Dose Assessment for the Emplacement of the CSMRI Site Containerized and Remaining Subsurface Soil into a RCRA Subtitle D Solid Waste Landfill

April 1, 2005

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1.0 Introduction

This document evaluates the potential radiological doses associated with the emplacement of Colorado School of Mines Research Institute (CSMRI) Site material into the BFI Foothills Landfill. The evaluation includes two source terms: (1) 457 Lift Liners (approximately 1,794 yds^3) of material currently on site and ready to be disposed of, and (2) 30,000 yds^3 of additional soil that may require excavation from the same area or nearby areas at the Site where the containerized material was generated. This document supports disposal of the containerized material as well as potential future soil requiring excavation from the site into the BFI Foothills Landfill, a RCRA Subtitle D solid waste landfill.

The Lift Liners were randomly sampled for radiological constituents and the following isotopes and concentrations were identified.

Table 1
Radiological Constituents

Isotope	Mean (pCi/g)	Max (pCi/g)	95% Upper Confidence Limit (UCL) (pCi/g)	Mean + 95% UCL (pCi/g)
Uranium 234	8.4	44.2	11.05	19.45
Uranium 235	0.47	2.71	0.65	1.13
Uranium 238	8.57	45.8	11.29	19.86
Thorium 228	1.69	3.9	1.87	3.56
Thorium 230	9.34	35.1	12.11	21.45
Thorium 232	1.65	3.88	1.82	3.47
Radium 226	12.6	43.9	15.36	27.96
Radium 228	1.73	4.1	1.94	3.66

The material will be placed in a cell at the solid waste landfill. The cell will then be backfilled to capacity with additional solid waste and then covered with a 36-inch layer of clayey soil as a protective cap. At the end of each day of solid waste emplacement and compaction, a 6-inch cover of native soil or alternate will be placed on the solid waste, creating a series of daily cells within the primary disposal cell. BFI Foothills Landfill is approved to use construction and demolition debris as an alternate daily cover because it serves the intended purpose of protecting the trash from wind dispersal.

The assumption is made that the solid waste landfill cell will be designed per the following minimum RCRA Subpart D criteria:

- Prepared soil subgrade foundation layer,
- A compacted clay liner on the soil subgrade with a minimum thickness of 600 mm and a maximum hydraulic conductivity of 1×10^{-7} cm/sec,
- A geomembrane of 0.75 mm or thicker, with a minimum thickness of 60 mil for HDPE membranes,
- A bottom leachate collection layer with a minimum thickness of 150 mm and a minimum hydraulic conductivity of 1×10^{-2} cm/sec, and a side slope leachate collection layer with a geocomposite, and

- A leachate removal system, i.e., perforated pipe network, is located within the leachate collection layer. The maximum head of leachate on the liner system must be less than 300 mm.

Minimum technology guidance concurrently developed by the federal government provides a minimum program of construction quality assurance (CQA) testing that must be performed during the construction of each landfill cell. The CQA document, commonly referred to as the certification document, must be submitted to the permit authority before the landfill can be operated. The individual states and/or local governments are the permit authority for all solid waste landfills and may require more stringent design requirements.

Figure 1. Minimum Design Requirements for RCRA Subtitle D Solid Waste Landfill Cell Liner/Containment System

Solid waste
Bottom Leachate Collection System k >1*10-2 cm/s, 30 cm min
Geomembrane, HDPE 60 mil min, others 0.75 mm
Compacted Clay Liner $k < 1*10^{-7}$ cm/s, 60 cm min
Soil Subgrade

For landfill closures, current federal regulations require that a final cover be constructed within one year after the last lift of waste is placed. The final covers on RCRA Subtitle D landfills must limit the infiltration through the cover to a rate less than the leakage rate of the liner system (40 CFR 258.60). The State approved landfill cover at BFI Foothills Landfill is an ET cap consisting of 30 inches of loose soil overlain by 6 inches of top soil and vegetated.

Waste placed in the landfill is compacted with a sheepsfoot roller on a continuous basis. This compacts the waste, however, for the purpose of this report the material is considered unconsolidated because geotechnical testing was not performed to confirm compaction.

The groundwater ingestion pathway for this dose assessment will not be considered based on the assumptions that the solid waste landfill cell will be designed per the minimum RCRA Subpart D criteria. The material in its current location at the CSMRI Site yields contaminant concentrations in groundwater near MCLs. Leachate, if it occurs at the landfill, is captured, treated and released, and the groundwater is monitored. In order for the groundwater pathway to be complete, several engineered barriers would need to fail. In addition, the quantity of leachate is too small to model effectively to yield meaningful (non-zero) results (U.S. NRC, 2003).

