Table C-4. Radiological Concentrations from Soil Samples Containing Lavery Till in the WMA 1 and WMA 2 Excavation Areas[1]

Location	Nuclide	Result (pCi/g)	Sample Depth Interval (ft)
	U-238	2.8E-01	14-16
	Pu-238	1.7E-01	14-16
	Pu-239/240	1.6E-01	14-16
	Pu-241	< 1.1E+00	14-16
	Am-241	1.1E-01	14-16

NOTE: (1) Data are from the 1993 RCRA facility investigation and the other Geoprobe® studies described in Section 4.

2.0 Information Provided in Attachment 1

Other information associated with the dose modeling is provided in Attachment 1. As explained in Section 5, the dose calculations were performed using RESRAD 6.4 and the results were exported to Microsoft Excel for post-processing. Attachment 1 provides:

- RESRAD input files to verify input parameters and model setup,
- RESRAD output files to verify input parameters and results,
- Excel result files containing (1) RESRAD output results (exported from the RESRAD summary report), (2) summaries of data [maximum dose-source ratios (DSRs) and times of maxima], (3) calculation of $DCGL_W$ values from the maximum DSRs, (4) calculation of area factors and $DCGL_{EMC}$ values, and (5) summary of sensitivity results

DCGL development was based on entering unit source concentrations (1pCi/g) for 18 radionuclides into RESRAD to generate DSRs in units of mrem/y per pCi/g (RESRAD output results based on unit concentrations can be interpreted as either the dose or DSR, and the terms are used interchangeably in this document). The individual, peak DSRs are then used to generate DCGLs for each radionuclide based on the following equation:

DCGL (pCi/g) = Dose Limit (mrem/y) / Maximum DSR (mrem/y per pCi/g) (Eq.1)

The dose limit of 25 mrem/y and maximum DSRs were used as the basis for developing the DCGLs. Further details regarding the Attachment 1 files are presented below. Because of the uncertainty in the actual distributions and mixtures of radionuclides in the environmental media, the DCGL for each radionuclide is calculated individually. Following characterization, the working cleanup levels for mixtures can be developed using the sum of fractions method discussed in Chapter 5 of the MARSSIM.

2.1 Input Parameters Tables

The parameters input to the RESRAD model include:

- Base case values for the $DCGL_W$ calculations,
- Modification of source area only for $DCGL_{EMC}$ calculations, and
- Variation of key parameters to evaluate model sensitivity

The Excel file "WV Sensitivity Parameters Table – Rev1.xls" (Table C.5) provides a summary of the following parameters which were varied to evaluate model sensitivity.

- Surface Soil Sources
  - Indoor/outdoor time fraction
  - Source thickness
  - Unsaturated zone thickness
  - Irrigation/well pumping rate
  - Soil/water distribution coefficients
  - Hydraulic conductivity (Vertical/Horizontal)
  - Runoff/Evapotranspiration coefficients/ Infiltration rate
  - Depth of well intake
  - Length of contaminated area parallel to aquifer flow
  - Hydraulic gradient
  - Gamma shielding factor
  - Indoor air filtration factor
  - Mass loading for dust inhalation
  - Depth of roots
  - Food transfer factors
  - Use of mass balance instead of non-dispersion groundwater model
- Subsurface Soil Sources (contaminated subsurface soil distributed on the surface not considering releases from the bottoms of the deep excavations as a continuing source to groundwater, a scenario described in Section 5.2.6):
  - Indoor/outdoor time fraction
  - Source thickness
  - Unsaturated zone thickness
  - Irrigation/well pumping rate
  - Soil/water distribution coefficients
  - Hydraulic conductivity (Vertical/Horizontal)
  - Runoff/Evapotranspiration coefficients/ Infiltration rate
  - Gamma shielding factor
  - Indoor air filtration factor
  - Mass loading for dust inhalation
  - Depth of roots
  - Food transfer factors
- Stream Bank Sediment sources:

- Outdoor time fraction
- Source thickness
- Unsaturated zone thickness
- Soil/water distribution coefficients
- Runoff/Evapotranspiration coefficients/ Infiltration rate
- Mass loading for dust inhalation
- Root depth
- Food transfer factors

These sensitivity parameters were selected based on preliminary model simulations and consideration of parameter priorities presented in Table 4.2 of NUREG-6697, Attachment B (Yu, et al. 2000). The parameters selected for analysis are discussed further below.

Sensitivity parameter values were selected to represent a reasonable range in order to provide bounds on the uncertainty in the DCGL calculations. The basis for particular parameter values are discussed below.

Indoor/Outdoor fraction – varied from 0.45/0.45 to 0.8/0.1 from the base case values of 0.66/0.25. The lower indoor fraction represents equal time indoors and outdoors, while the higher fraction was selected to represent a farmer spending inordinate amounts of time indoors.

Source thickness – for surface soil and sediment, varied from 0.5 to 3m to bound the base case value of 1m with potential thicknesses resulting from remedial activities and to account for potential source erosion uncertainty. For subsurface soil, the source volume was evaluated for three thickness/area configurations to conserve the total amount of excavated material. The source thickness/area was varied from 0.1m/300m^2 to 0.6 m/50 m^2, to bound the base case of 0.3 m/100 m^2. The subsurface source thickness is dependent on the amount of material excavated during well/cistern installation, and depths less than the base case would correspond with a smaller source area for a given excavated volume (assumed to be ~30 m^3).

