This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

ROUTINE DOSE ESTIMATES FOR THE REMOVAL OF SOIL FROM A BASIN TO THE BURIAL GROUND AT THE SAVANNAH RIVER SITE

Ali A. Simpkins
Westinghouse Savannah River Company
Aiken, SC 29808

Abstract - Worker dose estimates have been made for various exposure scenarios resulting from the relocation of soil from the H Area Retention Basin (HRB) to the Old Radioactive Waste Burial Ground (ORWBG) at the Savannah River Site (SRS). Estimates were performed by hand calculations and using RESRAD (Yu et al. 2001) and MAXDOSE (Simpkins 1999). Doses were estimated for the following pathways: (1) shine and inhalation as a result of standing on contaminated soil at HRB and ORWBG; (2) exposure to off-unit receptors due to soil disturbances from excavation type activities at HRB and ORWBG; (3) exposure to off-unit receptors due to soil disturbances from dumping of soil from bucket and from roll-off pan; and (4) exposure to off-unit receptors from wind driven dust from contaminated area. The highest dose estimates (0.25 mSv hr^{-1}) resulted from the receptor standing on HRB.

INTRODUCTION

The Savannah River Site (SRS) processes and stores nuclear materials in support of the national defense and U.S. nuclear non-proliferation efforts. The site also develops and deploys technologies to improve the environment and treat nuclear and hazardous wastes from the Cold War. The SRS complex is located in South Carolina along the Savannah River and covers approximately 800 km^2. As a result of operation in the early years, there are many waste units on site. The General Separations Area Consolidated Unit consists of the H Area Retention Basin (HRB) , two ponds and the Old Radioactive Waste Burial Ground (ORWBG). In an effort to remove potential threat source material, waste from the former three is being transferred to the latter. The contamination within the HRB represents the highest potential dose exposure.

Movement of contaminated debris comes with a variety of challenges. One of which is assessment of dose to workers involved in the process. Doses were estimated for the following pathways: (1) shine and inhalation as a result of standing on contaminated soil at HRB and ORWBG; (2) exposure to off-unit receptors due to soil disturbances from excavation type activities at HRB and ORWBG; (3) exposure to off-unit receptors due to soil disturbances from dumping of soil from bucket and from roll-off pan; and (4) exposure to off-unit receptors from wind driven dust from contaminated area. The pathway depicting emissions from soil becoming airborne by vehicular traffic is assumed to be included within the excavation pathway since this includes all soil emissions as a result of this process.

Estimating dose for each of these airborne pathways first requires the development of a source term, or the amount of radioactive material released to the atmosphere per unit time. Once this is determined, atmospheric dispersion models can be used to predict downwind air concentrations and finally dose. Methodologies such as these are crude approximations of complex processes and should be treated as such. Depending on weather conditions, actual dose could vary considerably.

SOURCE TERM DERIVATION FOR VARIOUS PATHWAYS

Standing at HRB and ORWBG

RESRAD was used to estimate dose from inhalation and incidental ingestion of the soil while performing work at the HRB or ORWBG. Average soil concentration values used for this analysis were taken from the H Area Retention Basin Baseline Risk Assessment (WSRC 2001a) and are shown in Table 1.

Soil Disturbances from Excavation

Workers adjacent to the contaminated soil can be exposed when the soil becomes airborne during excavation-type processes at HRB or ORWBG (e.g., digging, relocating, transferring, bull dozing, etc.). The emission rate due to excavation can be estimated by the following equation (USDOE 1994a):

$$e = 0.75\frac{0.45(s)^{1.5}}{(m)^{1.4}}$$

where

e emission rate in kg hr^{-1}

s silt content of surface material

m surface moisture content of material in percent

The silt content of the soil was estimated to be 0.5 and the moisture content was 19.2% (WSRC 2001a). Using these parameters, the resulting emission rate is 1.2 kg hr^{-1}. Using the concentrations supplied in Table 1, source terms (Bq hr^{-1}) can be estimated.

Soil Disturbances from Dumping of Soil from Bucket and From Roll-Off Pan

Off-unit receptors can become exposed when soil particles become airborne due to disturbances when dumping is performed both from the excavator bucket to the roll-off pan at HRB and from the roll-off pan to the dumping area at the ORWBG.