This document assesses radiological exposure resulting from the CSMRI Site waste material during and after placement in the landfill. Exposure routes evaluated include direct contact with airborne particles and waste during placement; ingestion of waste during placement; direct inhalation of radon gas during placement; and inhalation of radon gas after diffusing through varying thicknesses of soil cover. A graph of the radon flux attenuation through cover material for the 457 containers of material is presented as Figure 2 and a graph of the radon flux attenuation through cover material for the 30,000 yds^3 is presented as Figure 3. These graphs show that essentially all radon is attenuated with 20 feet of cover material. Receptors evaluated include current land use receptors; landfill workers, offsite resident (2 miles from cell) and future land use receptors; recreational user and offsite residential (1,700 feet from cell).

The remainder of this document presents the radiological dose assessment. Section 2.0 discusses the assessment methods, including the exposure pathways, key receptors, and methods used for dose determination. Section 3.0 presents the results of the dose assessment.

2.0 Assessment Methods

The assessment methods used in these analyses are conservative and are comparable to peer-reviewed methodologies. The assessment methods tend to overestimate radiological exposures and therefore are protective of human health.

2.1 Source Terms

Two source terms were evaluated to demonstrate the suitability of disposing site waste stored in Lift Liner containers as well as all additional waste that may require disposal. The first source term consists of 457 Lift Liner containers (a Lift Liner container has dimensions of 72-inch by 48-inch by 53-inch $\pm$ 2 inches, and holds approximately 106 cubic feet or 3.9 cubic yards) filled with soil with the radionuclides and concentrations specified in Table 1. To be conservative, background concentrations were not subtracted from the concentrations in Table 1. The second source term consists of 30,000 yds^3 of total site material that may require removal and also contains the radionuclides and concentrations specified in Table 1. To be conservative in lieu of using the minimum RCRA Subtitle D solid waste landfill design criteria, this assessment was completed with the both materials being placed with three different cover scenarios. These scenarios are (1) no cover, (2) the waste material placed at the top of a disposal cell with a 36-inch thick unconsolidated clayey overburden, and (3) the material being placed anywhere in the cell, but more than 20 feet below the final grade. Final grade is inclusive of the 36-inch unconsolidated loose clayey cap.

The area encompassed by a single layer of supersacks placed within a disposal cell is 10,967 square feet (1,019 square meters). This equates to an approximate volume of 1,794 cubic yards (1,372 cubic meters). The density of this material has been estimated to be 1.6 grams per cubic centimeter.

The area encompassed by the second source term would equate to an 8-foot-thick layer of material placed over 91,700 square feet (8,520 square meters). This equates to an approximate volume of 30,000 cubic yards (22,926 cubic meters). The density of this material has also been assumed to be 1.6 grams per cubic centimeter.

The density of the unconsolidated clayey overburden has been estimated to be the same as the containerized waste material.

The potential retardation of the radon flux density due to the containerized material has been ignored for these analyses.

2.2 Exposure Scenarios and Pathways

Four exposure scenarios were considered for these analyses on each of the two source terms. Refer to Figure 2, which demonstrates that essentially all radon generated by the Site material is attenuated prior to reaching the surface when placed greater than 20 feet from the surface of the landfill.

2.2.1 Worker Scenario

This scenario considers the exposure to landfill workers placing the two source term materials into the disposal cell and then placing a minimum of 36-inches of unconsolidated overburden over it. The following calculations are for the containerized material. The second source term of 30,000 yds^3 of material was assumed to take twice as long to place as the 457 containers of material. This was thought to be reasonable because any further disposal of material from this site would be done in bulk (end dumps) and may not be containerized.

The time it takes to place all 457 containers has been estimated to be 10 days (it is assumed that the cover material can be placed during another 5-day period even though cover material is placed daily). The landfill workers work an 8-hour shift. Therefore the time fraction per year that the landfill workers could receive an exposure from the Lift Liner during waste emplacement is given as:

$$\Delta t = \frac{10 \text{ days/yr x } 8 \text{ hrs/day}}{8{,}760 \text{ hrs/yr}} = 9.132 \text{ x } 10^{-03}$$

For the clayey overburden construction is:

$$\Delta t = \frac{5 \text{ days/yr x } 8 \text{ hrs/day}}{8{,}760 \text{ hrs/yr}} = 4.57 \text{ x } 10^{-03}$$

The exposures due to inhalation of ^{222}Rn, inhalation of resuspended containerized waste material, ingestion of containerized waste material and external exposure have been assessed for one scenario. The scenario consists of the worker dose due to placing the waste into the cell plus the worker dose while constructing the clayey overburden.

The 30,000 yds^3 source term was evaluated using twice the exposure duration as the containerized material and evaluated the same exposures for the same construction phases.