Unsaturated zone thickness – varied from 1 to 5 m to bound the 2 m base case value with the range possible for the site. The range of results also provides an assessment of potential source erosion uncertainty. The sediment model assumes that there is no unsaturated zone for the stream bank.

Irrigation/well pumping rate - varied from 0.2/2720 to 0.8/8720 (m/y)/(m^3/y) to bound the base case of 0.5/5720 (m/y)/(m^3/y). The irrigation rate and well pump rate are directly related and the range reflects changes in crop irrigation only. For all cases, the assumed household and livestock water ingestion rates were held constant. This parameter is applicable to soil exposure only, not to sediment exposure

Soil/Water distribution coefficients – varied for each radionuclide based on site-specific data where available. If a range of site-specific distribution coefficients was not available (as was the case for the majority of radionuclides), values were selected from the literature to provide a bound on the base case uncertainty. The conceptual models assume the sand and gravel unit is representative of the three RESRAD zones (contaminated, unsaturated and saturated), except that in the SB and SD analyses, the contaminated zone is assumed to be represented by the Lavery till.

Hydraulic conductivity – for the contaminated and unsaturated zone, varied the vertical conductivity from 63 m/y (2.0E-04 cm/s) to 220 m/y (7.0E-03 cm/s) to bound the base case value of 140 m/y (4.4E-04 cm/s) which is the average for the sand and gravel unit divided by 10 to account for anisotropy (DEIS Appendix E, Table E-3). Similarly for the saturated zone, the horizontal conductivity was varied from 630 to 2200 m/y from the base case of 1400 m/y. The conceptual model assumes the sand and gravel unit is representative of the unsaturated and saturated zone. Values were selected to ensure that the site-specific groundwater conceptual model assumptions (that the well captures the entire width of the plume, but that there is some vertical dilution within the water table) were maintained.

Runoff/evapotranspiration coefficient – varied from 0.41/0.6 to 0.41/0.9 to bound the base case of 0.41/0.78. The base case was selected to achieve infiltration rate of 0.26m/y which corresponds to the calibrated three dimensional groundwater model used in the Decommissioning EIS (DEIS Appendix E). The upper and lower bounds are assumed values for these parameters that maintain the site-specific groundwater dilution assumptions.

Depth of well intake – applicable to non-dispersion model only (surface soil base case). Varied from 3 to 10 m to bound the base case value of 5m. The lower bound represents the minimum for a 1 m contaminated thickness and 2 m unsaturated zone. The upper bound represents the upper end of observed thickness of the saturated zone on site. The upper and lower bound values for these parameters also maintain the site-specific groundwater dilution assumptions.

Length of contaminated area parallel to aquifer flow - applicable to non-dispersion model only (surface soil base case). Varied from 50 m to 200 m to bound the base case of 165 m. Base value was selected to achieve site-specific groundwater dilution factor of 0.2. Values were selected to ensure that the site-specific groundwater conceptual model assumptions (that the well captures the entire width of the plume, but that there is some vertical dilution within the water table) were maintained.

Hydraulic gradient – applicable to non-dispersion model only (surface soil base case). Varied from 0.02 to 0.04 to bound the base case of 0.03.

Gamma shielding factor – applicable to the surface and subsurface soil models. Varied from 0.17 to 0.51 to bound base case of 0.273, representing a range of possible home construction methods.

Indoor air filtration factor – applicable to the surface and subsurface soil models. Varied from 0.4 to 0.75 to evaluate less conservative assumptions than the base case value of 1.0.

Mass loading for inhalation – applicable to all models. For the soil models, the range of 4.5E-06 to 2.5E-05 bound the base case of 1.5E-05 g/m^3. For sediment, the base case of 3.2E-06 is bounded by the range of 1E-06 to 1E-05.

Root depth – applicable to all models. Varied from 0.3 to 3.0 from the base case of 0.9 m to reflect a range of potential crops.

Food transfer factors – varied from the constituent specific base cases by increasing and decreasing each parameter an order of magnitude.

Groundwater model – the surface soil base case non-dispersion model is varied to provide results for the mass balance model for comparison. The RESRAD User's Manual suggests the non-dispersion model for areas >1,000 m^2 (Yu et al. 2001, p.E-18).

2.2 RESRAD Input Files

The following RESRAD input files are provided to allow verification of input parameters and reproduction of the output files and summary graphics:

- $DCGL_W$ input files:
  - WV Surface – 10k Base.RAD (Surface soil source of 10,000 m^2)
  - WV Subsurface – 100 Base.RAD (Subsurface material as a surface source of 100 m^2)
  - WV Sediment - 1k Base.RAD (Sediment source of 1,000 m^2)
- $DCGL_{EMC}$ input files (varying only source area from $DCGL_W$ files):
  - Surface Soil Source
    - WV Surface - 5k EMC.RAD (5,000 m^2 source)
    - WV Surface - 1k EMC.RAD (1,000 m^2 source)
    - WV Surface - 500 EMC.RAD (500 m^2 source)
    - WV Surface - 100 EMC.RAD (100 m^2 source)
    - WV Surface - 50 EMC.RAD (50 m^2 source)
    - WV Surface - 10 EMC.RAD (10 m^2 source)
    - WV Surface - 5 EMC.RAD (5 m^2 source)
    - WV Surface - 1 EMC.RAD (1 m^2 source)
  - Subsurface Source (not considering releases from the bottoms of the deep excavations as a continuing source)
    - WV Subsurface - 50 EMC.RAD (50 m^2 source)
    - WV Subsurface - 10 EMC.RAD (10 m^2 source)
    - WV Subsurface - 5 EMC.RAD (5 m^2 source)
    - WV Subsurface - 1 EMC.RAD (1 m^2 source)
  - Stream Bank Sediment Source
    - WV Sediment - 500 EMC.RAD (500 m^2 source)
    - WV Sediment - 100 EMC.RAD (100 m^2 source)

