic*** **= MDA** |

The Auxiliary Building end state source term is the unremediated estimate for the source term in the concrete floors and walls. The source terms used for the Containment Buildings are those calculated in TSD 13-006 (3) for the liner covered with concrete dust at 1000 dpm/100 cm^2. As seen in Table 6, the potential dose from the drill spoils scenario for the Auxiliary Building is 2.1 mrem/yr and in all cases the ROCs contribute over 98% of the dose.

In order to place the above drill spoils doses in context, the groundwater (GW) dose factors from TSD 14-010 (1) can be used to estimate the doses from the groundwater pathway as seen in Table 7 and compared to the drill spoils dose in Table 6. The drill spoils dose contributes 12% of the Auxiliary Building total dose, 12% of the Containment overall mix dose, 20% of the Containment Incore mix which has higher Europium and Tritium fractions and 9% of the Unit 1 and 2 normalized composite mix..

Note that the drilling spoils dose factors are based on the maximum fill concentrations (pCi/g fill per pCi total source term) from the DUST model results as shown in Attachment 1. The DUST results were based on the worst case fill Kds (i.e., the lowest Kds from various sources) in order to maximize the groundwater dose assuming that the fill material is concrete. If soil, or some combination of soil and concrete is used as fill, the Kd of the fill material would increase resulting in increased maximum fill concentrations. Use of higher Kds would lower the groundwater dose but would increase the drilling spoils dose. However, the effect of higher Kds is trivial since the maximum fill concentrations would increase by less than 0.4% for all ROCs other than Sr-90 which could increase by as much as 7%. The actual dose impact of a 7% increase in the Sr-90 maximum concentration on the final compliance dose is trivial when the radionuclide mixture percentage for Sr-90 and the dose contribution from the groundwater pathway are considered. For example, from Table 16 below, it is seen that the activity ratio of Sr-90 to Cs-137 (the predominant radionuclide) is 0.0068%. Therefore, a maximum Sr-90 concentration increase of 7% would result in a dose impact from drilling spoils of 0.005% (0.07*6.84E-04) relative to Cs-137 due to mixture considerations only. This potential trivial dose impact from increased Kd is attributed to drilling spoils only and would be further reduced when the dose from the groundwater pathway is considered, which contributes the majority of dose in the Auxiliary Building and Containment as described above. A higher Kd would significantly reduce the activity in solution with a corresponding decrease in groundwater dose. For the majority of radionuclides and basements, the overall effect of increased Kd, considering drilling spoils and groundwater, would be to decrease total dose. Given the very low dose impact from drilling spoils alone, no additional specific consideration of the impact of varying mixes of concrete and soil used as fill is considered necessary or justified.

The drill spoils ROCs and their dose factors (DFs) are summarized in Table 8.

Table 8 - Drill Spoils Dose Factors for Radionuclides of Concern

Nuclide	Aux Building Drill Spoils mrem/yr per mCi	CTMT Drill Spoils mrem per mCi	SFB Drill Spoils mrem/yr per mCi	Turbine Drill Spoils mrem/yr per mCi	Crib House Drill Spoils mrem/yr per mCi	WWTF Drill Spoils mrem/yr per mCi
H-3	0.00E+00	0.00E+00	1.45E-09	0.00E+00	0.00E+00	0.00E+00
Co-60	1.07E-02	2.97E-02	1.58E-01	9.58E-03	1.78E-02	2.26E-01
Ni-63	3.23E-08	5.61E-08	3.78E-07	1.86E-08	4.14E-08	4.16E-07
Sr-90	6.26E-05	1.39E-04	7.60E-04	4.61E-05	9.96E-05	1.04E-03
Cs-134	6.29E-03	1.72E-02	9.41E-02	5.54E-03	1.02E-02	1.31E-01
Cs-137	3.22E-03	7.27E-03	4.83E-02	2.35E-03	4.34E-03	5.57E-02
Eu-152	5.02E-03	1.38E-02	7.46E-02	4.45E-03	8.24E-03	1.05E-01
Eu-154	5.57E-03	1.47E-02	8.25E-02	4.73E-03	8.77E-03	1.12E-01

= Activated Concrete ROC

= Basement Fill and Soil ROC

The activated concrete ROCs should be included in addition to the basement fill and soil ROCs for the Containments which will have activated concrete from bioshield and incore area demolition in the residual dust left on the liner. It is unlikely there will be any significant neutron activation associated with the spent fuel since racks include neutron moderation and the storage configuration minimizes neutron flux.

3.2. Inadvertent Intruder Construction Scenario

As noted above, the Containment Buildings, Turbine Building, Crib House and Waste Water Treatment Facility (WWTF) end state source terms will be well below the potential activities in the Auxiliary Building and Spent Fuel Building. NUREG-1757 (7) Appendix J provides an example of inadvertent intruder construction which uses a 10 meter by 20 meter (200 m^2) house with a 3 meter deep basement. As seen in Table 2, the distance from the surface to the saturated zone is 12 feet. The basement is 3 meters or 9.8 feet deep, meaning the floor is 2.2 feet above the saturated zone.

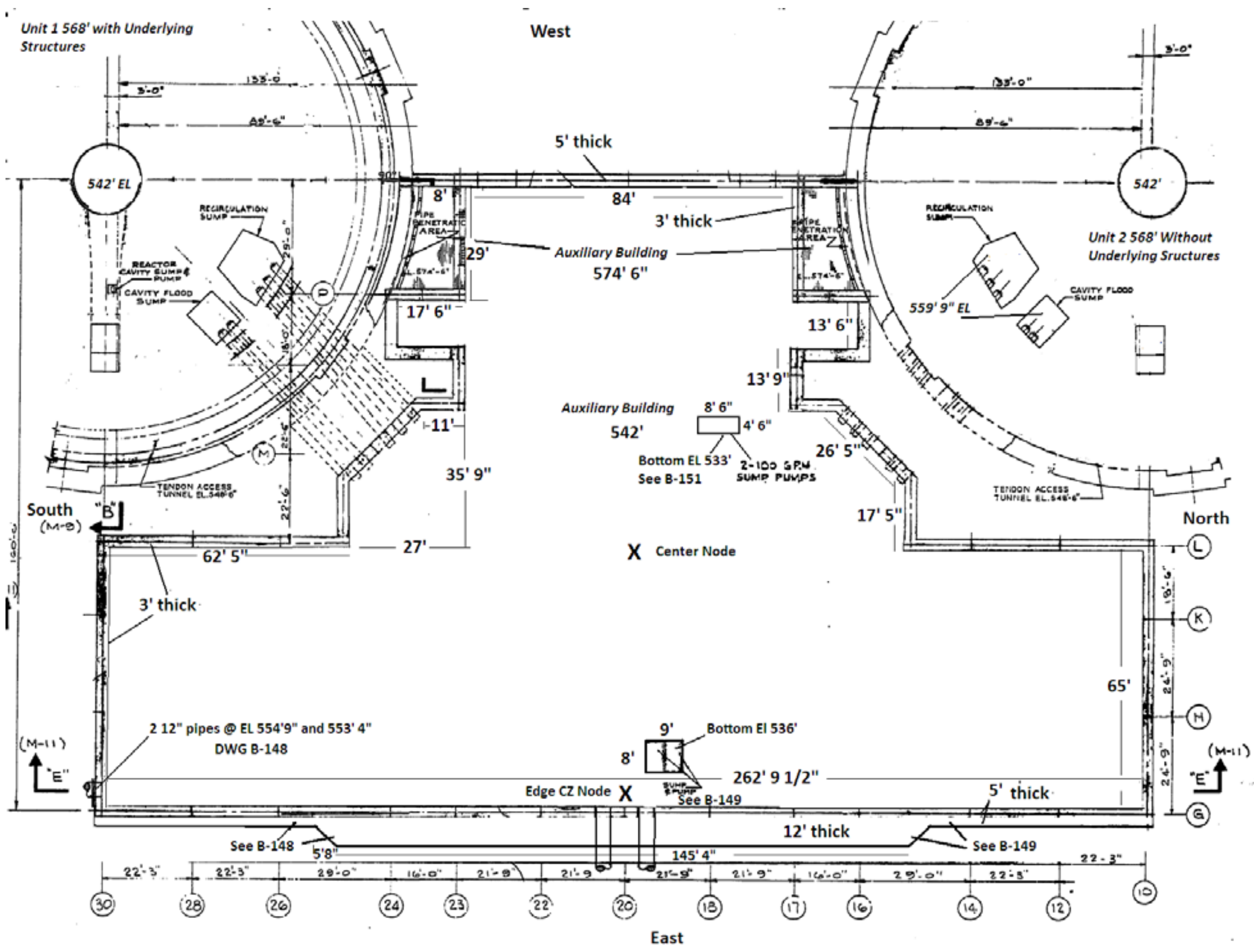

Figure 1 - Auxiliary Building End State Dimensions

As noted in Table 2, the Auxiliary Building basement floor is at the 542 foot elevation and the water table is at the 579 foot elevation.

Sand normally has a dry bulk density of 1.5 g/cc. (13) Site-specific sand bulk densities are higher at 1.81 g/cc (12) and fill material may be concrete at 2.34 g/cc or higher) or a mix of sand and concrete. Since use of a lower density leads to a lower mass of fill material and higher estimated concentration (pCi/g) at the time of maximum concentration as determined in TSD 14-010), this evaluation conservatively used the 1.5 g/cc value for a dry fill mass. At 25% porosity the actual density of the saturated zone source in the MicroShield model used in this assessment would be 1.75 g/cc wet source density as seen in Table 9.

Table 9 - Auxiliary Building MicroShield Construction Model Parameters

Parameter	Value	Units	Value	Units
House Basement Length	65.6	ft	20	m
House Basement Width	32.8	ft	10	m
House Basement Surface Area	2153	ft^2	200	m^2
End State Source Length	263	ft	80.1	m
End State Source Width	103	ft	31.5	m
End State Source Height	37	ft	11.3	m
End State Source Volume	2.84E+10	cc	28445.0	m^3
Dry Fill Density			1.5	g/cc
Dry Source Mass			4.27E+10	grams
Wet Source Mass @ 25% Porosity			4.98E+10	grams
Wet Source Density			1.75E+00	g/cc
Source Activity Co-60 Ci	3.83E-04	Ci	8.97E-03	pCi/g
Source Activity Cs-137 Ci	6.04E-01	Ci	1.42E+01	pCi/g
Basement Depth	9.8	ft	3	m
Dirt Top Shield Distance	2.16	ft	0.66	m
Source Density	1.50	g/cc	1.88	g/cc wet
Shield Density	1.5	g/cc		
Dose Point Contact with Excavation	39.199	ft	11.95	m

The Auxiliary Building source term and groundwater dose factors in Table 6 and Table 7 can be used to calculate the basement inventory limit equivalent to 25 mrem/yr as shown in Table 10. The profile activity divided by the sum of the Drill Spoils and Ground Water dose factors and converted from Ci to mCi provides the estimated dose for each nuclide. The total dose at the current estimated inventory is 19.1 mrem/yr, which means the activity could be 1.31 times higher at the 25 mrem/yr release criterion. Multiplying the Auxiliary profile activity by the 1.31 correction factor provides the maximum inventory at the BIL for the mix. The Auxiliary Building Full DUST MS report (10) data in Attachment 1 has the total activity in solution (pCi) and sorbed (pCi) at the time of peak fill activity for that nuclide, the sum of these values divided by the DUST MS modeled source term of 6. 503E-06 mCi provides the Table 10 total activity in the fill material conversion factor in pCi/mCi. This factor multiplied by the maximum BIL inventory and divided by 1000 mCi/Ci provides the saturated zone inventory at the time of peak concentration for each nuclide. Since the peak fill concentration times (e.g., t = peak) vary, radioactive decay results in differences in the peak concentration inventories.