2.2.2 Recreational User Scenario

This scenario considers the future land use exposures to a recreational user who frequents an outdoor recreational facility constructed on top of the closed solid waste landfill. The solid waste landfill has been closed with shallow emplacement of the two source term materials, each covered bya minimum 36-inch unconsolidated clayey overburden. The outdoor recreational facility is in close proximity to residences and hunting/fishing/ camping activities are not permitted. Additionally, the time fraction per year that the recreational user could receive an exposure from either waste is given as:

$$\Delta t = \frac{4\ \text{hrs/week x 26 weeks/year}}{8{,}760\ \text{hrs/yr}} = 1.19 \times 10^{-02}$$

The number of weeks per year (26) is based on the assumption that the majority of recreational facility use is during the warmer months of the year. The exposures due to inhalation of ^{222}Rn, inhalation of resuspended waste material, ingestion of waste material and external exposure have been assessed for this scenario.

2.2.3 Offsite Receptor Scenarios

This exposure considers the nearest offsite receptor located at a distance of 2 miles from the disposal cell under the current land-use scenario and the nearest offsite receptor located at a distance of 1,700 feet from the center of the disposal cell under the future land-use scenario. The only pathway for exposure for the offsite receptor is inhalation of ^{222}Rn. External exposure, inhalation, and ingestion of resuspended Lift Liner waste material are not considered pathways due to the low-intensity gamma emitting radionuclides in the waste mixture and the distance between the offsite receptor and the disposal cell.

The radon dose contribution from the methane vent flare stack was not modeled for this assessment. The reasoning for this is that the radon dose contribution for the nearest offsite receptor was modeled with both source term materials being emplaced in the disposal cell with no cover and with a 36-inch unconsolidated clayey cap. The radon dose contribution from the waste material with no cover is the most conservative assessment due to the radon plume being generated as a ground release. By modeling the radon plume as a stack release, the added plume rise due to the flare stack and the height of the stack would affect the Chi/Q dispersion coefficient resulting in greater dispersion than a ground level release resulting in a lower estimated dose. Therefore, assuming a ground-level release is extremely health-protective.

2.2.4 Onsite Suburban Resident

This scenario considers the ^{222}Rn exposure for a suburban resident living in a home that was built upon the material disposal cell for both source terms. The waste material is overburdened by approximately 20 feet of unconsolidated material. The exposure time is estimated to be 30 years for the resident. The resident is assumed to spend 16.4 hr/day for 350 days/yr inside the residence (time fraction of 6.55×10^{-1}) (U.S. EPA, 1997) and 2 hrs/day for 350 days/yr outside of the residence (time fraction of 7.99×10^{-2}) (U.S. EPA, 1997). External exposure, inhalation, and ingestion of material are not considered pathways due to the 20-foot-thick layer of overburden material. The house is estimated to have an approximate area of 100 m2 and a volume of 250 m3 (UNSCEAR, 1988). The ventilation exchange rate is 0.35/hr (ASHRAE, standard for typical house air exchange rate). The foundation of the house is a 6-inch concrete slab-on-grade with no basement. The slab-on-grade model was chosen since it allows for more radon diffusion to occur into the house than if a basement was present (U.S. NRC, 2003).

If in the near future a residence is built upon the closed solid waste landfill, the residents might experience a higher dose than the nearest offsite receptor. However, this is not a plausible scenario since Colorado has laws prohibiting such construction activities. Nevertheless, the future onsite suburban resident scenario is presented to provide a conservative estimate of exposure.

2.3 Radon Flux Density Model

The calculations used to determine the impact of radon use standard equations (Takeda, *et al*, 2002) to estimate radon emanation from both source term materials and the clean overburden. Generally, the radon exhalation rate from soil into an open atmosphere depends on many environmental factors such as soil water content, soil particle size, soil porosity, wind velocity, etc. Assuming a homogeneous ^{226}Ra distribution in the waste layer, the radon flux density is then computed by using the following equation:

$$J_w = 10{,}000\,\frac{cm^2}{m^2}\; C_{Ra}\rho_w E\lambda_{Rn}\sqrt{\frac{D_w}{\lambda_{Rn}}}\tanh\left(X_w/\sqrt{\frac{D_w}{\lambda_{Rn}}}\right)$$

Equation 1

Where:
- J_w = Radon flux density at upper surface of waste layer: pCi/m^2-sec
- C_{Ra} = ^{226}Ra concentration in the waste layer: pCi/g
- ρ_w = Density of waste material: g/cm^3
- E = Emanation Fraction: dimensionless
- λ_{Rn} = ^{222}Rn decay constant: 1/sec
- D_w = Diffusion coefficient of ^{222}Rn in the waste layer: cm^2/sec
- X_w = Thickness of the waste layer: cm

If a non-contaminated layer of overburden soil covers the waste layer, then the radon flux density into open air is computed using the following equation:

$$J_c = J_w \exp\left(-X_c/\sqrt{D_c/\lambda_{Rn}}\right)$$

Equation 2

Where:
- J_c = Radon flux density exiting material: pCi/m^2-sec
- J_w = Radon flux density at upper surface of waste layer: pCi/m^2-sec
- X_c = Thickness of the overburden layer: meters
- D_c = Diffusion coefficient of ^{222}Rn in the overburden layer: m^2/sec
- λ_{Rn} = ^{222}Rn decay constant: 1/sec

Due to the lack of site-specific parameters the diffusion coefficients were estimated based on soil types (Yu *et al*, 1993).