  - WV Sediment - 50 EMC.RAD (50 m^2 source)
  - WV Sediment - 10 EMC.RAD (10 m^2 source)
  - WV Sediment - 5 EMC.RAD (5 m^2 source)
  - WV Sediment - 1 EMC.RAD (1 m^2 source)

  Note: sediment source area width was maintained at 3 m when varying areas to represent assumed stream bank configuration.

- Sensitivity analysis input files:
  - Surface soil Source
    - WV Surface - SENS1.RAD (decreased indoor fraction)
    - WV Surface - SENS2.RAD (increased indoor fraction)
    - WV Surface - SENS3.RAD (decreased source layer thickness)
    - WV Surface - SENS4.RAD (increased source layer thickness)
    - WV Surface - SENS5.RAD (decreased unsaturated zone thickness)
    - WV Surface - SENS6.RAD (increased unsaturated zone thickness)
    - WV Surface - SENS7.RAD (decreased well pumping rate)
    - WV Surface - SENS8.RAD (increased well pumping rate)
    - WV Surface - SENS9.RAD (decreased K_d values)
    - WV Surface - SENS10.RAD (increased K_d values)
    - WV Surface - SENS11.RAD (decreased K_d value)
    - WV Surface - SENS12.RAD (increased K_d value)
    - WV Surface - SENS13.RAD (decreased runoff/evapotranspiration)
    - WV Surface - SENS14.RAD (increased runoff/evapotranspiration)
    - WV Surface - SENS15.RAD (decreased well intake depth)
    - WV Surface - SENS16.RAD (increased well intake depth)
    - WV Surface - SENS17.RAD (decreased length parallel to flow)
    - WV Surface - SENS18.RAD (increased length parallel to flow)
    - WV Surface – SENS19.RAD (decreased hydraulic gradient)
    - WV Surface – SENS20.RAD (increased hydraulic gradient)
    - WV Surface – SENS21.RAD (decreased gamma shielding factor)
    - WV Surface – SENS22.RAD (increased gamma shielding factor)
    - WV Surface – SENS23.RAD (decreased indoor air filtration factor)
    - WV Surface – SENS24.RAD (increased indoor air filtration factor)
    - WV Surface – SENS25.RAD (decreased mass loading factor for inhalation)

    - WV Surface – SENS26.RAD (increased mass loading factor for inhalation)
    - WV Surface – SENS27.RAD (decreased root depth)
    - WV Surface – SENS28.RAD (increased root depth)
    - WV Surface - SENS29.RAD (decreased food transfer factors)
    - WV Surface – SENS30.RAD (increased food transfer factors)
    - WV Surface - SENS31.RAD (mass balance groundwater model)
- Subsurface Soil Source (not considering releases from the bottoms of the deep excavations as a continuing source)
    - WV Subsurface - SENS1.RAD (decreased indoor fraction)
    - WV Subsurface - SENS2.RAD (increased indoor fraction)
    - WV Subsurface - SENS3.RAD (decreased source layer thickness)
    - WV Subsurface - SENS4.RAD (increased source layer thickness)
    - WV Subsurface - SENS5.RAD (decreased unsaturated zone thickness)
    - WV Subsurface - SENS6.RAD (increased unsaturated zone thickness)
    - WV Subsurface - SENS7.RAD (decreased well pumping rate)
    - WV Subsurface - SENS8.RAD (increased well pumping rate)
    - WV Subsurface - SENS9.RAD (decreased K_d values)
    - WV Subsurface - SENS10.RAD (increased K_d values)
    - WV Subsurface - SENS11.RAD (decreased K_h value)
    - WV Subsurface - SENS12.RAD (increased K_h value)
    - WV Subsurface - SENS13.RAD (decreased runoff/evapotranspiration)
    - WV Subsurface - SENS14.RAD (increased runoff/evapotranspiration)
    - WV Subsurface – SENS15.RAD (decreased gamma shielding factor)
    - WV Subsurface – SENS16.RAD (increased gamma shielding factor)
    - WV Subsurface – SENS17.RAD (decreased indoor air filtration factor)
    - WV Subsurface – SENS18.RAD (increased indoor air filtration factor)
    - WV Subsurface – SENS19.RAD (decreased mass loading factor for inhalation)
    - WV Subsurface – SENS20.RAD (increased mass loading factor for inhalation)
    - WV Subsurface – SENS21.RAD (decreased root depth)
    - WV Subsurface – SENS22.RAD (increased root depth)
    - WV Subsurface - SENS23.RAD (decreased food transfer factors)
    - WV Subsurface – SENS24.RAD (increased food transfer factors)