Table 10 - Auxiliary Building Basement Inventory Limit and Saturated Zone Activity at t = Peak Concentrations

Nuclide	Aux Profile Ci	Aux Building Drill Spoils mrem per mCi	Aux GW DF mrem/mCi	Aux Dose mrem/yr	Building Inventory Limit mCi	Saturated Zone Total Activity pCi per mCi	BIL Saturated Zone Peak Activity pCi/g	Sat Zone Total Source @ Peak Activity Ci
H-3	1.46E-03	0.00E+00	6.21E-03	9.05E-03	1.92E+00	9.94E+08	4.47E-02	1.908E-03
C-14	3.69E-04	3.08E-07	6.49E-02	2.39E-02	4.85E-01	1.00E+09	1.14E-02	4.854E-04
Fe-55	***8.85E-04***	2.97E-09	8.06E-07	7.16E-07	1.16E+00	2.34E+08	6.37E-03	2.719E-04
Ni-59	***4.17E-03***	1.51E-08	1.35E-04	5.62E-04	5.48E+00	1.00E+09	1.29E-01	5.507E-03
Co-60	7.60E-03	1.07E-02	1.00E-04	8.22E-02	9.99E+00	3.83E+07	8.97E-03	3.829E-04
Ni-63	1.97E-01	3.23E-08	2.86E-04	5.62E-02	2.58E+02	7.79E+08	4.72E+00	2.013E-01
Sr-90	4.27E-04	6.26E-05	3.29E-01	1.41E-01	5.61E-01	3.19E+08	4.19E-03	1.788E-04
Nb-94	***1.07E-04***	1.20E-02	2.03E-03	1.50E-03	1.40E-01	1.01E+09	3.30E-03	1.409E-04
Tc-99	1.34E-04	0.00E+00	1.48E-01	1.98E-02	1.76E-01	1.00E+09	4.13E-03	1.761E-04
Ag-108m	***1.44E-04***	1.23E-02	5.47E-03	2.57E-03	1.90E-01	9.37E+08	4.16E-03	1.775E-04
Sb-125	***1.46E-04***	2.75E-03	1.04E-02	1.92E-03	1.91E-01	2.35E+08	1.06E-03	4.508E-05
Cs-134	8.63E-05	6.29E-03	9.27E-03	1.34E-03	1.14E-01	2.05E+08	5.46E-04	2.329E-05
Cs-137	6.25E-01	3.22E-03	2.64E-02	1.85E+01	8.21E+02	7.36E+08	1.42E+01	6.041E-01
Eu-152	***1.46E-04***	5.02E-03	5.95E-05	7.43E-04	1.92E-01	6.78E+07	3.06E-04	1.304E-05
Eu-154	***7.89E-05***	5.57E-03	6.77E-05	4.45E-04	1.04E-01	5.25E+07	1.28E-04	5.451E-06
Eu-155	***6.48E-05***	2.83E-04	8.01E-06	1.88E-05	8.52E-02	4.00E+07	7.98E-05	3.405E-06
Np-237	***3.66E-06***	2.91E-03	4.92E+01	1.80E-01	4.81E-03	1.01E+09	1.14E-04	4.843E-06
Pu-238	***1.08E-05***	3.97E-05	2.11E-01	2.28E-03	1.42E-02	9.00E+08	3.00E-04	1.279E-05
Pu-239	***4.47E-06***	4.41E-05	2.61E-01	1.17E-03	5.87E-03	1.00E+09	1.38E-04	5.901E-06
Pu-240	***4.47E-06***	4.38E-05	2.61E-01	1.16E-03	5.87E-03	1.00E+09	1.38E-04	5.891E-06
Pu-241	***2.36E-04***	2.97E-06	4.57E-03	1.08E-03	3.11E-01	5.49E+08	4.00E-03	1.705E-04
Am-241	***1.06E-05***	1.51E-04	2.58E-01	2.74E-03	1.40E-02	9.83E+08	3.22E-04	1.372E-05
Am-243	7.95E-06	1.58E-03	2.63E-01	2.10E-03	1.05E-02	1.00E+09	2.46E-04	1.050E-05
Cm-243	***2.80E-06***	9.93E-04	2.59E-02	7.54E-05	3.68E-03	7.28E+08	6.29E-05	2.683E-06
Cm-244	***2.58E-06***	2.55E-05	1.74E-02	4.50E-05	3.40E-03	6.11E+08	4.87E-05	2.076E-06
Total	**8.37E-01**			**1.90E+01**	**1.10E+03**		**1.91E+01**	**8.15E-01**
			Activity CF	1.31				
	= Activated Concrete ROC				= ROC	***Bold Italic* = MDA**		

As seen in Table 9, the abstracted source dimension equivalent to the 262’ 9.5” length, 37’ height and 1.00E+06 cubic feet volume is a 103 foot width instead of the 65 foot width shown for the east area of the Auxiliary Building in Figure 1. This provides a rectangular geometry that can be modeled in MicroShield with the same volume and source term as the overall Auxiliary Building. The Ni-63, Co-60, and Cs-137 comprise 98.87% of the peak saturated zone source term. Ni-63 is not a gamma emitting nuclide and will not result in exposure through the 2.16 feet of soil above the saturated zone that the foundation would sit on. The Co-60 and Cs-137 source term in Table 10 were used to model the house occupancy potential direct radiation exposures. The dose rates at contact (e.g., ½ inch) and at 24 inches above the floor were modeled to provide contact and an above the knees whole body dose rate using MicroShield 8.03 using the parameters shown in Table 9. The MicroShield Reports are provided in Attachment 2. As a conservative assumption the dry bulk density of soil at 1.5 g/cc was used for the source density even though a wet density based on a very low 25% porosity was used in the MC DUST screening analysis would be 1.75 g/cc for the source. (10)

As seen in the MicroShield report provided in Attachment 2, the dose rates in the excavation are very low even though the Co-60 modeled source term is slightly higher than the maximum BIL inventory in Table 10. The ZSRP resident farmer RESRAD model uses the fraction of time spent indoors of 0.6571 specified in NUREG/CR-5512, Vol. 3 Table 6.87. (14) This equals 5,762 hours a year, at the calculated dose rates this equals 0.03 mrem/yr as shown in Table 11.

Table 11 - Calculated Dose Rates and Doses for 5,762 Hour Occupancy In Aux Building Excavation

Distance	mrem/hr	Annual Dose mrem/yr
Contact	3.278E-06	1.89E-02
24 inch	5.046E-06	2.91E-02

Given the extremely short construction durations (a few months) and likely actual occupancy times in the basement, as well as the conservative assumptions such as source term dispersal and source density, the potential direct radiation exposure from a construction worker this scenario is insignificant (inhalation and ingestion pathway doses are zero because the source term is 2.2 feet below the excavation floor). The construction scenario does not require consideration as a BFM pathway in demonstrating compliance with the 10 CFR 20 Subpart E license termination requirements.

The Spent Fuel Pool and transfer canal are at the 576’ elevation making the saturated zone 3 feet thick. As described in LTP Chapter 6, it is implausible for there to be any groundwater exposure pathways for the Spent Fuel Building end state. Therefore, the drill spoils exposure pathway limits the potential end state source term.

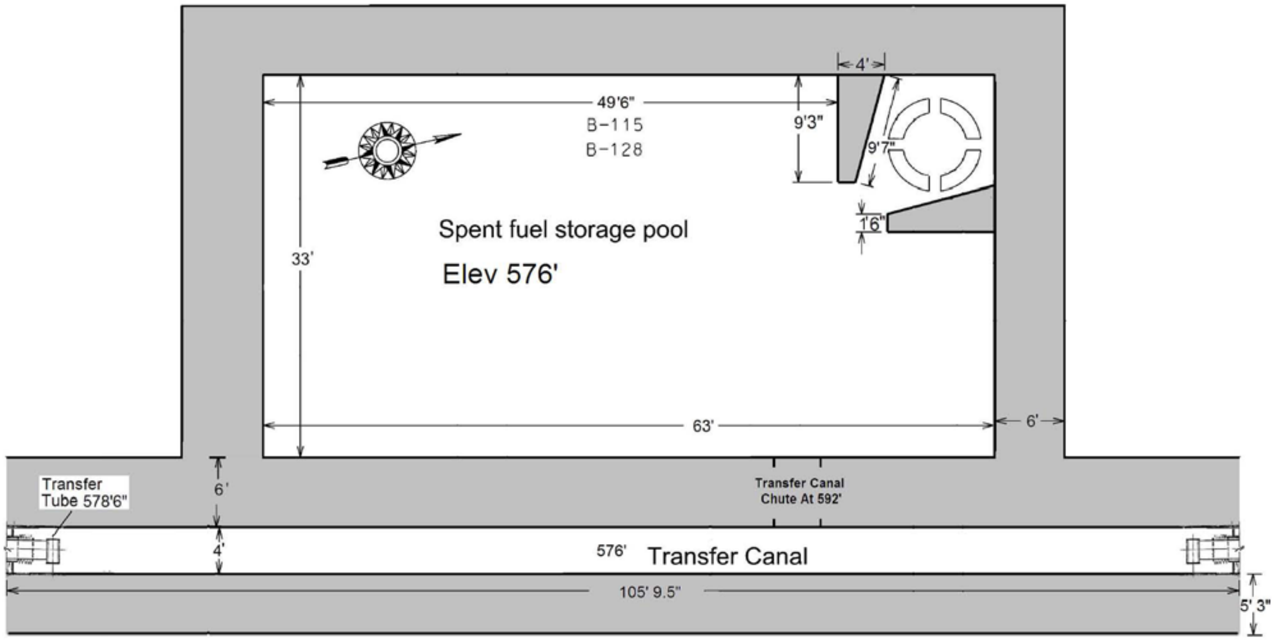

Figure 2 - Top View of Spent Fuel Building End State

The Auxiliary Building mix can be used to estimate the end state source term using the Spent Fuel Building drill spoils dose factors in Table 5 and the Attachment 1 DUST MS result as described for the Auxiliary Building above. The peak activity corresponding to the source term limits are shown in Table 12 for the Spent Fuel Building.

Table 12 - Spent Fuel Building Basement Fill Inventory Limit and Saturated Zone Activity at t = Peak Concentrations

Nuclide	Aux Profile Ci	SFB Drill Spoils mrem per mCi	SFB Dose mrem/yr	Building Inventory Limit mCi	Saturated Zone Total Activity pCi per mCi	BIL Saturated Zone Peak Activity pCi/g	Sat Zone Total Source @ Peak Activity Ci
H-3	1.46E-03	1.45E-09	2.12E-09	1.16E+00	9.93E+08	3.69E+00	1.152E-03
C-14	3.69E-04	3.72E-06	1.37E-06	2.93E-01	1.00E+09	9.41E-01	2.935E-04
Fe-55	***8.85E-04***	3.71E-08	3.28E-08	7.03E-01	2.33E+08	5.26E-01	1.640E-04
Ni-59	***4.17E-03***	1.77E-07	7.38E-07	3.32E+00	1.00E+09	1.06E+01	3.314E-03
Co-60	7.60E-03	1.58E-01	1.20E+00	6.04E+00	3.85E+07	7.45E-01	2.324E-04
Ni-63	1.97E-01	3.78E-07	7.43E-05	1.56E+02	7.78E+08	3.89E+02	1.215E-01
Sr-90	4.27E-04	7.60E-04	3.24E-04	3.39E-01	3.17E+08	3.44E-01	1.074E-04
Nb-94	***1.07E-04***	1.79E-01	1.91E-02	8.46E-02	9.99E+08	2.71E-01	8.456E-05
Tc-99	1.34E-04	0.00E+00	0.00E+00	1.06E-01	1.00E+09	3.41E-01	1.064E-04
Ag-108m	***1.44E-04***	1.85E-01	2.67E-02	1.15E-01	9.30E+08	3.42E-01	1.066E-04
Sb-125	***1.46E-04***	4.11E-02	5.99E-03	1.16E-01	2.34E+08	8.69E-02	2.711E-05
Cs-134	8.63E-05	9.41E-02	8.13E-03	6.86E-02	2.04E+08	4.49E-02	1.401E-05

Nuclide	Aux Profile Ci	SFB Drill Spoils mrem per mCi	SFB Dose mrem/yr	Building Inventory Limit mCi	Saturated Zone Total Activity pCi per mCi	BIL Saturated Zone Peak Activity pCi/g	Sat Zone Total Source @ Peak Activity Ci
Cs-137	6.25E-01	4.83E-02	3.02E+01	4.96E+02	7.35E+08	1.17E+03	3.649E-01
Pm-147	0	1.56E-06	0.00E+00	0.00E+00	2.29E+08	0.00E+00	0.000E+00
Eu-152	***1.46E-04***	7.46E-02	1.09E-02	1.16E-01	6.67E+07	2.48E-02	7.747E-06
Eu-154	***7.89E-05***	8.25E-02	6.51E-03	6.27E-02	5.21E+07	1.05E-02	3.270E-06
Eu-155	***6.48E-05***	4.55E-03	2.95E-04	5.15E-02	3.96E+07	6.53E-03	2.036E-06
Np-237	***3.66E-06***	3.53E-02	1.29E-04	2.91E-03	9.99E+08	9.30E-03	2.902E-06
Pu-238	***1.08E-05***	1.11E-03	1.20E-05	8.59E-03	8.92E+08	2.45E-02	7.659E-06
Pu-239	***4.47E-06***	1.23E-03	5.47E-06	3.55E-03	9.96E+08	1.13E-02	3.537E-06
Pu-240	***4.47E-06***	1.22E-03	5.46E-06	3.55E-03	9.96E+08	1.13E-02	3.535E-06
Pu-241	***2.36E-04***	5.85E-05	1.38E-05	1.88E-01	5.46E+08	3.28E-01	1.024E-04
Am-241	***1.06E-05***	3.06E-03	3.25E-05	8.43E-03	9.78E+08	2.64E-02	8.246E-06
Am-243	7.95E-06	2.51E-02	1.99E-04	6.32E-03	9.99E+08	2.02E-02	6.314E-06
Cm-243	***2.80E-06***	1.56E-02	4.36E-05	2.23E-03	7.24E+08	5.16E-03	1.611E-06
Cm-244	***2.58E-06***	7.09E-04	1.83E-06	2.05E-03	6.06E+08	3.99E-03	1.244E-06
Total	**8.37E-01**		**3.15E+01**	**6.65E+02**		**1.58E+03**	**4.92E-01**
		Activity CF	0.79				

= Activated Concrete ROC (Eu-152, Eu-154)   = ROC (Cs-137)   ***Bold Italic*** **= MDA**

The Spent Fuel Building end state construction scenario modeling parameters are provided in Table 13. The maximum release limit concentrations from the source terms in the saturated zone below the 3 meter deep excavation are 2.33E-04 Ci Co-60 and 3.65E-01 Ci Cs-137 as seen in Table 12. The Spent Fuel Building MicroShield 8.03 modeling parameters are shown in Table 13.