2.4 Outdoor Radon Contribution

For the Worker and Recreational User scenarios, the exposed individuals also receive a dose from the ambient concentration of radon outdoors. The surface flux estimates calculated by using equations 1 and 2 can then be utilized to determine ambient air radon concentrations on site, using the following formula (Yu *et al*, 1993):

$$C_{Radoninair} = \frac{0.5\, J_c \sqrt{A}}{H_{mix} U}$$

Equation 3

Where: $C_{radoninair}$ = Average radon concentration over a contaminated area: pCi/m^3
0.5 = Default time fraction wind is blowing toward individual
J_c = Radon flux density: pCi/m^2-sec
A = Area of contaminated zone: m^2
H_{mix} = Height of interest for uniform mixing (2 m for adults): meters
U = Average wind speed: meters/sec

2.5 Offsite Radon Contribution

Contributions to a receptor at the site boundary can occur only through gaseous diffusion of radon emanating on site. The gaseous concentration offsite is determined using the on site open air radon flux density estimate. The flux density is then multiplied by the area of the assumed contamination. This value is then multiplied by the Gaussian diffusion factor χ/Q. The formula for the calculation is as follows:

$$C_a = J_c A \frac{\chi}{Q} \frac{1}{1{,}000}$$

Equation 4

Where: C_a = Radon air concentration offsite: pCi/L
J_c = Radon flux density: pCi/m^2-sec
A = Area of contaminated zone: m^2
χ/Q = Gaussian diffusion factor: sec/m^3
$1/1{,}000$ = Conversion from cubic meters to Liters

The Gaussian diffusion factor χ/Q is calculated using the following ground-level-release equation (U.S. NRC, 1983):

$$\frac{\chi}{Q} = \frac{1}{\pi \mu \sigma_y \sigma_z}$$

Equation 5

Where: χ/Q = Gaussian diffusion factor: sec/m^3
π = Pi: dimensionless
μ = Mean wind speed: meters/sec
σ_y = Horizontal dispersion coefficient: meters
σ_z = Vertical dispersion coefficient: meters

2.6 Working Level Month and Dose Conversion Factor

The airborne concentration of ^{222}Rn (in units of pCi/L) can be used to estimate the working level (WL) due to the short lived radon daughters by using the EPA designated equilibrium ratio of

0.5. A working level is defined as any combination of the short lived radon daughters in 1 liter of air that results in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The equilibrium ratio F is rigorously defined as:

$$F = \frac{(\text{concentration C of progeny WL})(100\ \text{pCiL}^{-1}\text{WL}^{-1})}{\text{actual radon concentration U pCi/L}}$$

Equation 6

The above definition for F is based upon the fact that 100 pCi/L of ^{222}Rn is required to support 1 WL of short lived progeny under secular equilibrium conditions when the concentration of each short lived progeny equals the radon concentration of 100 pCi/L.

Working level is computed as follows:

$$C_{WL} = \frac{(C_a F)}{100\ \text{pCi/L}}$$

Equation 7

Where:	C_{WL}	= Concentration of radon progeny: WL
	C_a	= Radon concentration: pCi/L
	F	= Equilibrium ratio (0.5)

The working level is now converted to the exposure unit of working level months per year (WLM/yr). The WLM/yr is the exposure rate in WL, multiplied by the hours of exposure, divided by 170 hours (the number of hours per month that a uranium miner typically spends in the mines). The formula for WLM/year is as follows:

$$\text{WLM/yr} = \frac{C_{WL}\ \text{x Exposure Time}}{170\ \text{hours}}$$

Equation 8

Where:	*WLM/yr*	= Working level month per year
	C_{WL}	= Concentration of radon progeny: WL
	Exposure Time	= Exposure time: hours/year

The effective dose to an individual can now be determined by using the effective dose per unit exposure conversion factor for outdoor air of 1,320 mrem/WLM and for indoors of 830 mrem/WLM (Porstendorfer and Reineking, 1999).