- Sediment Source
  - WV Sediment - SENS1.RAD (decreased outdoor fraction)
  - WV Sediment - SENS2.RAD (increased outdoor fraction)
  - WV Sediment - SENS3.RAD (decreased source layer thickness)
  - WV Sediment - SENS4.RAD (increased source layer thickness)
  - WV Sediment - SENS5.RAD (increased unsaturated zone thickness)
  - WV Sediment - SENS6.RAD (largest unsaturated zone thickness)
  - WV Sediment - SENS7.RAD (decreased K_d values)
  - WV Sediment - SENS8.RAD (increased K_d values)
  - WV Sediment – SENS9.RAD (decreased runoff/evapotranspiration)
  - WV Sediment – SENS10.RAD (increased runoff/evapotranspiration)
  - WV Sediment - SENS11.RAD (decreased root depth)
  - WV Sediment – SENS12.RAD (increased root depth)
  - WV Sediment - SENS13.RAD (decreased food transfer factors)
  - WV Sediment – SENS14.RAD (increased food transfer factors)

The dose results from the above input files were the basis for calculation of $DCGL_W$ and $DCGL_{EMC}$ values. The DCGLs were calculated in Excel spreadsheets, based on exported data from the RESRAD summary output report. The following section describes the RESRAD output files, which are provided for informational purposes.

2.3 RESRAD Output Files

The RESRAD output files are provided to allow review of results without running the simulations. For the $DCGL_W$ simulations, summary, detailed, daughter, and concentration reports are included in the QA files. The summary report is also available for the $DCGL_{EMC}$ simulations. As indicated in the previous section, DCGL calculations are based on data exported from the RESRAD summary output report. RESRAD output files generated are as follows;

- $DCGL_W$ output files:
  - Surface Soil Source
    - WV Surface – 10k Base_sum.TXT (summary report)
    - WV Surface – 10k Base_ det.TXT (detailed report)
    - WV Surface – 10k Base _dtr.TXT (daughter report)
    - WV Surface – 10k Base _conc.TXT (concentration report)
  - Subsurface Soil Source (not considering releases from the bottoms of the deep excavations as a continuing source to groundwater)
    - WV Subsurface – 100 Base_sum.TXT (summary report)
    - WV Subsurface – 100 Base_det.TXT (detailed report)

    - WV Subsurface – 100 Base_dtr.TXT (daughter report)
    - WV Subsurface – 100 Base_conc.TXT (concentration report)
  - Sediment Source
    - WV Sediment – 1k Base_sum.TXT (summary report)
    - WV Sediment – 1k Base_det.TXT (detailed report)
    - WV Sediment – 1k Base_dtr.TXT (daughter report)
    - WV Sediment – 1k Base_conc.TXT (concentration report)
- $DCGL_{EMC}$ output files (varying only source area from $DCGL_w$ files):
  - Surface Soil Source
    - WV Surface - 5k EMC_sum.TXT (5,000 m^2 source)
    - WV Surface - 1k EMC_ sum.TXT (1,000 m^2 source)
    - WV Surface - 500 EMC_sum.TXT (500 m^2 source)
    - WV Surface - 100 EMC_sum.TXT (100 m^2 source)
    - WV Surface - 50 EMC_sum.TXT (50 m^2 source)
    - WV Surface - 10 EMC_sum.TXT (10 m^2 source)
    - WV Surface - 5 EMC_sum.TXT (5 m^2 source)
    - WV Surface - 1 EMC_sum.TXT (1 m^2 source)
  - Subsurface Soil Source (excluding the bottoms of the deep excavations as a continuing source to groundwater)
    - WV Subsurface - 50 EMC_sum.TXT (50 m^2 source)
    - WV Subsurface - 10 EMC_sum.TXT (10 m^2 source)
    - WV Subsurface - 5 EMC_sum.TXT (5 m^2 source)
    - WV Subsurface - 1 EMC_sum.TXT (1 m^2 source)
  - Sediment Source
    - WV Sediment - 500 EMC_sum.TXT (500 m^2 source)
    - WV Sediment - 100 EMC_sum.TXT (100 m^2 source)
    - WV Sediment - 50 EMC_sum.TXT (50 m^2 source)
    - WV Sediment - 10 EMC_sum.TXT (10 m^2 source)
    - WV Sediment - 5 EMC_sum.TXT (5 m^2 source)
    - WV Sediment - 1 EMC_sum.TXT (1 m^2 source)
- Sensitivity analysis output files:
  - Surface Soil Source
    - WV Surface - SENS1_sum.TXT (decreased indoor fraction)

- WV Surface - SENS2_sum.TXT (increased indoor fraction)
- WV Surface - SENS3_sum.TXT (decreased source layer thickness)
- WV Surface - SENS4_sum.TXT (increased source layer thickness)
- WV Surface - SENS5_sum.TXT (decreased unsaturated zone thickness)
- WV Surface - SENS6_sum.TXT (increased unsaturated zone thickness)
- WV Surface - SENS7_sum.TXT (decreased well pumping rate)
- WV Surface - SENS8_sum.TXT (increased well pumping rate)
- WV Surface - SENS9_sum.TXT (decreased K_d values)
- WV Surface - SENS10_sum.TXT (increased K_d values)
- WV Surface - SENS11_sum.TXT (decreased K value)
- WV Surface - SENS12_sum.TXT (increased K value)
- WV Surface - SENS13_sum.TXT (decreased runoff/evapotranspiration)
- WV Surface - SENS14_sum.TXT (increased runoff/evapotranspiration)
- WV Surface - SENS15_sum.TXT (decreased well intake depth)
- WV Surface - SENS16_sum.TXT (increased well intake depth)
- WV Surface - SENS17_sum.TXT (decreased length parallel to flow)
- WV Surface - SENS18_sum.TXT (increased length parallel to flow)
- WV Surface - SENS19_sum.TXT (decreased hydraulic gradient)
- WV Surface - SENS20_sum.TXT (increased hydraulic gradient)
- WV Surface - SENS21_sum.TXT (decreased gamma shielding factor)
- WV Surface - SENS22_sum.TXT (increased gamma shielding factor)
- WV Surface - SENS23_sum.TXT (decreased indoor air filtration factor)
- WV Surface - SENS24_sum.TXT (increased indoor air filtration factor)
- WV Surface - SENS25_sum.TXT (decreased mass loading factor for inhalation)
- WV Surface - SENS26_sum.TXT (increased mass loading factor for inhalation)
- WV Surface - SENS27_sum.TXT (decreased root depth)
- WV Surface - SENS28_sum.TXT (increased root depth)
- WV Surface - SENS29_sum.TXT (decreased food transfer factors)
- WV Surface - SENS30_sum.TXT (increased food transfer factors)
- WV Surface - SENS31_sum.TXT (mass balance groundwater model)