Table 13 - Spent Fuel Building MicroShield Construction Model Parameters

Parameter	Value	Units	Value	Units
House Basement Length	65.6	ft	20	m
House Basement Width	32.8	ft	10	m
House Basement Surface Area	2153	ft^2	200	m^2
End State Source Length	63	ft	19.2	m
End State Source Width	39	ft	11.8	m
End State Source Height	3	ft	0.9	m
End State Source Volume	2.08E+08	cc	208.0	m^3
Dry Fill Density			1.5	g/cc
Dry Source Mass			3.12E+08	grams
Wet Source Mass @ 25% Porosity			3.64E+08	grams
Wet Source Density			1.75E+00	g/cc
Source Activity Co-60 Ci	2.32E-04	Ci	7.45E-01	pCi/g

Parameter	Value	Units	Value	Units
Source Activity Cs-137 Ci	3.65E-01	Ci	1.17E+03	pCi/g
Basement Depth	9.8	ft	3	m
Dirt Top Shield Distance	2.16	ft	0.66	m
Source Density	1.50	g/cc	1.88	g/cc wet
Shield Density	1.5	g/cc		
Dose Point Contact with Excavation	5.199	ft	1.58	m

As seen in Attachment 2, the dose rates in the excavation are low. The ZSRP resident farmer RESRAD models uses the fraction of time spent indoors of 0.6571 as specified in NUREG/CR-5512, Vol. 3 Table 6.87. (14) which equals 5,762 hours per year. A typical residential floor slab is 4 inches thick with an average concrete density of 2.35 g/cc. The floor slab is included in the Spent Fuel Pool MicroShield model. As seen in the MicroShield report in Attachment 2 and Table 14 the Construction Scenario dose is 0.45 mrem/yr; thus, any acute exposure during excavation and construction would be trivial.

Table 14 - Calculated Dose Rates and Doses for 5,762 Hour Occupancy In Spent Fuel Building Residential Basement

Distance	mrem/hr	Annual Dose mrem/yr
Contact	7.74E-05	4.46E-01
24 inch	7.86E-05	4.53E-01

The estimated doses are less than 2% of the 25 mrem/yr release criterion and are therefore insignificant. The estimated dose is very conservative because it assumes 100% of the indoor occupancy time is spent in the basement and no credit is taken for the side shielding afforded by the concrete footings or vadose zone soil surrounding the basement floor slab. The potential dose from the construction scenario is insignificant and does not require consideration as a BFM pathway in demonstrating compliance with the 10 CFR 20 Subpart E license termination requirements.

3.3. Large Scale Excavation Scenario

As a further evaluation of potential alternate scenarios, the concentration of concrete debris and fill material resulting from removal of the end state structures below the 588 foot elevation is examined. This is considered to be a less likely but plausible scenario as described in the LTP Chapter 6. In accordance with NUREG-1757, Table 5.1 it is used to risk-inform the decision. The maximum inventory that can remain at license termination and still meet the 25 mrem/year release criteria can be calculated using the Auxiliary Building and Containment Mixes and the combined Drill Spoils and Groundwater Dose Factors from TSD 14-010 (1).

$$Max\ Inventory\ mCi = \frac{25\ mrem/yr}{DF_{GW} + DF_{spoils}}$$

The ROC Maximum allowable source terms that results in 25 mrem/year for each ROC are shown in Table 15.

Table 15 – ROC Maximum Allowable License Termination Source Term

Nuclide	Aux mCi	Containment mCi	Spent Fuel mCi	Turbine mCi	Crib House mCi	WWTF mCi
H-3	4.03E+03	9.20E+02	9.20E+02	3.68E+03	4.31E+03	2.02E+01
Co-60	2.31E+03	6.08E+02	1.58E+02	2.01E+03	1.23E+03	3.34E+01
Ni-63	8.75E+04	1.56E+04	1.56E+04	6.23E+04	7.27E+04	3.42E+02
Sr-90	7.59E+01	5.54E+00	5.54E+00	2.21E+01	2.59E+01	1.21E-01
Cs-134	1.61E+03	1.16E+02	1.16E+02	4.55E+02	4.76E+02	2.73E+00
Cs-137	8.45E+02	1.52E+02	1.52E+02	6.01E+02	6.60E+02	3.46E+00
Eu-152	4.92E+03	1.42E+03	3.35E+02	4.62E+03	2.76E+03	8.88E+01
Eu-154	4.44E+03	1.23E+03	3.03E+02	4.08E+03	2.51E+03	6.80E+01

= Activated Concrete ROC

= Basement Fill and Soil ROC

Note: Spent Fuel BILS set at lower of either Spent Fuel or Containment Limits per Reference 1

The normalized composite 1 Ci mixes at July 1, 2018 for the Containments and Auxiliary Building from TSD 14-019 (6) Table 19 for ROCs provide a mix that can be adjusted to equal a sum of the fractions equal to 1.0 for each building when divided by the Table 15 limits. The ROC mix source terms are provided in Table 16. They do not equal 1.0 Ci because the insignificant nuclide activities are not included, only the ROCs. It is the relative ratio of the nuclides activities that matter and not the overall source term since these initial source terms are adjusted to equal the maximum limit that can be left at License Termination.

The fraction of the Table 15 limit for each source term is calculated by dividing the Table 16 normalized mix activities by the Table 15 limit. As shown in Table 17 the 1 Ci normalized mix ROCs would exceed the inventory limits that could remain in the end state structures because the sum of the fractions exceed 1.0.

Table 16 - ROC Inventories Using Aux Building and CTMT Normalized Composite Source Terms

Nuclide	Aux mCi	Containment mCi	Spent Fuel mCi	Turbine mCi	Crib House mCi	WWTF mCi
H-3		7.40E-01				
Co-60	9.08E+00	4.68E+01	9.08E+00	9.08E+00	9.08E+00	9.08E+00
Ni-63	2.35E+02	2.63E+02	2.35E+02	2.35E+02	2.35E+02	2.35E+02
Sr-90	5.10E-01	2.73E-01	5.10E-01	5.10E-01	5.10E-01	5.10E-01
Cs-134	1.03E-01	8.15E-02	1.03E-01	1.03E-01	1.03E-01	1.03E-01
Cs-137	7.46E+02	6.76E+02	7.46E+02	7.46E+02	7.46E+02	7.46E+02
Eu-152		4.36E+00				
Eu-154		5.79E-01				

= Activated Concrete ROC

= Basement Fill and Soil ROC

Table 17 - ROC Max Inventory Fractions for Auxiliary Building and Containment Source Terms

Nuclide	Aux	Containment	Spent Fuel	Turbine	Crib House	WWTF
H-3		8.04E-04				
Co-60	3.93E-03	7.69E-02	5.75E-02	4.52E-03	7.35E-03	2.71E-01
Ni-63	2.68E-03	1.69E-02	1.51E-02	3.77E-03	3.23E-03	6.87E-01
Sr-90	6.71E-03	4.94E-02	9.20E-02	2.31E-02	1.97E-02	4.20E+00
Cs-134	6.42E-05	7.00E-04	8.86E-04	2.27E-04	2.16E-04	3.78E-02
Cs-137	8.83E-01	4.44E+00	4.90E+00	1.24E+00	1.13E+00	2.15E+02
Eu-152		3.08E-03				
Eu-154		4.69E-04				
Total	0.90	4.58	5.06	1.27	1.16	220.69

= Activated Concrete ROC

= Basement Fill and Soil ROC

The Table 16 inventories divided by the sum of the fractions (e.g., Total) in Table 17 calculates the maximum allowed end state source term that equals an ROC inventory with a sum of the fractions act 1.0. The maximum inventory in mCi is shown in Table 18.

Table 18 - Maximum Allowable Inventory at License Termination

Nuclide	Aux mCi	Containment mCi	Spent Fuel mCi	Turbine mCi	Crib House mCi	WWTF mCi
H-3		1.62E-01				
Co-60	1.01E+01	1.02E+01	1.79E+00	7.14E+00	7.82E+00	4.11E-02
Ni-63	2.62E+02	5.73E+01	4.64E+01	1.85E+02	2.02E+02	1.06E+00
Sr-90	5.68E-01	5.97E-02	1.01E-01	4.01E-01	4.39E-01	2.31E-03
Cs-134	1.15E-01	1.78E-02	2.04E-02	8.11E-02	8.89E-02	4.67E-04
Cs-137	8.32E+02	1.47E+02	1.47E+02	5.87E+02	6.43E+02	3.38E+00
Eu-152		9.51E-01				
Eu-154		1.26E-01				
Total	**1.10E+03**	**2.16E+02**	**1.96E+02**	**7.79E+02**	**8.54E+02**	**4.49E+00**

= Activated Concrete ROC

= Basement Fill and Soil ROC

The concrete volumes below the 588 foot elevation associated with each building are calculated in TSD 13-006, TSD 14-013, and TSD 14-014 (3), (4), (5). The end state concrete volumes and masses for each building are summarized in Table 19.

Table 19 - Summary of End State Concrete Volumes and Masses

Structure	Total Concrete Volume per Item ft^3	Total Concrete Volume per Item m^3	Concrete Mass grams
Auxiliary Building	5.20E+05	14714.41	3.53E+10
Unit 1 Containment Outside Liner Only	2.21E+05	6269.53	1.50E+10
Unit 2 Containment Outside Liner Only	2.21E+05	6269.53	1.50E+10
Spent Fuel Building	3.94E+04	1116.31	2.68E+09
Turbine Bld, Main Steam Tunnel, Diesel Oil	1.11E+06	31446.15	7.55E+10
Crib House and Forebay	3.46E+05	9788.53	2.35E+10
Waste Water Treatment Facility	1.27E+04	358.88	8.61E+08
Totals	**2.47E+06**	**7.00E+04**	**1.68E+11**

The Table 18 inventories decayed 10 years and converted to pCi divided by the concrete masses in Table 19 provide the average concentration of the concrete debris shown in Table 20 along with the industrial scenario soil DCGLs from TSD 14-010. Soil DCGL concentrations are considered bounding values for screening excavation concrete debris.

Table 20 - Concrete Debris Concentrations at t = 10 years and Soil DCGLs

Nuclide	Decay Const yr^{-1}	Aux pCi/g	Containment pCi/g	Spent Fuel pCi/g	Turbine pCi/g	Crib House pCi/g	WWTF pCi/g
H-3	5.626E-02		6.12E-03				
Co-60	1.315E-01	7.70E-02	1.82E-01	1.80E-01	2.54E-02	8.94E-02	1.28E-02
Ni-63	6.925E-03	6.92E+00	3.55E+00	1.62E+01	2.28E+00	8.04E+00	1.15E+00
Sr-90	2.408E-02	1.27E-02	3.12E-03	2.95E-02	4.17E-03	1.47E-02	2.11E-03
Cs-134	3.357E-01	1.14E-04	4.12E-05	2.65E-04	3.74E-05	1.32E-04	1.89E-05
Cs-137	2.298E-02	1.87E+01	7.79E+00	4.37E+01	6.18E+00	2.18E+01	3.12E+00
Eu-152	5.120E-02		3.79E-02				
Eu-154	7.877E-02		3.82E-03				
Total		**2.57E+01**	**1.16E+01**	**6.01E+01**	**8.49E+00**	**2.99E+01**	**4.29E+00**

= Activated Concrete ROC

= Basement Fill and Soil ROC

Area factors for a 1 meter thick layer of soil are provided in TSD 14-011 (15). The interpolated values that correspond to the Table 19 volumes divided by 1 meter are shown in Table 21.

Table 21 - Interpolated Area Factors for Concrete Volumes 1 Meter Thick

Nuclide	Auxiliary Building	Containment Outside Liner Only	Spent Fuel Building	Turbine Bld, Main Steam Tunnel, Diesel Oil	Crib House and Forebay	Waste Water Treatment Facility
Co-60	1.06E+00	1.10E+00	1.16E+00	1.04E+00	1.07E+00	1.25E+00
Ni-63	1.73E+00	3.04E+00	6.38E+00	1.49E+00	1.87E+00	2.04E+01
Sr-90	1.27E+00	1.49E+00	1.77E+00	1.18E+00	1.31E+00	5.57E+00
Cs-134	1.20E+00	1.35E+00	1.55E+00	1.13E+00	1.23E+00	1.75E+00
Cs-137	1.29E+00	1.53E+00	1.89E+00	1.19E+00	1.33E+00	2.26E+00

When the Table 20 concentrations are divided by the soil DCGL times the area factor the fractions of the adjusted soil DCGL are calculated. The sum of the fractions of the adjusted soil DCGL times 25 mrem/year provides an estimate of the dose consequence for the concrete excavation. The fraction of the adjusted soil DCGL and the bounding doses are shown in Table 22.

The Table 21 area factors are based on the Resident Farmer scenario and are approximations of the area factors that would be applicable to the Industrial Scenario. Therefore, Table 22 also contains the dose with no area factor correction which provides the maximum dose.