2.7 Radon Entry into a House

The rate of radon entry into a house from a concrete slab (ignoring cracks in the slab is given by:

$$Q_{Rn} = AJ_c$$

Equation 9

Where: Q_{Rn} = Rate of radon entry into house: pCi/sec
A = Area of concrete slab: m^2
J_c = Radon flux density: pCi/m^2-sec

The concentration of radon in the air in the house is given by the steady state assumption:

$$C_{net} = C_{in} - C_{out} = \frac{Q_{Rn}}{V_h H_{vr}}$$

Equation 10

Where: C_{net} = Net indoor radon concentration from foundation: pCi/m^3
C_{in} = Net indoor radon concentration: pCi/m^3
C_{out} = Net outdoor radon concentration: pCi/m^3
Q_{rn} = Rate of radon entry into house: pCi/sec
V_h = Volume of house: m^3
H_{vr} = House ventilation exchange rate: 1/sec

2.8 Resuspension Inhalation, Ingestion, and External Exposure

The RESRAD computer code, version 6.22, was used to calculate the dose/source concentration ratios $DSR_{ip}(t)$ for all identified radionuclides (i) and pathways (p) at time (t) after emplacement. Radioactive decay and ingrowth were considered in deriving the dose/source concentration ratios. The various parameters used in the RESRAD code for these analyses are listed in Attachment A. The calculations performed for radon flux are summarized in Attachment B, and the actual RESRAD calculations are on CD in Attachment C. The calculated maximum dose contributions for all considered pathways are presented in Section 3.0. The maximum dose contributions and total dose/source concentration ratios for the modeled scenarios are predicted to occur at time zero.

Uncertainty in the derivation of dose contributions and dose/source concentration ratios comes from the distribution of possible input parameter values, as well as uncertainty in the conceptual model used to represent the site. Uncertainties in the following parameters have the greatest significance on the model predictions: occupancy factors, thickness of the contaminated zone, mass loading, and inhalation rate.

The radionuclide concentrations used in the RESRAD calculations were taken directly from the Mean + 95% UCL column of Table 1. The following pathways were considered for the RESRAD analysis.

Table 2
Summary of Pathways Considered for RESRAD Scenarios

Pathway	All Scenarios
External exposure	Yes
Particulate inhalation	Yes
Radon inhalation	No*
Ingestion of soil	Yes
Ingestion of produce from onsite garden	No
Ingestion of meat from onsite livestock	No
Ingestion of milk from onsite livestock	No
Ingestion of fish from onsite pond	No
Ingestion of water from onsite well	No

*For accuracy and consistency RESRAD was not used to calculate Radon flux. All radon calculations were completed by hand as shown on the spreadsheets in Attachment B.

3.0 Results

This section presents the results of the dose assessments for the pathways and scenarios identified in Section 2.2. Results for the containerized material are presented first, followed by the results of the 30,000 yds^3 material.

3.1 Worker Exposure during Lift Liner Waste Emplacement and Cover Construction

Table 3 identifies the effective dose equivalent due to radon, soil inhalation/ingestion, and external exposure for a solid waste landfill worker during waste emplacement and construction of a 36-inch clayey unconsolidated cover for both the containerized material and the 30,000 yds^3 material. The effective dose equivalents (EDEs) were estimated using the conservative methodologies outlined in Section 2.0. The EDEs have been estimated for a worker spending 10 days on site, 8 hours per day during containerized material emplacement and the same worker spending 5 days on site, 8 hours per day, placing a minimum of 36 inches of overburden. Exposure durations were doubled for the 30,000 yds^3 material.

Table 3
Worker Exposure Scenarios Effective Dose Equivalents (mrem/yr)

Containerized Material					
	No Cover	**Percentage**	**With Cover**	**Percentage**	**Total**
Radon	2.95E-01	8.61	7.4E-02	100	3.853E-01
Inhalation	1.03E-01	2.84	0.00E-00	0	1.027E-01
Ingestion	1.29E-01	3.57	0.00E-00	0	1.291E-01
External	3.07E+00	84.97	1.00E-05	0	3.071E+00
Total	**3.454E+00**	100	**7.418E-02**	100	**3.52E+00**
30,000 yds^3 Material					
	No Cover	**Percentage**	**With Cover**	**Percentage**	**Total**
Radon	2.646	28.7	6.31E-01	100	3.46
Inhalation	2.56E-01	2.62	0.000E-00	0	2.56E-01
Ingestion	2.59E-01	2.65	0.000E-00	0	2.59E-01
External	6.43	66.02	2.00E-05	0	6.43
Total	**9.59**	100	**6.31E-01**	100	**10.2**

As shown in Table 3, the sum of the effective dose equivalents for the solid waste landfill worker, using very conservative parameters, is below the 25 mrem/yr dose unrestricted use criteria (as well as the worker criteria) for both source term scenarios.