- Subsurface Soil Source (not considering releases from the bottoms of the deep excavations as a continuing source to groundwater)

  - WV Subsurface - SENS1_sum.TXT (decreased indoor fraction)
  - WV Subsurface - SENS2_sum.TXT (increased indoor fraction)
  - WV Subsurface - SENS3_sum.TXT (decreased source layer thickness)
  - WV Subsurface - SENS4_sum.TXT (increased source layer thickness)
  - WV Subsurface - SENS5_sum.TXT (decreased unsaturated zone thickness)
  - WV Subsurface - SENS6_sum.TXT (increased unsaturated zone thickness)
  - WV Subsurface - SENS7_sum.TXT (decreased well pumping rate)
  - WV Subsurface - SENS8_sum.TXT (increased well pumping rate)
  - WV Subsurface - SENS9_sum.TXT (decreased K_d values)
  - WV Subsurface - SENS10_sum.TXT (increased K_d values)
  - WV Subsurface - SENS11_sum.TXT (decreased K value)
  - WV Subsurface - SENS12_sum.TXT (increased K value)
  - WV Subsurface - SENS13_sum.TXT (decreased runoff/evapotranspiration)
  - WV Subsurface - SENS14_sum.TXT (increased runoff/evapotranspiration)
  - WV Subsurface – SENS15.RAD (decreased gamma shielding factor)
  - WV Subsurface – SENS16.RAD (increased gamma shielding factor)
  - WV Subsurface – SENS17.RAD (decreased indoor air filtration factor)
  - WV Subsurface – SENS18.RAD (increased indoor air filtration factor)
  - WV Subsurface – SENS19.RAD (decreased mass loading factor for inhalation)
  - WV Subsurface – SENS20.RAD (increased mass loading factor for inhalation)
  - WV Subsurface – SENS21.RAD (decreased root depth)
  - WV Subsurface – SENS22.RAD (increased root depth)
  - WV Subsurface - SENS23_sum.TXT (decreased food transfer factors)
  - WV Subsurface – SENS24_sum.TXT (increased food transfer factors)

- Stream Bank Sediment Source
  - WV Sediment - SENS1_sum.TXT (decreased outdoor fraction)
  - WV Sediment - SENS2_sum.TXT (increased outdoor fraction)
  - WV Sediment - SENS3_sum.TXT (decreased source layer thickness)
  - WV Sediment - SENS4_sum.TXT (increased source layer thickness)
  - WV Sediment - SENS5_sum.TXT (increased unsaturated zone thickness)

- WV Sediment - SENS6_sum.TXT (largest unsaturated zone thickness)
- WV Sediment - SENS7_sum.TXT (decreased K_d values)
- WV Sediment - SENS8_sum.TXT (increased K_d values)
- WV Sediment – SENS9_sum.TXT (decreased runoff/evapotranspiration)
- WV Sediment – SENS10_sum.TXT (increased runoff/evapotranspiration)
- WV Sediment - SENS11_sum.TXT (decreased root depth)
- WV Sediment – SENS12_sum.TXT (increased root depth)
- WV Sediment - SENS13_sum.TXT (decreased food transfer factors)
- WV Sediment – SENS14_sum.TXT (increased food transfer factors)

The following section presents the methods used to generate DCGLs from the RESRAD model output previously described.

2.4 Excel Result Files

The outputs of the RESRAD simulations (the DSR for each of the radionuclides at various future times) were exported to Excel from the RESRAD summary output report (specifically, the DSR values in the table presented at the bottom of page 45 of each RESRAD summary report). For each simulation, dose results were exported for each of the 18 radionuclides, which includes the simulation year and dose (for that year) for each radionuclide. These have been generated for $DCGL_W$, $DCGL_{EMC}$, and sensitivity simulations for each source media and isotope. The peak dose for each radionuclide is identified and used as the basis for the DCGL calculation as follows;

$$DCGL_w = \text{Dose Limit / Peak radionuclide DSR} \quad \text{(Eq.2)}$$

Specific Excel result files are described below.

2.4.1 Surface Soil DCGLs

Surface soil DCGLs were calculated to conform with the annual dose limit for large areas ($DCGL_W$), smaller areas of elevated concentrations ($DCGL_{EMC}$), and to evaluate the sensitivity of the model to variations in specific parameters. The files associated with these calculations are described below.