Using DOE (1994b) the airborne release fraction (ARF) can be estimated using the following equation:

$$ARF = 0.1064M^{0.125}H^{2.37} / \rho^{1.02}$$

where

M mass of soil dumped, kg

H height of drop, m

ρ density of the soil, kg m^{-3}

For excavation of soil at HRB, the excavator bucket is assumed to contain approximately 1.9 m^3 of soil, which is loose with a density of 1200 kg m^{-3}. Therefore, the mass of the soil contained within the bucket is about 2300 kg. The height is assumed to be about 2 m. Using the above equation, the fraction of soil that could become airborne is about 0.001. For each dump potentially 2.3 kg of soil could become airborne. Assuming an estimated cycle time of 2.5 minutes (370 m^3 in an 8-hour workday), 24 dumps could be performed per hour resulting in the potential for 57 kg hr^{-1} to become airborne. Using the concentrations supplied in Table 1, source terms (Bq hr^{-1}) can be estimated.

For dumping of soil from the roll-off pan at ORWBG, estimates are performed in a similar manner. The roll-off pan/ burrito bag is assumed to contain 23 m^3 of soil and approximately two dumps will be made per hour (370 m^3 in an 8-hour workday). Considering that the bag could potentially fail upon dumping, about half of the soil is assumed to be available for release. Using these assumptions 32 kg hr^{-1} could become airborne as a result of dumping the burrito bags. This number is highly conservative in that the burrito bags will likely not fail to the extent that half of the material is available for release. Using the concentrations supplied in Table 1, source terms (Bq hr^{-1}) can be estimated.

Wind Driven Dust from Contaminated Area

Using USDOE (1994b), the airborne release rate for wind driven dust is 4×10^{-3} g m^{-2} hr^{-1}. Using the estimated area of 2400 m^2 for the HRB, the release rate is estimated to be 0.0097 kg hr^{-1}. Using the concentrations supplied in Table 1, source terms (Bq hr^{-1}) can be estimated. This release rate is appropriate for wind speeds of 1 m s^{-1} which is much lower than average wind speeds at SRS (3.25 m s^{-1}). This pathway is not expected to be a main dose contributor, but more sophisticated modeling could be used to refine these estimates if necessary.

The airborne release rate for wind driven dust at ORWBG are assumed to be bounded by the above mentioned values because it is anticipated that the size of the contaminated area at ORWBG will be smaller.

Dose Estimates

Shine and Inhalation from standing at HRB and ORWBG

Dose from inhalation and ground shine for workers standing at HRB and ORWBG were estimated using a combination of radiation surveys and RESRAD output. Dose rates were measured at HRB in 1994. These dose rate measurements range from 0.05 to 1 mSv hr^{-1} with the majority of the measurements being around 0.25 mSv hr^{-1}. Assuming the worker does not spend a prolonged period of time adjacent to location reflecting the highest dose rate, 0.25 mSv hr^{-1} would be the estimated dose from external exposure.

RESRAD was used to estimate dose from inhalation and incidental ingestion of the soil while performing work at the HRB. Average soil concentration values as taken from the H Area Retention Basin Baseline Risk Assessment (WSRC 2001a) shown in Table 1. Other input parameters used for RESRAD are shown in Table 2. The estimated dose contribution from inhalation and incidental ingestion of soil is 3.5×10^{-4} mSv hr^{-1} and 1.8×10^{-4} mSv hr^{-1}, respectively. Therefore, the total estimated dose to a person standing on the HRB would be 0.25 mSv hr^{-1}. These results are summarized in Table 3.

Dose estimates at ORWBG are assumed to be bounded by the above mentioned values because it is anticipated that the size of the contaminated area at ORWBG will be smaller.

Dose Estimates Involving Atmospheric Dispersion Of Materials

Given the source terms estimated above, the methods contained within MAXDOSE-SR (Simpkins 1999) can be used to estimate downwind dose. MAXDOSE-SR is an atmospheric dispersion model used to estimate dose for routine releases and applies a straight-line Gaussian plume model. MAXDOSE-SR only estimates dose at the Savannah River Site boundary, so to estimate dose at 100 m, a spreadsheet was developed that employs the relevant methods.

Using the relative air concentrations and ground deposition given as output in MAXDOSE, concentrations can be estimated at other distances using logarithmic interpolation. For HRB and ORWBG, it is appropriate to use the H Area meteorological data. At 100 m from either source, the sector resulting in the highest concentration, and therefore dose, is the southwest sector. At 100 m, the relative air concentration and ground deposition were estimated to be 1.6E-4 s m^{-3} and 4.93E-7 m^{-2}, respectively.

Once the air and ground concentrations are known, inhalation and plume shine dose can be calculated using the following equations.