The estimated fill volume for a large scale excavation is calculated by multiplying the height from the 591' grade elevation to the floor elevation by the abstracted floor surface area in square feet shown in Table 2. The volumes and masses using a density of 1.5 g/cm^3 are provided in Table 24, contains the fill concentrations decay corrected to calculate the worst case concentrations in the fill at 10 years. As seen in Table 24 and the DUST MS Auxiliary and Spent Fuel Building results in Attachment 1, some radionuclides reach their peak concentrations in the fill before 10 years and some after 10 years. As a conservative assumption, the concentration assigned to any radionuclides reaching peak concentration after ten years as reported in the DUST MS TSD 14-0031 (10) data (Attachment 1), is the peak value as opposed to the 10 year decay value since this is the peak concentration the nuclide will ever reach in the fill. Radionuclides with peak concentrations before 10 years are decayed to 10 years as indicated by the decay years in Table 24. The decay corrected fill concentrations are provided in Table 24.

Table 22 - Concrete Fractions of Soil DCGLs and Bounding Large Excavation Doses at t=10 years

Nuclide	Soil DCGL pCi/g	Aux DCGL Fraction	Containment DCGL Fraction	Spent Fuel DCGL Fraction	Turbine DCGL Fraction	Crib House DCGL Fraction	WWTF DCGL Fraction
H-3	1815.89		3.37E-06				
Co-60	12.34	5.86E-03	1.34E-02	1.26E-02	1.97E-03	6.76E-03	8.30E-04
Ni-63	9480000	4.22E-07	1.24E-07	2.67E-07	1.62E-07	4.53E-07	5.95E-09
Sr-90	14.07	7.06E-04	1.49E-04	1.18E-03	2.51E-04	7.97E-04	2.69E-05
Cs-134	23.33	4.05E-06	1.31E-06	7.31E-06	1.42E-06	4.60E-06	4.62E-07
Cs-137	55.76	2.60E-01	9.11E-02	4.15E-01	9.28E-02	2.93E-01	2.48E-02
Eu-152	27.43		1.38E-03				
Eu-154	25.43		1.50E-04				
Total		**2.66E-01**	**1.06E-01**	**4.29E-01**	**9.50E-02**	**3.00E-01**	**2.56E-02**
Dose mrem/yr		6.66	2.65	10.72	2.37	7.51	0.64
mrem/yr no AF		8.57	3.90	20.02	2.83	9.96	1.43

= Activated Concrete ROC

= Basement Fill and Soil ROC

Table 23 - Excavated Fill Material Volumes and Masses

Structure	Fill Volume 591' to Floor ft^3	Total Fill Volume per Item m^3	Fill Mass grams
Auxiliary Building	1.33E+06	3.76E+04	5.65E+10
Unit 1 Containment OutsideLiner Only	4.29E+05	1.21E+04	1.82E+10
Unit 2 Containment Outside Liner Only	4.29E+05	1.21E+04	1.82E+10
Spent Fuel Building	3.67E+04	1.04E+03	1.56E+09
Turbine Bld, Main Steam Tunnel, Diesel Oil	1.51E+06	4.26E+04	6.40E+10
Crib House and Forebay	1.39E+06	3.92E+04	5.89E+10
Waste Water Treatment Facility	3.56E+04	1.01E+03	1.51E+09
Totals	**5.15E+06**	**1.46E+05**	**2.19E+11**

Table 24 - Worst Case Fill Concentrations at 10 Years

Nuclide	Decay Constant	Years to t = Peak	Decay Years	Aux pCi/g	Containment pCi/g	Spent Fuel pCi/g	Turbine pCi/g	Crib House pCi/g	WWTF pCi/g
H-3	5.63E-02	1.00E-01	10		5.05E-03				
Co-60	1.31E-01	4.00E+00	10	4.81E-02	1.50E-01	3.09E-01	3.00E-02	3.57E-02	7.30E-03
Ni-63	6.92E-03	3.70E+01	37	3.59E+00	2.44E+00	2.30E+01	2.23E+00	2.66E+00	5.45E-01
Sr-90	2.41E-02	2.10E+01	21	6.07E-03	1.98E-03	3.89E-02	3.78E-03	4.50E-03	9.21E-04
Cs-134	3.36E-01	1.50E+00	10	7.09E-05	3.40E-05	4.55E-04	4.42E-05	5.26E-05	1.08E-05
Cs-137	2.30E-02	1.40E+01	14	1.07E+01	5.87E+00	6.85E+01	6.65E+00	7.92E+00	1.62E+00
Eu-152	5.12E-02	1.00E+01	10		3.13E-02				
Eu-154	7.88E-02	6.00E+00	10		3.16E-03				
Total				**1.43E+01**	**8.50E+00**	**9.19E+01**	**8.92E+00**	**1.06E+01**	**2.17E+00**

(pink)	= Activated Concrete ROC
(yellow)	= Basement Fill and Soil ROC

Area factors for a 1-meter thick soil layer are provided in TSD 14-011 (15). The interpolated area factor values that correspond to the surface area calculated using volumes divided by 1 meter are shown in Table 25.

Table 25 - Interpolated Area Factors for Fill Volumes 1 Meter Thick

Nuclide	Auxiliary Building	Containment Outside Liner Only	Spent Fuel Building	Turbine Bld, Main Steam Tunnel, Diesel Oil	Crib House and Forebay	Waste Water Treatment Facility
Co-60	1.03E+00	1.05E+00	1.16E+00	1.03E+00	1.03E+00	1.16E+00
Ni-63	1.39E+00	1.09E+00	6.47E+00	1.32E+00	1.37E+00	6.51E+00
Sr-90	1.15E+00	1.19E+00	1.78E+00	1.12E+00	1.14E+00	1.78E+00
Cs-134	1.11E+00	1.15E+00	1.56E+00	1.09E+00	1.10E+00	1.56E+00
Cs-137	1.16E+00	1.20E+00	1.90E+00	1.13E+00	1.15E+00	1.90E+00

In Table 26, the Table 24 Basement Fill concentrations are divided by the industrial scenario 1-meter soil DCGL times the area factor to calculate the fractions of the adjusted soil DCGLs. The Activated Concrete ROCs are divided by the industrial scenario 1-meter soil DCGL without an area factor correction, which is again a conservative assumption. The sum of the fractions of the adjusted soil DCGL times 25 mrem/year provides an estimate of the dose consequence for the fill excavation. The fraction of the adjusted soil DCGL and the bounding doses are shown in Table 26.

The Table 25 area factors are based on the Resident Farmer scenario and are approximations for the area factors that would be applicable to the Industrial Scenario. Therefore, Table 26 also contains the dose with no area factor correction which provides the maximum dose.

The Table 26 estimated DCGL fractions and doses are conservative because they assume all of the activity, including that dissolved in the water is in the fill removed during the excavation at 10 years. It should be noted that these are maximum allowable source terms and that the source terms in the all the end state structures are known to be significantly less with the possible exception of the Spent Fuel Pool/Transfer Canal which remains to be characterized.

Table 26 - Fill Fractions of Soil DCGLs and Bounding Large Excavation Doses

Nuclide	Soil DCGL pCi/g	Aux DCGL Fraction	Containment DCGL Fraction	Spent Fuel DCGL Fraction	Turbine DCGL Fraction	Crib House DCGL Fraction	WWTF DCGL Fraction
H-3	1815.89		2.78E-06				
Co-60	12.34	3.77E-03	1.16E-02	2.16E-02	2.36E-03	2.80E-03	5.10E-04
Ni-63	9480000	2.71E-07	2.35E-07	3.75E-07	1.78E-07	2.05E-07	8.82E-09
Sr-90	14.07	3.76E-04	1.18E-04	1.56E-03	2.40E-04	2.81E-04	3.68E-05
Cs-134	23.33	2.74E-06	1.27E-06	1.25E-05	1.74E-06	2.05E-06	2.96E-07
Cs-137	55.76	1.65E-01	8.79E-02	6.48E-01	1.06E-01	1.24E-01	1.53E-02
Eu-152	27.43		1.14E-03				
Eu-154	25.43		1.24E-04				
Total		**1.70E-01**	**1.01E-01**	**6.71E-01**	**1.08E-01**	**1.27E-01**	**1.58E-02**
Dose mrem/yr		4.24	2.52	16.77	2.71	3.17	0.40
mrem/yr no AF		4.89	2.97	31.40	3.05	3.63	0.74

(pink)	= Activated Concrete ROC
(yellow)	= Basement Fill and Soil ROC

4. WORST CASE CALCULATION TO SUPPORT BFM ELEVATED AREA ASSESSMENT

The drill spoils calculations in Section 3.1 use the average concrete concentration based upon the estimated source term. There is a potential that the drill could hit a hot spot remaining on the concrete floor of the end state structure and pull the concrete debris from the hot spot to the surface. This calculation addresses that potential by modeling the source term that results in the 2 mrem/hr open air demolition limit using the Auxiliary Buildings highest activity core's depth profile. Then evaluating the dose consequence of the hot spot activity in drill spoils. This bounding calculation was performed to support an assessment in LTP Chapter 6 regarding the potential impact of the hypothetical worst-case hot spot radionuclide concentrations that could remain in the Auxiliary basement (and possibly the Spent Fuel Pool although characterization has not yet been performed) after demolition to the 2 mR/hr open air demolition limits. (16) To "risk-inform" the acceptability of the worst-case concentrations, the potential dose consequences of this worst-case concentrations are evaluated. The dose was assessed using the drilling and spoils scenario described in Section 3.1 with the exception that the highest concentrations that could hypothetically remain in the Auxiliary Basement after remediation to the open air demolition limits are used as the concrete source term. This scenario is called the 'Worst-Case" Drilling Spoils.

As described in LTP Chapter 6, the Worst-Case Drilling Spoils assessment is considered a "less likely but plausible" scenario (as defined in NUREG-1757, Table 5.1). Consistent with NUREG 1757, Table 5.1 the scenario is not analyzed as an alternate scenario but is used to help "risk inform" and justify the decision that the hypothetical maximum concentrations that could remain in elevated areas after remediation to the 2 mR/hr demolition limit are acceptable assuming all activity is accounted for by the BFM inventory using the ground water and drill spoils dose factors.

The "less likely but plausible" Worst-Case Drilling Spoils scenario assumes that the water supply well is drilled directly into a spot of residual radioactivity with the highest hypothetical concentration immediately after license termination taking no credit for decay or release to the fill water. The entire inventory in the spot is assumed to be excavated and brought to the surface while mixing with overburden fill and soil. This is very unlikely for two reasons. First, the scenario assumes that a Resident Farmer water supply well is installed immediately after license termination, while the Independent Spent Fuel Storage Installation (ISFSI) is present, which is a highly unlikely, essentially non-credible, land use (as discussed in LTP section 6.5.3). Second, the probability of an assumed eight inch borehole hitting an area containing the maximum hypothetical contamination level during drilling is low. For example, the area in the Auxiliary Basement floor with the highest contamination levels is limited to ~20 m^2 (in two RHR rooms) of the ~2500 m^2 total floor area. Note that the dose from the worst-case drilling spoil scenario is separate and distinct from the BFM dose in that it is assumed to occur before any release of activity from the concrete and therefore the water and fill concentrations are zero.

This scenario assumes an inadvertent intruder drills into the first half inch of a concrete floor at t=0. As seen in Table 27, the highest sample from the Auxiliary Building floor was from the 2A Residual Heat Removal Pump Room. (4). The concentrations of the 2A RHR and average core decay corrected to July 1, 2018 are shown in Table 27. The 2A RHR Pump core sample levels are approximately an order of magnitude higher than the overall average concentrations in the first few inches of concrete. However, the depth profile is similar with the majority of the source term in the first two inches.

Table 27 - Highest Core Sample and Average Auxiliary Floor Concentration Profiles on July 1, 2018

					First 2 Inches	86%	96%	81%	83%
		AUX 542 2A RHR Pump		Average all Aux Floor Cores		AUX 542 2A RHR Pump		Average all Floor Cores	
Puck #	**Top Depth inches**	**B105103-CJFCCV-001 Co-60 pCi/g**	**B105103-CJFCCV-001 Cs-137 pCi/g**	**Avg. Co-60 pCi/g**	**Avg. Cs-137 pCi/g**	**B105103-CJFCCV-001 Co-60 %**	**B105103-CJFCCV-001 Cs-137 %**	**Avg. Co-60 %**	**Avg. Cs-137 %**
Puck 1	0	196.1	20205.4	20.3	2751.2	26%	47%	28%	41%
Puck 2	0.5	172.4	11353.3	12.0	1266.7	23%	27%	16%	19%
Puck 3	1	124.5	5430.6	11.6	737.6	16%	13%	16%	11%
Puck 4	1.5	79.0	2210.2	7.7	450.9	10%	5%	10%	7%
Puck 5	2	83.1	1782.9	7.7	364.1	11%	4%	11%	5%
Puck 6	2.5	47.7	1187.1	5.3	260.5	6%	3%	7%	4%
Puck 7	3	30.0	319.9	3.4	196.8	4%	1%	5%	3%
Puck 8	3.5	25.3	195.1	2.8	234.7	3%	0%	4%	4%
Puck 9	4	***NS***	***NS***	0.2	114.8	0.0%	0%	0.3%	2%
Puck 10	4.5	***NS***	***NS***	0.1	286.6	0.0%	0%	0.2%	4%

Notes: ***NS*** equals Not Sampled

As noted in TSD 10-002 (16), there are limits for open air demolition of concrete that include a less than 2 millirem per hour (mrem/hr) on contact requirement. The dose rate from a 8 inch diameter hot spot at the 2A RHR Pump concentrations is calculated by modeling the Table 27 profile as a 8 inch diameter hot spot in MicroShield.