Surface Soil $DCGL_W$ Values

The soil $DCGL_W$ values were calculated based on resident farmer exposure for a 10,000 m^2 source area and results from the RESRAD summary output report are presented in the Excel file "WVDP Surface DCGLs_Rev1.XLS" in the sheet "Base" (Table C-6). The input files for the surface soil evaluation are presented in Section 2.2. These surface soil $DCGL_W$ values are the basis for calculation of surface soil area factors and $DCGL_{EMC}$ values.

Surface Soil $DCGL_{EMC}$ Values

The $DCGL_W$ values calculated on the Excel summary sheet previously discussed serve as the base case for subsequent $DCGL_{EMC}$ development; $DCGL_{EMC}$ values are based on varying the source area from the 10,000 m^2 value used for the $DCGL_W$ as discussed in Chapter 5 of the MARSSIM. The Excel file "WV Surface DCGLs_Rev1.XLS" has sheets for each of the source areas used to generate the $DCGL_{EMC}$ (Tables C-7 to C-14). The sheet "Summary" in the Excel file "WV Surface DCGLs_Rev1.XLS" summarizes the $DCGL_{EMC}$ (Table C-15) and Soil Area Factors (TableC-16) for each of the 18 radionuclides and selected source areas (ranging from 1 to 10,000 m^2).

Surface Soil $DCGL_W$ Sensitivity Analysis

The surface soil $DCGL_W$ sensitivity to key parameters was assessed by varying the input values for specific parameters and tabulating the results. The Excel file "WV Surface DCGL Sensitivity_Rev1.XLS" contains the DSRs and DCGLs for each of 18 radionuclides from the RESRAD summary report output for each of the sensitivity simulations. Results of each run are in sheets SENS1 through SENS31 (Tables C-17 to C-47). Also included in the file are a summarization of the calculated DCGLs (Table C-48) and a summary of the percent change from the base case (Table C-49) for each of the sensitivity runs (also presented in Table 5-9). Table C-50 below presents a summary of the surface soil sensitivity results.

Table C-50 Summary of Surface Soil DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
Indoor/Outdoor Fraction	1	-32%	-22%	U-232	0%	Cm-244
	2	21%	0%	C-14 I-129 Np-237 Tc-99 U-234	28%	U-232
Source Thickness	3	-50%	9%	U-232	231%	C-14
	4	200%	-57%	C-14	0%	Am-241 Cm-243 Cm-244 Cs-137 Pu-239 Pu-240
Unsaturated Zone Thickness	5	-50%	-10%	Tc-99	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232
	6	150%	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232	12%	U-235
Irrigation/Pump Rate	7	-57%	-1%	U-232	65%	I-129
	8	70%	-36%	I-129	1%	U-232
Soil/Water Distribution Coefficients (Kd)	9	lower	-99%	Pu-239	2%	C-14
	10	higher	-3%	U-232	867%	U-234
Hydraulic Conductivity	11	-55%	-36%	I-129	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137

Table C-50 Summary of Surface Soil DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
(K_h)						Pu-238 Pu-239 Pu-240 Sr-90 U-232
	12	57%	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232	40%	I-129
Runoff/Evaporation Coefficient	13	-23%	-29%	U-234	2%	U-232
	14	15%	-2%	U-232	81%	Np-237
Depth of Well Intake	15	-40%	-40%	I-129	0.0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232
	16	100%	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232	99%	I-129
Length Parallel to Aquifer Flow	17	-30%	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232	30%	I-129
	18	21%	-12%	I-129	0.0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Pu-241 Sr-90 U-232
Hydraulic Gradient	19	-33%	-23%	I-129	0.0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232
	20	33%	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232	23%	I-129

Table C-50 Summary of Surface Soil DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
Gamma Shielding Factor	21	-38%	0%	no change	0.0%	no change
	22	87%	-24%	U-232	0.0%	Np-237
Indoor Dust Filtration Factor	23	-60%	0%	C-14 Cs-137 I-129 Np-237 Sr-90 Tc-99 U-234	0.6%	Cm-244
	24	-25%	0%	C-14 Cs-137 I-129 Np-237 Sr-90 Tc-99 U-233 U-234	0.3%	Pu-241
Dust Loading Factor	25	-70%	0%	C-14 Cs-137 I-129 Np-237 Sr-90 Tc-99 U-234	1.0%	Cm-244
	26	67%	-1%	Cm-244	0.0%	C-14 Cs-137 I-129 Sr-90 Tc-99 U-235 U-238
Root Depth	27	-67%	0%	no change	0.0%	no change
	28	233%	0%	I-129	200%	C-14
Food Transfer Factors	29	lower	-38%	U-235	875%	Sr-90
	30	higher	-97%	Sr-90	-14%	Np-237
Mass Balance Model	31	NA	-67%	U-234	0.0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Sr-90 U-232

2.4.2 Subsurface Soil (Lavery till excavated to surface) DCGLs

To evaluate an excavation that would expose the resident farmer to subsurface material, DCGLs were developed to address this potential future source. It is possible that a farmer may install a cistern or well to access groundwater, and in the excavation process, contaminated Lavery till material from the subsurface may be spread on the ground surface and be a source of exposure. The following subsections discuss the files associated with this calculation. Note that a separate analysis was conducted to evaluate the Lavery till at the bottom of the deep excavations as a continuing source to groundwater, as presented in Attachment 3.

Subsurface Soil $DCGL_W$ Values

The subsurface $DCGL_w$ values are presented in the Excel file "WV Subsurface DCGLs_Rev1.XLS" in the sheet "Base" (TableC-51), and are based on the RESRAD input file "WV Subsurface – 100 Base.RAD" and results from page 45 of the RESRAD summary output report "WV Subsurface – 100 Base.TXT".