3.2 Recreational User

Table 4 identifies the effective dose equivalent due to radon exposure for a recreational user. The EDEs were estimated using the conservative methodologies outlined in Section 2.0. The EDEs have been estimated for an adult recreational user spending 4 hrs per week for 26 weeks per year of his/her time in the outdoor recreational facility. The waste is emplaced below grade into the landfill and covered with a 36-inch clayey unconsolidated cover.

Table 4
Recreational User Exposure Scenario Effective Dose Equivalents (mrem/yr)

Containerized Material		
	With Cover	**Percentage**
Radon	1.90E-01	100
Inhalation	0.000E+00	0
Ingestion	0.000E+00	0
External	2.610E-05	0
Total	**1.90E-01**	100
30,000 yds^3 Material		
	With Cover	**Percentage**
Radon	0.82	100
Inhalation	0.000E+00	0
Ingestion	0.000E+00	0
External	2.610E-05	0
Total	**0.82**	100

As shown in Table 4, the sum of the effective doses across the available pathways for the recreational user scenario is well below the 25 mrem/yr dose unrestricted use criteria for both source terms.

3.3 Offsite Receptor Exposure

Table 5 identifies the effective dose equivalent due to radon for an offsite receptor located 2 miles from the center of the disposal cell under the current land use and at a location of 1,700 feet from the center of the disposal cell under a future land use. The receptor is assumed to spend the majority of his/her time at the location and does not consume water or foods from the site. The radon plume dose is calculated using the Gaussian ground-level-release equation for determining the relative radon concentration at the plume centerline for a downwind distance of 100 meters. The scenario was assessed with the assumptions that the Lift Liner waste material was emplaced with and without a cover. The dose contributions due to soil ingestion/inhalation and external exposure were not assessed for this scenario due to the distance from the emplaced waste material.

Table 5
Offsite Receptor Exposure Scenarios Effective Dose Equivalents (mrem/yr)

Containerized Material				
Current Land Use	**No Cover (2 miles)**	**Percentage**	**With Cover (2 miles)**	**Percentage**
Radon	0.023	100	0.012	100
Inhalation	N/A	N/A	N/A	N/A
Ingestion	N/A	N/A	N/A	N/A
External	N/A	N/A	N/A	N/A
Total	**0.023**	100	**0.012**	100
Future Land Use	**No Cover (1,700 feet)**	**Percentage**	**With Cover (1,700 feet)**	**Percentage**
Radon	0.347	100	0.175	100
Inhalation	N/A	N/A	N/A	N/A
Ingestion	N/A	N/A	N/A	N/A
External	N/A	N/A	N/A	N/A
Total	**0.347**	100	**0.175**	100
30,000 yds^3 Material				
Current Land Use	**No Cover (2 miles)**	**Percentage**	**With Cover (2 miles)**	**Percentage**
Radon	0.304	100	0.145	100
Inhalation	N/A	N/A	N/A	N/A
Ingestion	N/A	N/A	N/A	N/A
External	N/A	N/A	N/A	N/A
Total	**0.304**	100	**0.145**	100
Future Land Use	**No Cover (1,700 feet)**	**Percentage**	**With Cover (1,700 feet)**	**Percentage**
Radon	4.504	100	2.147	100
Inhalation	N/A	N/A	N/A	N/A
Ingestion	N/A	N/A	N/A	N/A
External	N/A	N/A	N/A	N/A
Total	**4.504**	100	**2.147**	100

As shown on Table 5, the radon doses received by an offsite receptor at both current and future land use locations and for both no cover and covered waste scenarios are well below the 25 mrem/yr dose unrestricted use criteria.

3.4 Suburban Resident Exposure

Table 6 identifies the effective dose equivalent due to radon for a suburban resident occupying a single-story residence with no basement slab-on-grade located over the disposal cell for both source term materials. The house is the standard radon model home consisting of an area of 100 m^2 and a volume of 250 m^3. The air exchange rate within the home is 0.35/hr and the resident is assumed that he/she occupies the home for 16.4 hrs/day for 350 days per year. The waste material is placed within the disposal cell and covered with 2 feet of unconsolidated material. The concrete slab thickness of the house is assumed to be 6 inches. The dose contributions due to soil ingestion/inhalation and external exposure were not assessed for this scenario due to the

20-foot-thick layer of overburden. Figures 4 and 5 show the attenuation of radon flux for the 457 containers and the 30,000 yds^3 respectfully.

Table 6
Suburban Resident Exposure Scenario Effective Dose Equivalents (mrem/yr)

Containerized Material		
	With 20-foot Cover	**Percentage**
Radon	6.62E-1	100
Inhalation	N/A	0
Ingestion	N/A	0
External	N/A	0
Total	**6.62E-1**	100
30,000 yds^3 Material		
	With 20-foot Cover	**Percentage**
Radon	1.028	100
Inhalation	N/A	0
Ingestion	N/A	0
External	N/A	0
Total	**1.028**	100

As shown on Table 6, the radon dose received by a suburban resident is well below the 25 mrem/yr dose unrestricted use criteria.