The activity of a 8 inch diameter source is calculated by multiplying by the puck concentration in pCi/g times the 968 gram mass of ½ inch thick section with a density of 2.35 g/cc and dividing by 1E+12 pCi/Ci. MicroShield 8.03 was used to calculate the dose rate each core depth would contribute for a one foot diameter area at the 2A RHR Pump core concentrations. The reports are provided in Attachment 2 and are summarized in Table 28.

Table 28 - July 1, 2018 Estimated Bore Hole Source Terms, Modeled Dose Rates and Open Air Demolition Cut Off Concentrations

	Top Depth inches	**2A RHR Pump One Foot Dia Co-60 Ci**	**2A RHR Pump One Foot Dia Cs-137 Ci**	**Dose Rate at Surface mrem/hr**	**Percent Dose Rate**	**Max Cut-Off Conc Co-60 pCi/g**	**Max Cut-Off Conc Cs-137 pCi/g**
Puck 1	0	1.90E-07	1.96E-05	2.06	62%	118.8	12242.8
Puck 2	0.5	1.67E-07	1.10E-05	0.77	23%	104.5	6879.2
Puck 3	1	1.21E-07	5.26E-06	0.26	8%	75.5	3290.5
Puck 4	1.5	7.65E-08	2.14E-06	0.11	3%	47.9	1339.2
Puck 5	2	8.04E-08	1.73E-06	0.07	2%	50.3	1080.3

	Top Depth inches	2A RHR Pump One Foot Dia Co-60 Ci	2A RHR Pump One Foot Dia Cs-137 Ci	Dose Rate at Surface mrem/hr	Percent Dose Rate	Max Cut-Off Conc Co-60 pCi/g	Max Cut-Off Conc Cs-137 pCi/g
Puck 6	2.5	4.62E-08	1.15E-06	0.03	1%	28.9	719.3
3 inch Avg		1.13E-07	6.80E-06			7.10E+01	4.26E+03
Cut-Off	2	mrem/hr	**Total**	3.3	CF	0.61	

As seen in Table 28, the contact dose rate on the 2A RHR Pump core would be approximately 3.3 mrem/hr. This is slightly above the 2 mrem/hr contact limit; thus, this area would be remediated. In addition, the source term beneath the two inch depth within the concrete, contributes less than 1% of the contact dose rates due to the lower concentration and shielding of the concrete layers above. The concentrations at 61% of those in the 2A RHR Pump core puck sample would equal the 2 mrem/hr open air demolition limit.

Adjusting the upper 2.5 inches to the cut off value concentrations in Table 28, the source term of the remediated profile in the 8 inch diameter drill is shown in Table 29.

Table 29 - July 1, 2018 2a RHR Pump Room Core at 2 mrem/hr Cut Off

	Top Depth inches	B105103-CJFCCV-001 Co-60 pCi/g	B105103-CJFCCV-001 Cs-137 pCi/g	2A RHR Pump 8 Inch Dia Co-60 pCi Ci	2A RHR Pump 8 Inch Dia Cs-137 pCi
Puck 1	0	118.8	12242.8	1.15E+05	1.18E+07
Puck 2	0.5	104.5	6879.2	1.01E+05	6.66E+06
Puck 3	1	75.5	3290.5	7.30E+04	3.18E+06
Puck 4	1.5	47.9	1339.2	4.63E+04	1.30E+06
Puck 5	2	50.3	1080.3	4.87E+04	1.05E+06
Puck 6	2.5	28.9	719.3	2.80E+04	6.96E+05

As noted in Table 2, there are 7.27E+05 grams in the Auxiliary Building drill spoils including the ½ inch concrete cutting and there are 2.23E+05 grams in the Spent Fuel Building drill spoils. The Cs-137 scaling factors of the July 1, 2018 source terms are calculated from the Auxiliary Building concrete mix in Table 10. The source terms of the ROCs are calculated from the first half inch puck Co-60 and Cs-137 activities in Table 29. When compared to the area factor adjusted soil DCGLs in Table 30, the fraction of the Auxiliary Building DCGL is 0.170. Thus, the potential dose from a rejected drilling attempt at the hypothetical worst-case concentration that could remain after remediation to the open air demotion limit is 4.24 mrem/yr for the Auxiliary Building. The fraction of the DCGL is 0.228 or 5.71 mrem/yr for the Spent Fuel Building. See Table 30.

Table 30 - Drill Spoils Concentrations for Aux Building Floor

Nuclide	Cs-137 SF	Drill Cutting Source Term pCi	Aux Drill Spoil pCi/g	SFB Drill Spoil pCi/g	Aux Area Factor DCGL pCi/g	Aux DCGL Fraction	SFB Area Factor DCGL pCi/g	SFB DCGL Fraction
H-3	0.23%	2.77E+04	3.81E-02	1.24E-01	3.68E+06	1.03E-08	1.16E+07	1.07E-08
Co-60	1.22%	1.15E+05	1.58E-01	5.15E-01	2.44E+01	6.49E-03	5.96E+01	8.65E-03
Ni-63	31.48%	3.73E+06	5.13E+00	1.67E+01	1.06E+07	4.85E-07	3.28E+07	5.10E-07
Sr-90	0.07%	8.09E+03	1.11E-02	3.63E-02	4.10E+03	2.72E-06	1.22E+04	2.97E-06
Cs-134	0.01%	1.64E+03	2.25E-03	7.34E-03	4.24E+01	5.32E-05	1.02E+02	7.17E-05
Cs-137	100.00 %	1.18E+07	1.63E+01	5.31E+01	1.00E+02	1.63E-01	2.42E+02	2.20E-01
Eu-152	0.02%	2.77E+03	3.82E-03	1.24E-02	5.27E+01	7.25E-05	1.28E+02	9.69E-05
Eu-154	0.01%	1.50E+03	2.06E-03	6.71E-03	4.95E+01	4.16E-05	1.21E+02	5.56E-05
Total	1.33	1.57E+07	21.64279			**1.70E-01**		**2.28E-01**
					mrem/yr	**4.24E+00**		**5.71E+00**

An additional cross-check was performed to assess the potential dose from drilling through embedded pipe in the Auxiliary Basement concrete floor. The drilling spoils scenario assumes that drilling stops after meeting refusal by contact with the concrete floor. It is not considered "plausible" as defined in NUREG-1757, Table 5.1, that a driller expecting to encounter sand and clay would proceed to drill after encountering concrete. After the first 0.5 inch of concrete, the drill would need to traverse 8 inches of the lightly reinforced (rebar) concrete finish floor and then through the four feet of the heavily reinforced (1.38 inch diameter rebar) concrete foundation slab to encounter the embedded drain pipes in the Auxiliary Basement floor. The worst case drilling spoils assessment in TSD 14-021 assumes contact with the highest concentrations that could remain in the first 0.5 inch of concrete after remediation to the open air demolition criteria and is considered the bounding dose.

There are a few equipment drains embedded in the Auxiliary Basement floor concrete at a depth of 2 inches from the floor surface. The drains have diameters of 2 inches and 6 inches. These pipes were assessed under the worst-case drilling spoils scenario because it is considered "less likely but plausible" (as defined in NUREG-1757, Table 5.1) that a driller could continue beyond the assumed 0.5 inch of concrete to a depth of 2 inches and then through the equipment drains before stopping. Per NUREG-1757, Table 5.1, a "less likely but plausible" scenario is not analyzed for compliance but used to risk-inform the decision. The activity in the 8 inch length of pipe assumed to be encountered by the 8 inch diameter borehole is brought to the surface with the drilling spoils. The resulting dose from the activity in the 2 inch and 6 inch drains, after 2-year decay to the projected July 2018 license termination date, is 23 mrem/yr and 2 mrem/yr, respectively. These dose levels are considered insignificant particularly when the probability of the hypothetical borehole encountering the drain is considered. The surface areas of the drains, when projected to the floor surface, are 0.9% and 1.4% of the Auxiliary floor surface area for the 2 inch and 6 inch drains, respectively. When the surface area of all basements is considered, the projected surface areas are 0.2% and 0.3% for the 2 inch and 6 inch drains, respectively

5. CONCLUSION

Based upon this evaluation, the inadvertent intruder construction alternate scenario will not result in significant exposure and will not require consideration for demonstrating compliance with the 10 CFR 20 Subpart E (17) license termination criteria. However, the BFM Drill Spoils scenario has the potential to result in exposures that are significant relative to the license termination criteria (i.e., exceeding 10% of the 25 mrem/yr dose criteria) and were therefore evaluated in detail and the BFM Drilling Spoils pathway dose added to the BFM for demonstrating compliance with the 10 CFR 20 Subpart E (17) license termination criteria. Table 8 provides the BFM Drilling Spoils Dose Factors. The large scale excavation scenario could result in significant exposure for the Spent Fuel Pool and Transfer Canal end states and should be re-evaluated when characterization data and estimated source term inventories are available.

The dose from a hypothetical worst-case concentration in concrete after remediation to the open air demolition limits was calculated for use in LTP Chapter 6 to risk-inform the evaluation of elevated areas in the BFM.

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12. Evaluation of Hydrological Parameters in Support of Dose Modeling for the Zion Restoration Project," Conestoga-Rovers & Associates, Chicago, IL, January 14, 2014, Reference No.054638, Revision 4, Report No. 3.

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15. TSD 14-011 Soil Area Factors.

16. TSD 10-002 Technical Basis for Radiological Limits for Structure, Building Open Air Demolition.

17. 10 CFR 20 Standards for Protection Against Radiation, Subpart E—Radiological Criteria for License Termination.

18. TSD 14-005 Backfill Material Specifications.

19. TSD 14-015, Buried Piping Dose Modeling and Derived Concentration Guideline Levels.

6. ATTACHMENTS

6.1. Attachment 1 – Dust MS Full Radionuclide Suite Results

6.2. Attachment 2 – Construction Scenario MicroShield Calculations

6.3. Attachment 3 - Open Air Demolition MicroShield Reports

Table 31 - DUST MS Results for Auxiliary Building Diffusion Model with 6503 pCi Source Terms per Nuclide

Nuclide	Decay Constant yr-1	Kd (ml/g)	Diffusion Coefficient (cm^2/s)	Time to Peak (years)	Peak Conc pCi/L	Peak Activity in Solution pCi	Peak Activity Sorbed pCi	Peak Sorbed Conc pCi/g	Sorbed Conc pCi/g per mCi	Concrete Total at Peak pCi per mCi
H-3	5.63E-02	0	5.50E-07	0.1	9.10E-04	6467	0	0.00E+00	0.000E+00	0.000E+00
C-14	1.22E-04	1.2	3.00E-09		1.11E-04	793	5710	1.33E-07	2.045E-02	0.000E+00
Fe-55	2.53E-01	2857	3.00E-09		1.24E-08	0.09	1519	3.54E-08	5.444E-03	7.664E+08
Ni-59	6.86E-06	62	1.10E-09		2.45E-06	17.4	6512	1.52E-07	2.337E-02	0.000E+00
Co-60	1.31E-01	223	4.10E-11	4	2.60E-08	0.2	249	5.80E-09	8.919E-04	5.527E+08
Ni-63	6.92E-03	62	1.10E-09	37	1.90E-06	13.6	5051	1.18E-07	1.815E-02	0.000E+00
Sr-90	2.41E-02	2.3	5.20E-10	21	1.96E-05	140.1	1933	4.51E-08	6.935E-03	2.844E+08
Nb-94	3.41E-05	45	3.00E-09		3.38E-06	24	6521	1.52E-07	2.337E-02	0.000E+00
Tc-99	3.28E-06	0	5.50E-07		9.15E-04	6503	0	0.00E+00	0.000E+00	0.000E+00
Ag-108m	1.66E-03	27	3.00E-09		5.23E-06	37	6054	1.41E-07	2.168E-02	6.336E+07
Sb-125	2.51E-01	17	3.00E-09		2.08E-06	15	1516	3.54E-08	5.444E-03	7.646E+08
Cs-134	3.36E-01	45	3.00E-09	1.5	6.89E-07	5	1329	3.10E-08	4.767E-03	3.992E+08
Cs-137	2.30E-02	45	3.00E-09	14	2.47E-06	17.7	4766	1.11E-07	1.707E-02	0.000E+00
Pm-147	2.64E-01	95	3.00E-09		3.68E-07	3	1499	3.50E-08	5.382E-03	7.690E+08
Eu-152	5.12E-02	95	5.00E-11	10	1.07E-07	0.8	440	1.02E-08	1.569E-03	5.315E+08
Eu-154	7.88E-02	95	5.00E-11	6	8.38E-08	0.6	341	7.96E-09	1.224E-03	5.708E+08
Eu-155	1.46E-01	95	5.00E-11		6.39E-08	0	260	6.07E-09	9.334E-04	9.600E+08
Np-237	3.23E-07	1	3.00E-09		1.31E-04	936	5616	1.31E-07	2.014E-02	0.000E+00
Pu-238	7.90E-03	174	3.00E-09		7.84E-07	6	5848	1.36E-07	2.091E-02	9.980E+07
Pu-239	2.87E-05	174	3.00E-09		8.75E-07	6	6527	1.52E-07	2.337E-02	0.000E+00
Pu-240	1.06E-04	174	3.00E-09		8.74E-07	6	6519	1.52E-07	2.337E-02	0.000E+00
Pu-241	4.83E-02	174	3.00E-09		4.78E-07	3	3566	8.32E-08	1.279E-02	4.512E+08
Am-241	1.60E-03	177	3.00E-09		8.42E-07	6	6389	1.49E-07	2.291E-02	1.661E+07
Am-243	9.40E-05	177	3.00E-09		8.60E-07	6	6526	1.52E-07	2.337E-02	0.000E+00
Cm-243	2.43E-02	889	3.00E-09		1.24E-07	1	4736	1.10E-07	1.692E-02	2.716E+08
Cm-244	3.83E-02	889	3.00E-09		1.04E-07	1	3973	9.27E-08	1.425E-02	3.889E+08

Note: Concrete Total at Peak pCi per mCi in last column is total activity remaining in concrete at time to peak using Equation 1.