Inhalation dose:

$$D_h^{inh} = \chi_i \bullet BR \bullet DF_i^{inh} \bullet \left(\frac{1\text{yr}}{365\text{d yr}^{-1} * 24\text{h d}^{-1}} \right)$$

where

χ_i atmospheric concentration, Bq m^{-3}

BR breathing rate, 8400 m^3 yr^{-1} (USDOE 1990)

DF_i^{inh} nuclide specific dose conversion factor, Sv Bq^{-1} (USDOE 1988b)

Plume shine dose:

$$D_i^g = d_i \bullet SF \bullet DF_i^g \bullet \frac{1-e^{-\lambda_i t_b}}{\lambda_i} \bullet \left(\frac{1yr}{365d\ yr^{-1} * 24h\ d^{-1}} \right)$$

where

d_i deposition rate, Bq m^{-2}

SF shielding factor, 1.0, unitless

DF_i^g nuclide-specific ground-shine dose factor, Sv m^2 yr^{-1} Bq^{-1} (USDOE 1988a)

λ_i nuclide-specific radiological decay constant, yr^{-1}

t_b buildup time in the soil (length of operation), 1 yr assumed

Using these methods, worker doses were estimated at 100 m for all potential emission pathways. The results are shown in Table 3.

DISCUSSION OF RESULTS

Table 3 shows the dose for various exposure pathways associated with the movement of soil. Facility managers located adjacent to the process indicated any additional exposure was unacceptable so a comparison was made with typical background levels in the area. Referring to Table 3 several of the exposure pathways lead to doses that are above background. SRS has set an administrative goal of 5 mSv yr^{-1} (WSRC 2001b). Using the SRS administrative goal as a point of comparison, workers could only work near contaminated soils (with 0.25 mSv hr^{-1} shine + inhalation) at HRB or ORWBG for 20 hours per year.

For the co-located worker the limited number of hours is not as straight forward since the actual dose is wind-direction dependent. The doses predicted in Table 3 are for a constant wind direction. The maximum number of hours per year that the wind blows in a given direction is typically less than 10% (200 hrs for 2000 hour work year) for H Area meteorology as taken from the MAXDOSE-SR output. To ensure co-located workers do not receive dose in excess of the SRS administrative limit, processes involving dumping of soil from the excavator bucket into a roll-off pan at HRB or from the roll-off pan to the dumping area at ORWBG would need to be limited to 940 hours per year or roughly half of the work year. However the wind will not blow in this constant direction half of the year, so there should not be a problem in exceeding the administrative goal even for this most limiting pathway.

With respect to the DOE administrative goal of 20 mSv yr^{-1}, workers could work at HRB or ORWBG for 80 hours per year and excavation type activities would not need to be limited to protect co-located workers. With respect to the DOE occupational whole body dose limit for general employees of 50 mSv/yr (10 CFR 835), workers could work at HRB or ORWBG for 200 hours per year and excavation type activities would not need to be limited to protect co-located workers.

Mathematical modeling of complex processes such as these is crude at best and the results should be treated as such. The use of atmospheric dispersion modeling implies that wind direction stays the same over the entire period of the release. This, however, may not be the case. While these estimates are assumed to be bounding, stable weather conditions could potentially produce higher doses. Also, atmospheric models such as these are based on a point source release, whereas these releases will actually be from area sources. The use of the point source instead of the area source is conservative.

CONCLUSIONS

Dose estimates established here provide project managers with an additional tool to effectively manage dose during the transport of soil. As with all dose modeling, these estimates are approximate and monitoring at the site should override any previous recommendations. With the proper application of ALARA techniques, movement of soil from HRB to ORWBG can be done in such a way to minimize dose to individuals involved.

References

Carlton WH. Dose estimates for PAR pond dam repair. , Aiken, SC: Westinghouse Savannah River Company Inter-Office Memorandum: , SRT-EST-99-176; 1999.

Simpkins AA. MAXDOSE-SR: A routine-release atmospheric dose model used at SRS. Aiken, SC: Westinghouse Savannah River Company; WSRC-TR-99-00281; 1999.

U.S. Department of Energy. External dose conversion factors for calculation of dose to the public. Washington, DC: DOE/EH-0070; 1988a.

U.S. Department of Energy. Internal dose conversion factors for calculation of dose to the public. Washington, DC: DOE/EH-0071; 1988b.

U.S. Department of Energy, Radiation protection of the public and the environment., Washington, DC: DOE Order 5400.5; 1990.

U.S. Department of Energy, Dust mitigation study for the environmental restoration disposal facility. Richland, WA: DOE//RL/12074-30-2 Rev. 0; 1994a.

U.S. Department of Energy, Airborne release fractions/rates and respirable fractions for nonreactor nuclear facilities, Volume 1 – Analysis of Experimental Data. Washington, DC: DOE-HDBK-3010-94; 1994b.

Westinghouse Savannah River Company. RCRA Facility investigation/remediation investigation report with baseline risk assessment for the h-area retention basin (281-3H). Aiken, SC: WSRC-RP-98-4136 Rev. 1.1; 2001a.