For calculation of the distributed soil, $DCGL_W$ values for a 100 m^2 source area of Lavery till on the surface were increased by a factor of 10 to account for an assumed blending of residually contaminated till with clean overlying soil in the excavation process (assuming 0.5 m of till for each 5 m of total excavation). This factor is applied to the final RESRAD generated DCGLw as presented in the overall summary table (See "DCGL Summary" section).

The input files for the subsurface soil evaluation are discussed in Section 2.2. These Lavery Till $DCGL_W$ values are used as the basis for calculation of the subsurface soil $DCGL_{EMC}$ values and for sensitivity analysis as described below.

Subsurface Soil $DCGL_{EMC}$ Values

Calculation of $DCGL_{EMC}$ values for the subsurface Lavery till was based on the base case area of 100 m^2 used for development of the $DCGL_W$ values (after accounting for blending). The $DCGL_{EMC}$ values were generated by varying the source area. The RESRAD output for these simulations are presented and summarized in the Excel file "WV Subsurface DCGLs_Rev1.XLS". The results for each source area are presented in individual sheets (Tables C-52 to C-55). The sheet "Summary" presents the $DCGL_{EMC}$ values (Table C-56) and subsurface soil area factors (Table C-57) for each of the 18 radionuclides and selected source areas (ranging from 1 to 100 m^2).

Subsurface Soil Sensitivity Analysis

The subsurface soil $DCGL_W$ sensitivity to key parameters was assessed by varying the input values for specific parameters and tabulating the results. The Excel file "WV Subsurface DCGL Sensitivity_Rev1.XLS" contains the DSRs and DCGLs for each of 18 radionuclides from the RESRAD summary report output for each of the sensitivity simulations. Results of each run are in sheets SENS1 through SENS24 (Tables C-58 to C-81). Also included in the file is a summarization of the calculated DCGLs (Table C-82) and a summary of the percent change from the base case (Table C-83) for each of the sensitivity runs (also presented in Table 5-10). Table C-84 below presents a summary of the subsurface soil sensitivity results.

Table C-84 Summary of Subsurface Soil DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
Indoor/Outdoor Fraction	1	-32%	-25%	Cs-137	0.5%	Pu-238
	2	21%	0%	C-14	35%	U-232
Source Thickness	3	-67%	-65%	U-238	204%	Tc-99
	4	233%	-33%	C-14	98%	U-234
Unsaturated	5	-50%	-2%	Np-237	58%	U-238

Table C-84 Summary of Subsurface Soil DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
Zone Thickness	6	150%	0%	Am-241 C-14 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240 Pu-241 Sr-90 Tc-99 U-232 U-235	2218%	U-234
Irrigation/Pump Rate	7	-57%	-39%	I-129	57%	U-238
	8	70%	0%	Am-241 Cm-243 Cm-244 Pu-238 Pu-239 Pu-240	20%	I-129
Soil/Water Distribution Coefficients (Kd)	9	lower	-99%	Pu-239	116%	U-232
	10	higher	-20%	U-232	2168%	U-234
Hydraulic Conductivity (K_h)	11	-55%	0%	No change	0%	No change
	12	57%	0%	No change	0%	No change
Runoff/Evaporation Coefficient	13	-23%	-44%	U-234	61%	U-238
	14	15%	-11%	U-232	117%	U-234
Indoor Gamma Shielding Factor	15	-38%	0%	U-238	19%	U-232
	16	87%	-27%	Cs-137	1%	U-238
Indoor Dust Filtration Factor	17	-60%	0%	U-238	13%	Cm-244
	18	-25%	0%	C-14 Cs-137 I-129 Np-237 Sr-90 Tc-99 U-233 U-234 U-238	5%	Cm-244
Inhalation Dust Loading	19	-70%	0%	U-238	22%	Cm-244
	20	67%	-15%	Cm-244	0%	C-14 Cs-137 I-129 Np-237 Sr-90 Tc-99
Root Depth	21	-67%	-67%	Tc-99	1%	U-233
	22	233%	0%	U-238	227%	Tc-99
Food Transfer Factors	23	lower	-0.1%	U-238	582%	Tc-99
	24	higher	-93%	Sr-90	0%	U-234

2.4.3 Streambed Sediment DCGLs

DCGLs were also developed to account for potential exposure associated with stream bank sediment (including direct pathways, fish ingestion, and venison ingestion). The stream bank rather than the streambed was the focus of the analysis because the recreationist is assumed to be in direct contact with the stream bank, and not the stream bed.

Files associated with the calculations are discussed below and presented in the files attachment.

Streambed Sediment $DCGL_W$ Values

The sediment $DCGL_W$ values were calculated based on a recreationist exposure for a 1,000 m^2 source area and results from the RESRAD summary output report are presented in the Excel file "WVDP Surface DCGLs_Rev1.XLS" in the sheet "Base" (Table C-85). The input files for the sediment evaluation are discussed in Section 2.2. These sediment $DCGL_W$ values are the basis for calculation of Sediment Area Factors and $DCGL_{EMC}$ values.