Table 32 - DUST MS Results for Reactor Building Instantaneous Release Model with 2759 pCi Source Terms per Nuclide

Nuclide	Decay Constant yr-1	Kd (ml/g)	Peak Conc pCi/L	Peak Activity in Solution pCi	Peak Activity Sorbed pCi	Peak Sorbed Conc pCi/g	Sorbed Conc pCi/g per mCi
H-3	5.63E-02	0	1.69E-03	2759	0	0.00E+00	0.000E+00
C-14	1.22E-04	1.2	2.06E-04	336.6	2422.4	2.47E-07	8.953E-02
Fe-55	2.53E-01	2857	9.82E-08	0.2	2758.8	2.81E-07	1.018E-01
Ni-59	6.86E-06	62	4.53E-06	7.4	2751.6	2.81E-07	1.018E-01
Co-60	1.31E-01	223	1.26E-06	2.1	2756.9	2.81E-07	1.018E-01
Ni-63	6.92E-03	62	4.53E-06	7.4	2751.6	2.81E-07	1.018E-01
Sr-90	2.41E-02	2.3	1.14E-04	186.4	2572.6	2.62E-07	9.496E-02
Nb-94	3.41E-05	45	6.23E-06	10.2	2748.8	2.80E-07	1.015E-01
Tc-99	3.28E-06	0	1.69E-03	2759	0	0.00E+00	0.000E+00
Ag-108m	1.66E-03	27	1.04E-05	16.9	2742.1	2.80E-07	1.015E-01
Sb-125	2.51E-01	17	1.64E-05	26.7	2732.3	2.79E-07	1.011E-01
Cs-134	3.36E-01	45	6.23E-06	10.2	2748.8	2.80E-07	1.015E-01
Cs-137	2.30E-02	45	6.23E-06	10.2	2748.8	2.80E-07	1.015E-01
Pm-147	2.64E-01	95	2.95E-06	4.8	2754.2	2.81E-07	1.018E-01
Eu-152	5.12E-02	95	2.95E-06	4.8	2754.2	2.81E-07	1.018E-01
Eu-154	7.88E-02	95	2.95E-06	4.8	2754.2	2.81E-07	1.018E-01
Eu-155	1.46E-01	95	2.95E-06	4.8	2754.2	2.81E-07	1.018E-01
Np-237	3.23E-07	1	2.41E-04	394	2365	2.41E-07	8.735E-02
Pu-238	7.90E-03	174	1.62E-06	2.6	2756.4	2.81E-07	1.018E-01
Pu-239	2.87E-05	174	1.62E-06	2.6	2756.4	2.81E-07	1.018E-01
Pu-240	1.06E-04	174	1.62E-06	2.6	2756.4	2.81E-07	1.018E-01
Pu-241	4.83E-02	174	1.62E-06	2.6	2756.4	2.81E-07	1.018E-01
Am-241	1.60E-03	177	1.59E-06	2.6	2756.4	2.81E-07	1.018E-01
Am-243	9.40E-05	177	1.59E-06	2.6	2756.4	2.81E-07	1.018E-01
Cm-243	2.43E-02	891	3.15E-07	0.5	2758.5	2.81E-07	1.018E-01
Cm-244	3.83E-02	891	3.15E-07	0.5	2758.5	2.81E-07	1.018E-01

Table 33 - DUST MS Results for Spent Fuel Building Diffusion Model with 780 pCi Source Terms per Nuclide

Nuclide	Decay Constant yr-1	Kd (ml/g)	Diffusion Coefficient (cm^2/s)	Time to Peak (years)	Peak Conc pCi/L	Peak Activity in Solution pCi	Peak Activity Sorbed pCi	Peak Sorbed Conc pCi/g	Sorbed Conc pCi/g per mCi	Concrete Total at Peak pCi per mCi
H-3	5.63E-02	0	5.50E-07	0.1	1.49E-02	774.8	0	0.00E+00	0.000E+00	1.056E+06
C-14	1.22E-04	1.2	3.00E-09		1.83E-03	95.2	685.2	2.20E-06	2.821E+00	0.000E+00
Fe-55	2.53E-01	2857	3.00E-09		2.04E-07	0.011	181.8	5.83E-07	7.474E-01	7.669E+08
Ni-59	6.86E-06	62	1.10E-09		4.02E-05	2.1	777.6	2.49E-06	3.192E+00	3.846E+05
Co-60	1.31E-01	223	4.10E-11	4	4.25E-07	0.022	30	9.48E-08	1.215E-01	5.525E+08
Ni-63	6.92E-03	62	1.10E-09	37	3.13E-05	1.6	605	1.94E-06	2.487E+00	0.000E+00
Sr-90	2.41E-02	2.3	5.20E-10	21	3.21E-04	16.7	230.3	7.38E-07	9.462E-01	2.865E+08
Nb-94	3.41E-05	45	3.00E-09		5.53E-05	2.9	776.4	2.49E-06	3.192E+00	8.974E+05
Tc-99	3.28E-06	0	5.50E-07		1.50E-02	780	0	0.00E+00	0.000E+00	0.000E+00
Ag-108m	1.66E-03	27	3.00E-09		8.56E-05	4.5	721.1	2.31E-06	2.962E+00	6.974E+07
Sb-125	2.51E-01	17	3.00E-09		3.41E-05	1.8	180.9	5.80E-07	7.436E-01	7.658E+08
Cs-134	3.36E-01	45	3.00E-09	1.5	1.13E-05	0.6	158.7	5.09E-07	6.526E-01	4.002E+08
Cs-137	2.30E-02	45	3.00E-09	14	4.07E-05	2.1	571.4	1.83E-06	2.346E+00	0.000E+00
Pm-147	2.64E-01	95	3.00E-09		6.03E-06	0.3	178.7	5.73E-07	7.346E-01	7.705E+08
Eu-152	5.12E-02	95	5.00E-11	10	1.75E-06	0.09	51.9	1.66E-07	2.128E-01	5.326E+08
Eu-154	7.88E-02	95	5.00E-11	6	1.37E-06	0.07	40.6	1.30E-07	1.667E-01	5.712E+08
Eu-155	1.46E-01	95	5.00E-11		1.04E-06	0.05	30.8	9.88E-08	1.267E-01	9.604E+08
Np-237	3.23E-07	1	3.00E-09		2.14E-03	111.3	667.7	2.14E-06	2.744E+00	1.282E+06
Pu-238	7.90E-03	174	3.00E-09		1.28E-05	0.67	694.9	2.23E-06	2.859E+00	1.082E+08
Pu-239	2.87E-05	174	3.00E-09		1.43E-05	0.74	776.3	2.49E-06	3.192E+00	3.795E+06
Pu-240	1.06E-04	174	3.00E-09		1.43E-05	0.74	776.3	2.49E-06	3.192E+00	3.795E+06
Pu-241	4.83E-02	174	3.00E-09		7.83E-06	0.41	425.1	1.36E-06	1.744E+00	4.545E+08
Am-241	1.60E-03	177	3.00E-09		1.38E-05	0.72	762.1	2.44E-06	3.128E+00	2.203E+07
Am-243	9.40E-05	177	3.00E-09		1.41E-05	0.73	778.7	2.50E-06	3.205E+00	7.308E+05
Cm-243	2.43E-02	889	3.00E-09		2.03E-06	0.11	564.3	1.81E-06	2.321E+00	2.764E+08
Cm-244	3.83E-02	889	3.00E-09		1.70E-06	0.09	472.6	1.51E-06	1.936E+00	3.940E+08

Note: Concrete Total at Peak pCi per mCi in last column is total activity remaining in concrete at time to peak using Equation 1

Table 34 - DUST MS Results for Turbine Building Instantaneous Release Model with 14,680 pCi Source Terms per Nuclide

Nuclide	Decay Constant yr-1	Kd (ml/g)	Peak Conc pCi/L	Peak Activity in Solution pCi	Peak Activity Sorbed pCi	Peak Sorbed Conc pCi/g	Sorbed Conc pCi/g per mCi
H-3	5.63E-02	0	2.25E-03	14679	0	0.00E+00	0.000E+00
C-14	1.22E-04	1.2	2.74E-04	1790.2	12888.8	3.29E-07	2.241E-02
Fe-55	2.53E-01	2857	1.31E-07	0.9	14678.1	3.74E-07	2.548E-02
Ni-59	6.86E-06	62	6.02E-06	39.4	14639.6	3.73E-07	2.541E-02
Co-60	1.31E-01	223	1.68E-06	11	14668	3.74E-07	2.548E-02
Ni-63	6.92E-03	62	6.02E-06	39.4	14639.6	3.73E-07	2.541E-02
Sr-90	2.41E-02	2.3	1.52E-04	991.8	13687.2	3.49E-07	2.378E-02
Nb-94	3.41E-05	45	8.29E-06	54.2	14624.8	3.73E-07	2.541E-02
Tc-99	3.28E-06	0	2.25E-03	14679	0	0.00E+00	0.000E+00
Ag-108m	1.66E-03	27	1.38E-05	90.1	14588.9	3.72E-07	2.534E-02
Sb-125	2.51E-01	17	2.18E-05	142.2	14536.8	3.71E-07	2.527E-02
Cs-134	3.36E-01	45	8.29E-06	54.2	14624.8	3.73E-07	2.541E-02
Cs-137	2.30E-02	45	8.29E-06	54.2	14624.8	3.73E-07	2.541E-02
Pm-147	2.64E-01	95	3.93E-06	25.7	14653.3	3.74E-07	2.548E-02
Eu-152	5.12E-02	95	3.93E-06	25.7	14653.3	3.74E-07	2.548E-02
Eu-154	7.88E-02	95	3.93E-06	25.7	14653.3	3.74E-07	2.548E-02
Eu-155	1.46E-01	95	3.93E-06	25.7	14653.3	3.74E-07	2.548E-02
Np-237	3.23E-07	1	3.21E-04	2097.1	12581.9	3.21E-07	2.187E-02
Pu-238	7.90E-03	174	2.15E-06	14	14665	3.74E-07	2.548E-02
Pu-239	2.87E-05	174	2.15E-06	14	14665	3.74E-07	2.548E-02
Pu-240	1.06E-04	174	2.15E-06	14	14665	3.74E-07	2.548E-02
Pu-241	4.83E-02	174	2.15E-06	14	14665	3.74E-07	2.548E-02
Am-241	1.60E-03	177	2.11E-06	13.8	14665.2	3.74E-07	2.548E-02
Am-243	9.40E-05	177	2.11E-06	13.8	14665.2	3.74E-07	2.548E-02
Cm-243	2.43E-02	891	4.19E-07	2.7	14676.3	3.74E-07	2.548E-02
Cm-244	3.83E-02	891	4.19E-07	2.7	14676.3	3.74E-07	2.548E-02

Table 35 - DUST MS Results for Crib House/Forebay Building Instantaneous Release Model with 6940 pCi Source Terms per Nuclide