Westinghouse Savannah River Company. Westinghouse Savannah River Company 2002 ALARA goals. Aiken, SC: ESH-RPD-2001-00091 Rev. 2001b.

Yu C, Zielen AJ, Cheng JJ, LePoire DJ, Gnanapragasam E, Kamboj S, Arnish J, Wallo A III, Williams WA, Peterson H. User's manual for RESRAD version 6.0. Argonne, IL: Argonne National Laboratory, 2001.

Table 1. Average Radionuclide Concentrations in H Area Retention Basin

Constituent	Concentration Bq g^{-1}
^{228}Ac	3.96×10^{-2}
^{241}Am	5.55×10^{-1}
^{14}C	5.59×10^{-3}
^{137}Cs	2.33×10^{2}
^{60}Co	4.59×10^{-3}
^{242}Cm	2.74×10^{-2}
$^{243}Cm/^{244}Cm$	3.49×10^{0}
$^{245}Cm/^{246}Cm$	1.01×10^{-2}
^{154}Eu	3.62×10^{-1}
Gross alpha	$6.77 \times 10^{0*}$
^{212}Pb	4.70×10^{-2}
^{237}Np	1.32×10^{-3}
Nonvolatile beta	$1.34 \times 10^{2\dagger}$
^{238}Pu	5.07×10^{0}
$^{239}Pu/^{240}Pu$	2.78×10^{-1}
^{40}K	2.80×10^{-2}
^{147}Pm	2.71×10^{-2}
^{226}Ra	2.73×10^{-2}
^{228}Ra	4.07×10^{-2}
^{22}Na	9.07×10^{-4}
^{90}Sr	6.11×10^{1}
^{99}Tc	8.03×10^{-2}
^{228}Th	1.08×10^{-1}
^{230}Th	4.37×10^{-2}
^{232}Th	8.55×10^{-2}
$^{233}U/^{234}U$	3.20×10^{-1}
^{235}U	1.84×10^{-2}
^{238}U	2.78×10^{-1}

* Includes reduction of original reported gross alpha concentration by: ^{241}Am, ^{226}Ra, ^{237}Np and all isotopes of Cm, Pu, Th, and U soil concentration values.

† Includes reduction of original reported gross beta concentration by: ^{228}Ac, ^{137}Cs, ^{154}Eu, ^{212}Pb, ^{40}K, ^{147}Pm, ^{22}Na, ^{90}Sr, and ^{99}Tc.

Table 2. Input for RESRAD Dose Estimates

Parameter	Value	units	Reference
Contaminated Zone			
Area	2400	m^2	WSRC 2001a
Thickness	1.2	m	WSRC 2001a
Soil Density	1.65	$g\ cm^{-3}$	WSRC 2001a
Erosion Rate	0.001	$m\ yr^{-1}$	Yu et al. 2001
Total Porosity	0.359		WSRC 2001a
Effective Porosity	0.2		WSRC 2001a
Hydraulic Conductivity	11.2	$m\ yr^{-1}$	WSRC 2001a
Exponential Parameter	7.14		WSRC 2001a
Cover			
Thickness	0	m	
Erosion Rate	0.001	$m\ yr^{-1}$	Yu et al. 2001
Other			
Outdoor time fraction	1		Scenario specific
Breathing Rate	8400	$m^3\ yr^{-1}$	USDOE 1990
Mass loading	0.001	$g\ m^{-3}$	Carlton 1999
Soil ingestion	36.5	$g\ yr^{-1}$	Yu et al. 2001

Table 3. Dose Estimates for Workers as a Result of Removal of HRB Soil to ORWBG

Pathway	Inhalation Dose mSv hr^{-1}	Ground Shine mSv hr^{-1}	Ingestion mSv hr^{-1}	Total mSv hr^{-1}	Greater than Backgound ($4x10^{-4}$ mSv hr^{-1})*
On-Unit worker					
Standing at HRB	$3.5x10^{-3}$	$2.5x10^{-1}$	1.8x10-01	$2.5x10^{-1}$	yes
100 m Co-Located Worker					
Excavation (HRB or ORWBG)	$1.1x10^{-4}$	$2.3x10^{-6}$	na	$1.1x10^{-4}$	no
Dumping Bucket (HRB)	$5.2x10^{-3}$	$1.1x10^{-4}$	na	$5.3x10^{-3}$	yes
Dumping Roll-off Pan (ORWBG)	$2.9x10^{-3}$	$6.1x10^{-5}$	na	$3.0x10^{-3}$	yes
Wind-Driven (HRB or ORWBG)	$8.9x10^{-7}$	$1.8x10^{-8}$	na	$9.1x10^{-7}$	no

*Average annual dose in the area