4.0 Conclusion

The results of the dose assessments as presented in Section 3.0 are conservative in nature in the sense that they overestimate the doses compared to what actual doses would be. Additional conservatism is built into the different scenarios that were modeled for this assessment. The two most realistic scenarios are the worker scenario and the nearest offsite receptor scenario. The remaining scenarios should not occur due to state and federal regulations prohibiting the use of the land for recreational or residential purposes. The worker scenario is the most limiting scenario of the modeled scenarios. The dose estimated from this model is very conservative and does not account for the use of heavy equipment to emplace the waste material. The steel chassis and the elevated cab of the heavy equipment would sufficiently attenuate the external dose rate from the waste material to negligible levels. None of the assessed scenarios exceeded the 25 mrem/yr dose unrestricted use criteria for either source term evaluated.

Figure 4

Figure 5

5.0 References

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ATTACHMENT A

RESRAD Parameters

Table A.1
RESRAD Parameters Used in Dose Assessment Scenarios

Parameter	Units	Worker	Recreational	Defaults	Reference/Rationale
R011 Contaminated Zone					
Area of CZ	m2	1018.89	1018.89	1.000E+04	Area of contamination (457 supersacks)
Thickness of CZ	m	1.22	1.22	2.000E+00	Depth of waste (a supersack is 4 feet deep)
Length Parallel to Aquifer Flow	m	not used	not used	1.000E+02	
Radiation Dose Limit	mrem/yr	25	25	2.5E+001	
Elapsed Time Since Placement of Material	yr	0.0	0.0	0.0	
R012 Initial Principle Radionuclide					
Radium-226 (soil)	pCi/g	27.96	27.96	0.0	LIFT LINER bag sampling results
Radium-228 (soil)	pCi/g	3.66	3.66	0.0	LIFT LINER bag sampling results
Thorium-232 (soil)	pCi/g	3.47	3.47	0.0	LIFT LINER bag sampling results
Thorium-230 (soil)	pCi/g	21.45	21.45	0.0	LIFT LINER bag sampling results
Thorium-228 (soil)	pCi/g	3.56	3.56	0.0	LIFT LINER bag sampling results
Uranium-234 (soil)	pCi/g	19.45	19.45	0.0	LIFT LINER bag sampling results
Uranium-235 (soil)	pCi/g	1.13	1.13	0.0	LIFT LINER bag sampling results
Uranium-238 (soil)	pCi/g	19.86	19.86	0.0	LIFT LINER bag sampling results
R013 Cover and Contaminated Zone Hydrological Data					
Cover Depth	m	0.0/0.9144	0.0/0.9144	0.0	No cover and 36-inch cover
Density of Cover Material	g/cm^3	1.60	1.60	1.5	
Cover Depth Erosion Rate	m/yr	1.000E-03	1.000E-03	1.000E-03	
Density of Contaminated Zone	g/cm^3	1.60	1.60	1.65	Assumed
Contamination Zone Erosion Rate	m/yr	1.000E-03	1.000E-03	1.000E-03	
Contaminated Zone Total Porosity	-	4.000E-01	4.000E-01	4.000E-01	
Contaminated Zone Field Capacity	-	2.000E-01	2.000E-01	2.000E-01	
Contaminated Zone Hydraulic Conductivity	m/yr	1.000E+01	1.000E+01	1.000E+01	
Contaminated Zone b Parameter	-	5.300E+00	5.300E+00	5.300E+00	
Average Annual Wind Speed	m/sec	2.000E+00	2.000E+00	2.000E+00	
Humidity in Air	g/m^3	not used	not used	8.000E+00	
Evapotranspiration Coefficient	-	5.000E-01	5.000E-01	5.000E-01	
Precipitation	m/yr	1.000E+00	1.000E+00	1.000E+00	
Irrigation	m/yr	2.000E-01	2.000E-01	2.000E-01	
Irrigation Mode	-	overhead	overhead	overhead	
Runoff Coefficient	-	2.000E-01	2.000E-01	2.000E-01	
Watershed Area for Nearby Stream or Pond	m^2	not used	not used	1.000E+06	
Accuracy for Water/Soil Computations	-	not used	not used	1.000E-03	
R014 Saturated Zone Hydrological Data					
Density of Saturated Zone	g/cm^3	not used	not used	1.500E+00	
Saturated Zone Total Porosity	-	not used	not used	4.000E-01	
Saturated Zone Effective Porosity	-	not used	not used	2.000E-01	
Saturated Zone Field Capacity	-	not used	not used	2.000E-01	
Saturated Zone Hydraulic Conductivity	m/yr	not used	not used	1.000E+02	
Saturated Zone Hydraulic Gradient	-	not used	not used	2.000E-02	
Saturated Zone b Parameter	-	not used	not used	5.300E+00	
Water Table Drop Rate	m/yr	not used	not used	1.000E-03	
Well Pump Intake Depth	m	not used	not used	1.000E+01	
Model: Nondispersion or Mass-Balance	-	not used	not used	ND	
Well Pumping Rate	m^3/yr	not used	not used	2.500E+02	