Nuclide	Decay Constant yr-1	Kd (ml/g)	Peak Conc pCi/L	Peak Activity in Solution pCi	Peak Activity Sorbed pCi	Peak Sorbed Conc pCi/g	Sorbed Conc pCi/g per mCi
H-3	5.63E-02	0	9.08E-04	6936	0	0.00E+00	0.000E+00
C-14	1.22E-04	1.2	1.11E-04	845.8	6094.2	1.33E-07	1.916E-02
Fe-55	2.53E-01	2857	5.29E-08	0.4	6939.6	1.52E-07	2.190E-02
Ni-59	6.86E-06	62	2.44E-06	18.6	6921.4	1.51E-07	2.176E-02
Co-60	1.31E-01	223	6.78E-07	5.2	6934.8	1.51E-07	2.176E-02
Ni-63	6.92E-03	62	2.44E-6	14.6	6925.4	1.51E-07	2.176E-02
Sr-90	2.41E-02	2.3	6.14E-05	468.5	6471.5	1.41E-07	2.032E-02
Nb-94	3.41E-05	45	3.35E-06	25.6	6914.4	1.51E-07	2.176E-02
Tc-99	3.28E-06	0	9.09E-04	6936	0	0.00E+00	0.000E+00
Ag-108m	1.66E-03	27	5.58E-06	42.5	6897.5	1.51E-07	2.176E-02
Sb-125	2.51E-01	17	8.80E-06	67.2	6872.8	1.50E-07	2.161E-02
Cs-134	3.36E-01	45	3.35E-06	25.6	6914.4	1.51E-07	2.176E-02
Cs-137	2.30E-02	45	3.35E-06	25.6	6914.4	1.51E-07	2.176E-02
Pm-147	2.64E-01	95	1.59E-06	12.1	6927.9	1.51E-07	2.176E-02
Eu-152	5.12E-02	95	1.59E-06	12.1	6927.9	1.51E-07	2.176E-02
Eu-154	7.88E-02	95	1.59E-06	12.1	6927.9	1.51E-07	2.176E-02
Eu-155	1.46E-01	95	1.59E-06	12.1	6927.9	1.51E-07	2.176E-02
Np-237	3.23E-07	1	1.30E-04	990.8	5949.2	1.30E-07	1.873E-02
Pu-238	7.90E-03	174	8.70E-07	6.6	6933.4	1.51E-07	2.176E-02
Pu-239	2.87E-05	174	8.70E-07	6.6	6933.4	1.51E-07	2.176E-02
Pu-240	1.06E-04	174	8.70E-07	6.6	6933.4	1.51E-07	2.176E-02
Pu-241	4.83E-02	174	8.70E-07	6.6	6933.4	1.51E-07	2.176E-02
Am-241	1.60E-03	177	8.55E-07	6.5	6933.5	1.51E-07	2.176E-02
Am-243	9.40E-05	177	8.55E-07	6.5	6933.5	1.51E-07	2.176E-02
Cm-243	2.43E-02	891	1.70E-07	1.3	6938.7	1.52E-07	2.190E-02
Cm-244	3.83E-02	891	1.70E-07	1.3	6938.7	1.52E-07	2.190E-02

Table 36 - DUST MS Results for Waste Water Treatment Facility Instantaneous Release Model with 1124 pCi Source Terms per Nuclide

Nuclide	Decay Constant yr-1	Kd (ml/g)	Peak Conc pCi/L	Peak Activity in Solution pCi	Peak Activity Sorbed pCi	Peak Sorbed Conc pCi/g	Sorbed Conc pCi/g per mCi
H-3	5.63E-02	0	3.13E-02	1126	0	0.00E+00	0.000E+00
C-14	1.22E-04	1.2	3.82E-03	137.5	990.3	4.58E-06	4.075E+00
Fe-55	2.53E-01	2857	1.82E-06	0.1	1124.9	5.21E-06	4.635E+00
Ni-59	6.86E-06	62	8.40E-05	3	1124.8	5.21E-06	4.635E+00
Co-60	1.31E-01	223	2.34E-05	0.8	1125.5	5.21E-06	4.635E+00
Ni-63	6.92E-03	62	8.40E-05	3	1124.8	5.21E-06	4.635E+00
Sr-90	2.41E-02	2.3	2.12E-03	76.2	1051.4	4.87E-06	4.333E+00
Nb-94	3.41E-05	45	1.16E-04	4.2	1123.7	5.20E-06	4.626E+00
Tc-99	3.28E-06	0	3.13E-02	1128	0	0.00E+00	0.000E+00
Ag-108m	1.66E-03	27	1.92E-04	6.9	1120.9	5.19E-06	4.617E+00
Sb-125	2.51E-01	17	3.03E-04	10.9	1114.1	5.16E-06	4.591E+00
Cs-134	3.36E-01	45	1.16E-04	4.2	1123.4	5.20E-06	4.626E+00
Cs-137	2.30E-02	45	1.16E-04	4.2	1123.4	5.20E-06	4.626E+00
Pm-147	2.64E-01	95	5.48E-05	2	1125.3	5.21E-06	4.635E+00
Eu-152	5.12E-02	95	5.48E-05	2	1125.3	5.21E-06	4.635E+00
Eu-154	7.88E-02	95	5.48E-05	2	1125.3	5.21E-06	4.635E+00
Eu-155	1.46E-01	95	5.48E-05	2	1125.3	5.21E-06	4.635E+00
Np-237	3.23E-07	1	4.48E-03	161.1	966.7	4.48E-06	3.986E+00
Pu-238	7.90E-03	174	3.00E-05	1.1	1126.8	5.22E-06	4.644E+00
Pu-239	2.87E-05	174	3.00E-05	1.1	1126.8	5.22E-06	4.644E+00
Pu-240	1.06E-04	174	3.00E-05	1.1	1126.8	5.22E-06	4.644E+00
Pu-241	4.83E-02	174	3.00E-05	1.1	1126.8	5.22E-06	4.644E+00
Am-241	1.60E-03	177	2.95E-05	1.1	1126.8	5.22E-06	4.644E+00
Am-243	9.40E-05	177	2.95E-05	1.1	1126.8	5.22E-06	4.644E+00
Cm-243	2.43E-02	891	5.85E-06	0.2	1124.9	5.21E-06	4.635E+00
Cm-244	3.83E-02	891	5.85E-06	0.2	1124.9	5.21E-06	4.635E+00

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

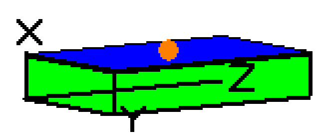
Filename	Run Date	Run Time	Duration
AUXINTRUDER.msd	December 11, 2014	12:56:21 PM	00:00:00

Project Info	
Case Title	Zion Intruder
Description	Aux Building Construction Foundation Excavation
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	1.1e+3 cm (37 ft 0.9 in)
Width	8.0e+3 cm (263 ft)
Height	3.1e+3 cm (103 ft 0.0 in)

Dose Points

A	X	Y	Z
#1	1.2e+3 cm (39 ft 3.3 in)	1.6e+3 cm (51 ft 6.0 in)	4.0e+3 cm (131 ft 6.0 in)
#2	1.3e+3 cm (41 ft 2.8 in)	1.6e+3 cm (51 ft 6.0 in)	4.0e+3 cm (131 ft 6.0 in)



Shields

Shield N	Dimension	Material	Density
Source	1.00e+06 ft³	Concrete	1.5
Shield 1	2.16 ft	Concrete	1.5
Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ba-137m	5.7148e-001	2.1145e+010	2.0095e-005	7.4353e-001
Co-60	3.8310e-004	1.4175e+007	1.3471e-008	4.9844e-004
Cs-137	6.0410e-001	2.2352e+010	2.1243e-005	7.8598e-001

Buildup: The material reference is Shield 1

Integration Parameters	
X Direction	10
Y Direction	20
Z Direction	20

Results - Dose Point # 1 - (3.93e+01,51.5,131.5) ft

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	2.195e+08	0.000e+00	3.026e-28	0.000e+00	2.074e-28
0.0318	4.378e+08	1.441e-65	8.441e-27	1.200e-67	7.031e-29
0.0322	8.077e+08	1.865e-63	1.618e-26	1.501e-65	1.303e-28
0.0364	2.939e+08	4.320e-48	9.019e-27	2.454e-50	5.124e-29
0.6616	1.903e+10	4.572e-05	1.657e-03	8.864e-08	3.213e-06
0.6938	2.312e+03	7.412e-12	2.490e-10	1.431e-14	4.808e-13
1.1732	1.417e+07	9.246e-07	1.397e-05	1.652e-09	2.496e-08
1.3325	1.417e+07	1.819e-06	2.304e-05	3.156e-09	3.998e-08
Totals	**2.081e+10**	**4.847e-05**	**1.694e-03**	**9.345e-08**	**3.278e-06**

Results - Dose Point # 2 - (4.12e+01,51.5,131.5) ft

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	2.195e+08	0.000e+00	2.781e-28	0.000e+00	1.906e-28
0.0318	4.378e+08	6.667e-59	7.758e-27	5.554e-61	6.462e-29
0.0322	8.077e+08	5.351e-57	1.488e-26	4.307e-59	1.197e-28
0.0364	2.939e+08	2.078e-43	8.290e-27	1.181e-45	4.710e-29
0.6616	1.903e+10	8.152e-05	2.561e-03	1.580e-07	4.964e-06
0.6938	2.312e+03	1.294e-11	3.786e-10	2.499e-14	7.310e-13
1.1732	1.417e+07	1.319e-06	1.797e-05	2.358e-09	3.211e-08
1.3325	1.417e+07	2.489e-06	2.862e-05	4.318e-09	4.966e-08
Totals	**2.081e+10**	**8.533e-05**	**2.607e-03**	**1.647e-07**	**5.046e-06**

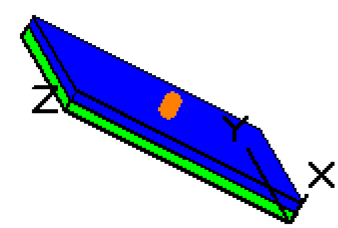
MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
SFBINTRUDERSLAB.msd	December 11, 2014	1:14:33 PM	00:00:01

Project Info	
Case Title	Zion Intruder
Description	Spent Fuel Building Construction Foundation Excavation Slab
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	91.44 cm (3 ft)
Width	1.9e+3 cm (63 ft)
Height	1.2e+3 cm (39 ft 0.0 in)



A	X	Y	Z
#1	168.402 cm (5 ft 6.3 in)	594.36 cm (19 ft 6.0 in)	960.12 cm (31 ft 6.0 in)
#2	228.092 cm (7 ft 5.8 in)	594.36 cm (19 ft 6.0 in)	960.12 cm (31 ft 6.0 in)

Shields

Shield N	Dimension	Material	Density
Source	7371.0 ft³	Concrete	1.5
Shield 1	2.15 ft	Concrete	1.5
Shield 2	.333 ft	Concrete	2.35
Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ba-137m	3.4520e-001	1.2772e+010	1.6538e-003	6.1192e+001
Co-60	2.3260e-004	8.6062e+006	1.1144e-006	4.1233e-002
Cs-137	3.6490e-001	1.3501e+010	1.7482e-003	6.4685e+001

Buildup: The material reference is Shield 2
Integration Parameters

X Direction	10
Y Direction	20
Z Direction	20

Results - Dose Point # 1 - (5.525,19.5,31.5) ft

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	1.326e+08	0.000e+00	2.434e-27	0.000e+00	1.668e-27
0.0318	2.644e+08	6.883e-57	6.789e-26	5.734e-59	5.655e-28
0.0322	4.879e+08	4.936e-55	1.302e-25	3.973e-57	1.048e-27
0.0364	1.775e+08	7.368e-42	7.254e-26	4.186e-44	4.121e-28
0.6616	1.149e+10	1.089e-03	3.908e-02	2.111e-06	7.575e-05
0.6938	1.404e+03	1.770e-10	5.921e-09	3.417e-13	1.143e-11
1.1732	8.606e+06	2.262e-05	3.564e-04	4.042e-08	6.369e-07
1.3325	8.606e+06	4.534e-05	6.038e-04	7.865e-08	1.048e-06
Totals	**1.257e+10**	**1.157e-03**	**4.004e-02**	**2.230e-06**	**7.744e-05**

Results - Dose Point # 2 - (7.48e+00,19.5,31.5) ft

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	1.326e+08	0.000e+00	1.935e-27	0.000e+00	1.326e-27
0.0318	2.644e+08	9.599e-57	5.397e-26	7.996e-59	4.495e-28
0.0322	4.879e+08	6.615e-55	1.035e-25	5.324e-57	8.327e-28
0.0364	1.775e+08	7.176e-42	5.766e-26	4.077e-44	3.276e-28
0.6616	1.149e+10	1.096e-03	3.968e-02	2.124e-06	7.693e-05
0.6938	1.404e+03	1.783e-10	6.016e-09	3.443e-13	1.162e-11
1.1732	8.606e+06	2.299e-05	3.623e-04	4.107e-08	6.474e-07
1.3325	8.606e+06	4.607e-05	6.130e-04	7.994e-08	1.064e-06
Totals	**1.257e+10**	**1.165e-03**	**4.066e-02**	**2.245e-06**	**7.864e-05**

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
AUX Core 1.msd	June 30, 2014	4:19:01 AM	00:00:00

Project Info	
Case Title	Aux Worst
Description	First 0 - 0.5 in Eight Inch Diameter
Geometry	8 - Cylinder Volume - End Shields

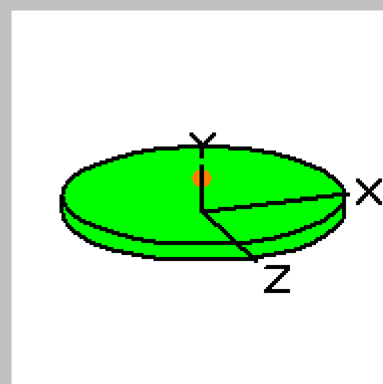
Source Dimensions	
Height	1.27 cm (0.5 in)
Radius	10.16 cm (4.0 in)

Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	2.54 cm (1.0 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	25.133 in³	Concrete	2.35
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ba-137m	1.8447e-005	6.8254e+005	4.4790e-002	1.6572e+003
Co-60	1.9000e-007	7.0300e+003	4.6133e-004	1.7069e+001
Cs-137	1.9500e-005	7.2150e+005	4.7347e-002	1.7518e+003

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate	Fluence Rate	Exposure Rate	Exposure Rate