Parameter	Units	Worker	Recreational	Defaults	Reference/Rationale
R015 Uncontaminated and Unsaturated Strata Hydrological Data					
Number of Unsaturated Zone Strata	-	not used	not used	1	
Thickness	m	not used	not used	4.000E+00	
Soil Density	g/cm^3	not used	not used	1.500E+00	
Total Porosity	-	not used	not used	4.000E-01	
Effective Porosity	-	not used	not used	2.000E-01	
Field Capacity	-	not used	not used	2.000E-01	
Soil-specific b Parameter	-	not used	not used	5.300E+00	
Hydraulic Conductivity	m/yr	not used	not used	1.000E+01	
R016 Distribution Coefficients and Leach Rates					
Contaminated Zone K_d (all Zones)	cm^3/g				RESRAD Defaults
Saturated Leach Rate	/yr	0.0	0.0	0.0	
Solubility Constant	-	0.0	0.0	0.0	
R017 Inhalation and External Gamma					
Inhalation Rate	m^3/yr	7.300E+03	5.548E+03	8.400E+03	EPA, 1997 and RAGS
Mass Loading for Inhalation	g/m^3	6.000E-04	1.000E-04	1.000E-04	Default, Yu, et. al., 1993.
Exposure Duration	yr	1	30	30	Assumed
Shielding Factor Inhalation	-	1	1	0.4	RESRAD User Manual Guidance
Shielding Factor External Gamma	-	1	1	0.7	RESRAD User Manual Guidance
Fraction of Time Spent Indoors	-	0.0	0.0	0.5	Scenario Specific
Fraction of Time Spent Outdoors	-	9.132E-03	7.990E-02	0.25	Scenario Specific
Shape Factor	-	1.0	1.0	1.0	
R018 Ingestion Pathway Data, Dietary Parameters					
Fruits, Vegetables, and Grain Consumption	kg/yr	not used	not used	1.600E+02	
Leafy Vegetable Consumption	kg/yr	not used	not used	1.400E+01	
Milk Consumption	L/yr	not used	not used	9.200E+01	
Meat and Poultry Consumption	kg/yr	not used	not used	6.300E+01	
Fish Consumption	kg/yr	not used	not used	5.400E+00	
Other Seafood Consumption	kg/yr	not used	not used	9.000E-01	
Soil Ingestion Rate	g/yr	175.2	36.5	36.5	EPA, 1997
Drinking Water Intake	L/yr	not used	not used	5.100E+02	
Drinking Water Contaminated Fraction	-	not used	not used	1.000E+00	
Household Water Contaminated Fraction	-	not used	not used	1.000E+00	
Livestock Water Contaminated Fraction	-	not used	not used	1.000E+00	
Irrigation Water Contaminated Fraction	-	not used	not used	1.000E+00	
Aquatic Food Contamination Fraction	-	not used	not used	5.000E-01	
Plant Food Contamination Fraction	-	not used	not used	-1	
Meat Contamination Fraction	-	not used	not used	-1	
Milk Contamination Fraction	-	not used	not used	-1	
R019 Ingestion Pathway Data, Nondietary					
Livestock Fodder Intake for Meat	kg/day	not used	not used	6.800E+01	
Livestock Fodder Intake for Milk	kg/day	not used	not used	5.500E+01	
Livestock Water Intake for Meat	L/day	not used	not used	5.000E+01	
Livestock Water Intake for Milk	L/day	not used	not used	1.600E+02	
Livestock Soil Intake	kg/day	not used	not used	5.000E-01	
Mass Loading for Foliar Deposition	g/m^3	not used	not used	1.000E-04	
Depth of Soil Mixing layer	m	1.500E-01	1.500E-01	1.500E-01	
Depth of Roots	m	not used	not used	9.000E-01	
Drinking Water Fraction from Groundwater	-	not used	not used	1.000E+00	

Parameter	Units	Worker	Recreational	Defaults	Reference/Rationale
Household Water Fraction from Groundwater	-	not used	not used	1.000E+00	
Livestock Water Fraction from Groundwater	-	not used	not used	1.000E+00	
Irrigation Fraction from Groundwater	-	not used	not used	1.000E+00	
R021 Radon					
Radon Parameters Not Used					

ATTACHMENT B

Calculations for Radon Flux

Attachment C
Calculations on CD