		MeV/cm²/sec No Buildup	MeV/cm²/sec With Buildup	mR/hr No Buildup	mR/hr With Buildup
0.0045	7.085e+03	1.765e-03	1.807e-03	1.210e-03	1.239e-03
0.0318	1.413e+04	2.039e-01	2.458e-01	1.698e-03	2.047e-03
0.0322	2.607e+04	3.915e-01	4.746e-01	3.151e-03	3.820e-03
0.0364	9.487e+03	2.119e-01	2.732e-01	1.204e-03	1.552e-03
0.6616	6.141e+05	8.334e+02	1.021e+03	1.616e+00	1.979e+00
0.6938	1.147e+00	1.640e-03	1.995e-03	3.166e-06	3.852e-06
1.1732	7.030e+03	1.791e+01	2.050e+01	3.200e-02	3.663e-02
1.3325	7.030e+03	2.057e+01	2.325e+01	3.569e-02	4.034e-02
Totals	**6.850e+05**	**8.727e+02**	**1.065e+03**	**1.691e+00**	**2.064e+00**

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
AUX Core 2.msd	June 30, 2014	4:21:14 AM	00:00:00

Project Info

Case Title	Aux Worst
Description	First 0.5-1.0 in 8 Inch Diameter
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions

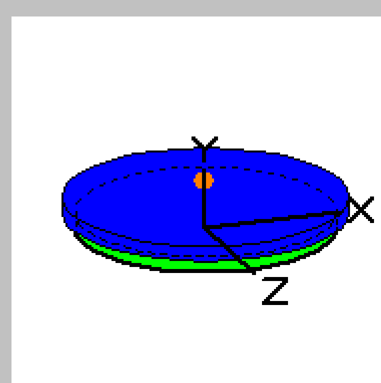
Height	1.27 cm (0.5 in)
Radius	10.16 cm (4.0 in)

Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	3.81 cm (1.5 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	25.133 in³	Concrete	2.35
Shield 1	.5 in	Concrete	2.35



Air Gap		Air	0.00122

Source Input: Grouping Method - Actual Photon Energies				
Nuclide	**Ci**	**Bq**	**μCi/cm³**	**Bq/cm³**
Ba-137m	1.0406e-005	3.8502e+005	2.5266e-002	9.3486e+002
Co-60	1.6700e-007	6.1790e+003	4.0549e-004	1.5003e+001
Cs-137	1.1000e-005	4.0700e+005	2.6709e-002	9.8822e+002

Buildup: The material reference is Shield 1 **Integration Parameters**	
Radial	20
Circumferential	10
Y Direction (axial)	10

Results					
Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.0045	3.997e+03	1.497e-15	1.649e-15	1.026e-15	1.130e-15
0.0318	7.971e+03	1.501e-03	2.302e-03	1.250e-05	1.917e-05
0.0322	1.471e+04	3.201e-03	4.953e-03	2.576e-05	3.986e-05
0.0364	5.352e+03	4.323e-03	7.386e-03	2.456e-05	4.196e-05
0.6616	3.464e+05	2.281e+02	3.737e+02	4.422e-01	7.244e-01
0.6938	1.008e+00	7.048e-04	1.137e-03	1.361e-06	2.195e-06
1.1732	6.179e+03	8.346e+00	1.165e+01	1.491e-02	2.082e-02
1.3325	6.179e+03	9.763e+00	1.321e+01	1.694e-02	2.292e-02
Totals	**3.908e+05**	**2.462e+02**	**3.986e+02**	**4.741e-01**	**7.683e-01**

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	**By**	**Checked**

Filename	**Run Date**	**Run Time**	**Duration**
AUX Core 3.msd	June 30, 2014	4:23:22 AM	00:00:00

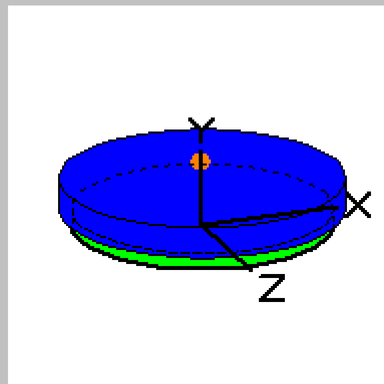
Project Info	
Case Title	Aux Worst

Description	First 1.0 - 1.5 in 8 Inch Diameter
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	1.27 cm (0.5 in)
Radius	10.16 cm (4.0 in)

Dose Points			
A	**X**	**Y**	**Z**
#1	0.0 cm (0 in)	5.08 cm (2.0 in)	0.0 cm (0 in)

Shields			
Shield N	**Dimension**	**Material**	**Density**
Source	25.133 in³	Concrete	2.35
Shield 1	1.0 in	Concrete	2.35
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies				
Nuclide	**Ci**	**Bq**	**μCi/cm³**	**Bq/cm³**
Ba-137m	4.9665e-006	1.8376e+005	1.2059e-002	4.4618e+002
Co-60	1.2100e-007	4.4770e+003	2.9379e-004	1.0870e+001
Cs-137	5.2500e-006	1.9425e+005	1.2747e-002	4.7165e+002

Buildup: The material reference is Shield 1 Integration Parameters	
Radial	20
Circumferential	10
Y Direction (axial)	10

Results					
Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.0045	1.908e+03	1.266e-26	1.417e-26	8.680e-27	9.709e-27
0.0318	3.804e+03	2.292e-05	3.827e-05	1.909e-07	3.187e-07
0.0322	7.019e+03	5.344e-05	9.019e-05	4.301e-07	7.259e-07
0.0364	2.554e+03	1.553e-04	2.960e-04	8.825e-07	1.682e-06
0.6616	1.653e+05	6.257e+01	1.236e+02	1.213e-01	2.397e-01

0.6938	7.303e-01	2.952e-04	5.716e-04	5.699e-07	1.104e-06
1.1732	4.477e+03	3.706e+00	5.908e+00	6.624e-03	1.056e-02
1.3325	4.477e+03	4.392e+00	6.716e+00	7.620e-03	1.165e-02
Totals	**1.896e+05**	**7.067e+01**	**1.363e+02**	**1.356e-01**	**2.619e-01**

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

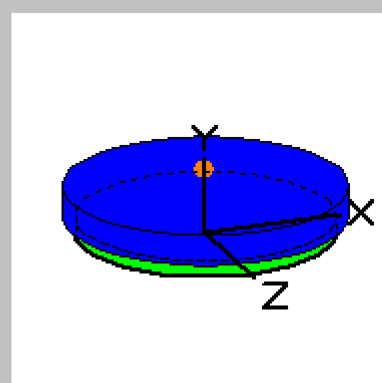
Filename	Run Date	Run Time	Duration
AUX Core 4.msd	June 30, 2014	4:25:26 AM	00:00:00

Project Info	
Case Title	Aux Worst
Description	First 1.0 - 1.5 in 8 Inch Diameter
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	1.27 cm (0.5 in)
Radius	10.16 cm (4.0 in)

Dose Points			
A	**X**	**Y**	**Z**
#1	0.0 cm (0 in)	5.08 cm (2.0 in)	0.0 cm (0 in)

Shield N	Dimension	Material	Density
Source	25.133 in³	Concrete	2.35
Shield 1	1.0 in	Concrete	2.35
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies				
Nuclide	**Ci**	**Bq**	**μCi/cm³**	**Bq/cm³**
Ba-137m	2.0244e-006	7.4904e+004	4.9155e-003	1.8187e+002
Co-60	7.6400e-008	2.8268e+003	1.8550e-004	6.8636e+000
Cs-137	2.1400e-006	7.9180e+004	5.1960e-003	1.9225e+002

Buildup: The material reference is Shield 1 Integration Parameters	
Radial	20
Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	7.776e+02	5.162e-27	5.774e-27	3.538e-27	3.958e-27
0.0318	1.551e+03	9.343e-06	1.560e-05	7.783e-08	1.299e-07
0.0322	2.861e+03	2.178e-05	3.676e-05	1.753e-07	2.959e-07
0.0364	1.041e+03	6.332e-05	1.206e-04	3.597e-07	6.854e-07
0.6616	6.740e+04	2.551e+01	5.040e+01	4.945e-02	9.770e-02
0.6938	4.611e-01	1.864e-04	3.609e-04	3.599e-07	6.968e-07
1.1732	2.827e+03	2.340e+00	3.731e+00	4.182e-03	6.667e-03
1.3325	2.827e+03	2.773e+00	4.241e+00	4.811e-03	7.357e-03
Totals	**7.928e+04**	**3.062e+01**	**5.837e+01**	**5.844e-02**	**1.117e-01**

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
AUX Core 5.msd	June 30, 2014	4:27:22 AM	00:00:00

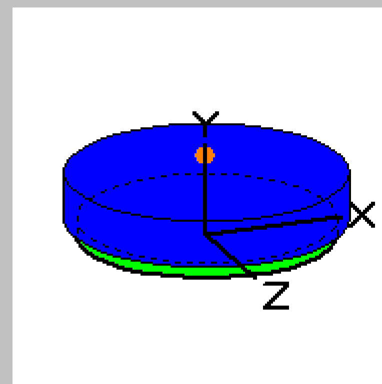
Project Info

Case Title	Aux Worst
Description	First 1.5 - 2.0 in 8 Inch Diameter
Geometry	8 - Cylinder Volume - End Shields

Source Dimensions	
Height	1.27 cm (0.5 in)
Radius	10.16 cm (4.0 in)

Dose Points			
A	**X**	**Y**	**Z**
#1	0.0 cm (0 in)	6.35 cm (2.5 in)	0.0 cm (0 in)

Shields			
Shield N	**Dimension**	**Material**	**Density**
Source	25.133 in³	Concrete	2.35
Shield 1	1.5 in	Concrete	2.35
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies				
Nuclide	**Ci**	**Bq**	**μCi/cm³**	**Bq/cm³**
Ba-137m	1.6271e-006	6.0203e+004	3.9507e-003	1.4618e+002
Co-60	8.0400e-008	2.9748e+003	1.9522e-004	7.2230e+000
Cs-137	1.7200e-006	6.3640e+004	4.1763e-003	1.5452e+002

Buildup: The material reference is Shield 1 Integration Parameters	
Radial	20
Circumferential	10
Y Direction (axial)	10

Results					
Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/hr No Buildup**	**Exposure Rate mR/hr With Buildup**
0.0045	6.250e+02	9.574e-38	2.985e-29	6.563e-38	2.046e-29
0.0318	1.246e+03	2.879e-07	5.112e-07	2.398e-09	4.258e-09
0.0322	2.300e+03	7.327e-07	1.316e-06	5.896e-09	1.059e-08
0.0364	8.368e+02	4.516e-06	9.271e-06	2.566e-08	5.267e-08
0.6616	5.417e+04	1.259e+01	2.898e+01	2.441e-02	5.619e-02
0.6938	4.852e-01	1.211e-04	2.721e-04	2.338e-07	5.253e-07
1.1732	2.975e+03	1.602e+00	2.847e+00	2.862e-03	5.087e-03

1.3325	2.975e+03	1.920e+00	3.247e+00	3.330e-03	5.634e-03
Totals	**6.513e+04**	**1.611e+01**	**3.508e+01**	**3.060e-02**	**6.691e-02**

MicroShield 8.03
Radiation Safety and Control Services (8.03-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
AUX Core 6.msd	June 30, 2014	4:29:47 AM	00:00:00

Project Info	
Case Title	Aux Worst
Description	First 2.0 - 2.5 in 8 Inch Diameter
Geometry	8 - Cylinder Volume - End Shields

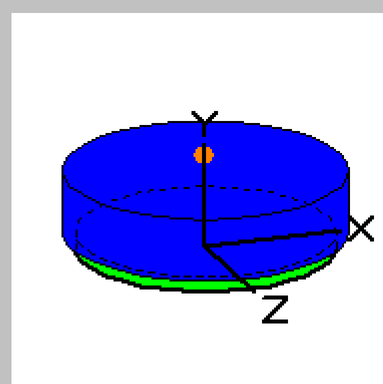
Source Dimensions	
Height	1.27 cm (0.5 in)
Radius	10.16 cm (4.0 in)

Dose Points

A	X	Y	Z
#1	0.0 cm (0 in)	7.62 cm (3.0 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	25.133 in³	Concrete	2.35
Shield 1	2.0 in	Concrete	2.35
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ba-137m	1.0879e-006	4.0252e+004	2.6415e-003	9.7735e+001
Co-60	4.6200e-008	1.7094e+003	1.1218e-004	4.1505e+000
Cs-137	1.1500e-006	4.2550e+004	2.7923e-003	1.0331e+002

Buildup: The material reference is Shield 1
Integration Parameters

Radial	20

Circumferential	10
Y Direction (axial)	10

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.0045	4.179e+02	1.651e-48	1.592e-29	1.132e-48	1.091e-29
0.0318	8.333e+02	8.033e-09	1.495e-08	6.691e-11	1.245e-10
0.0322	1.538e+03	2.230e-08	4.205e-08	1.795e-10	3.384e-10
0.0364	5.595e+02	2.899e-07	6.319e-07	1.647e-09	3.590e-09
0.6616	3.622e+04	5.366e+00	1.412e+01	1.040e-02	2.738e-02
0.6938	2.788e-01	4.457e-05	1.141e-04	8.604e-08	2.204e-07
1.1732	1.709e+03	6.192e-01	1.213e+00	1.107e-03	2.168e-03
1.3325	1.709e+03	7.502e-01	1.389e+00	1.302e-03	2.411e-03
Totals	**4.299e+04**	**6.736e+00**	**1.672e+01**	**1.281e-02**	**3.196e-02**