Streambed Sediment $DCGL_{EMC}$ Values

The $DCGL_W$ values calculated on the Excel summary sheet previously discussed serve as the base case for subsequent $DCGL_{EMC}$ development, which are based on varying the source area from the 1,000 m^2 value used for the $DCGL_W$ values. The RESRAD output for these simulations are presented and summarized in the Excel file "WV Sediment DCGLs_Rev1.XLS". The results for each source area are presented in individual sheets (Tables C-86 to C-91). The sheet "Summary" presents the $DCGL_{EMC}$ values (Table C-92) and sediment area factors (Table C-93) the 18 radionuclides and selected source areas (ranging from 1 to 1,000 m^2).

Streambed Sediment Sensitivity Analysis

The sediment $DCGL_W$ sensitivity to key parameters was assessed by varying the input values and tabulating the results. The Excel file "WV Sediment DCGL Sensitivity_Rev1.XLS" contains the RESRAD summary report output for each of the sensitivity simulations. Results of each run are in sheets SENS1 through SENS14 (Tables C-94 to C-107). Also included in the file is a summarization of the calculated DCGLs (Table C-108) and percent change from the base case (Table C-109) for each of the sensitivity runs (also presented in Table 5-11). Table C-110 below presents a summary of the sediment sensitivity analysis.

Table C-110 Summary of Sediment DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
Outdoor Fraction	1	-50%	0%	C-14	98%	Cm-243
	2	100%	-50%	Cm-243	0%	C-14
Source Thickness	3	-50%	0%	Am-241 Cm-243	157%	C-14
	4	200%	-52%	C-14	0%	Am-241 Cm-243 Cm-244 Pu-238 Pu-

Table C-110 Summary of Sediment DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum		Maximum	
			Change	Nuclide(s)	Change	Nuclide(s)
						239 Pu-240
Soil/Water Distribution Coefficients (Kd)	5	lower	-91%	Pu-239	26%	U-232
	6	higher	-65%	U-233	52%	U-234
Runoff/Evaporation Coefficient	7	-23%	0%	Am-241 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240	4%	U-232
	8	15%	-3%	I-129	0%	Am-241 Cm-243 Cm-244 Cs-137 Pu-238 Pu-239 Pu-240
Mass Loading for Inhalation	9	-70%	0%	Np-237	1%	Cm-244
	10	67%	-4%	Cm-244	0%	C-14 Cs-137 I-129 Sr-90
Root Depth	11	-67%	0%	no change	0%	no change
	12	233%	0%	Cm-243 U-232 U-235	50%	Sr-90
Food Transfer Factors	13	lower	1%	Cm-243	852%	Sr-90
	14	higher	-98%	Sr-90	-11%	Cm-243

Consideration of Subsurface Lavery till as a Continuing Source to Groundwater

An evaluation of the potential for the Lavery till to act as a continuing source to groundwater was conducted and is presented in Attachment 3 (see also Section 3.7, Table 3-19, and Section 5.2.6 of the body of the plan). The results presented below are based on the deterministic evaluations that did not include the Lavery till as a continuing source.

DCGL Summary

The Excel File "WV DCGL Summary Tables_Rev1.xls" (Table C-111) summarizes the DCGLs for the surface soil, subsurface soil and sediment, and presents $DCGL_W$ and $DCGL_{EMC}$ for a 1 m^2 area (also presented in Table 5-8).

Integrated Dose Assessment

In order to account for potential exposure to multiple sources, a combined dose assessment was conducted. The assessment considered which combination of exposures was likely, and concluded that the resident farmer may also spend time in recreation along the stream bank.

The Excel File "WV DCGL Summary Tables_Rev1.xls" presents the calculated $DCGL_W$ and $DCGL_{EMC}$ values when considering the combined doses from surface soil (90% x 25 mrem/y = 22.5 mrem/y) and sediment sources (10% x 25 mrem/y = 2.5 mrem/y), which are summarized in Tables C-112, C-113, and C-114 (also presented in Table 5-13). In the same Excel file, Table C-115 presents the cleanup goals to be used as the criteria for the proposed remediation activities. Values in Table C-115 represent the $DCGL_W$ and $DCGL_{EMC}$ values for surface soil and sediment (considering the combined dose), as well as cleanup goals for subsurface soil (which are 50% of the $DCGL_W$ and $DCGL_{EMC}$ values adjusted to provide a margin of confidence/safety factor for excavation success for each radionuclide (also presented in Table 5-12).

Evaluation of Institutional Control Period

After Phase 1 proposed remediation there is assumed to be a 30 year period of institutional controls (associated with storage of the HLW canisters until 2041), prior to site access by the critical receptors. During this period, radionuclide inventories will be subject to decay and leaching, which will result in site concentrations at the time of exposure that are reduced from the initial concentrations left at the time of proposed remediation. With the exception of Sr-90 and Cs-137, DCGLs were developed neglecting the effects of decay and leaching from the source during the 30 year institutional control period. The ratio of the initial concentrations in soil to the RESRAD generated soil concentration after a 30 year simulation was used to provide an evaluation of uncertainty associated with the assumption of neglecting decay/leaching. A RESRAD simulation was run using the surface soil base case without irrigation, well pumping, or plant/animal/human uptake from soil (see RESRAD input file "WV SURFACE – 10k – LCH_DCAY.RAD" and output file "WV SURFACE – 10k – LCH_DCAY_sum.txt". The RESRAD concentration output summary file (see page 8 of the file "WV SURFACE – 10k – LCH_DCAY_conc.txt") provides the soil concentration at year 30, which is then related to the initial soil concentration to quantify the effects of leaching/decay (see Excel file "WV Institutional Control.xls" Table C-116).

Evaluation of Potential Dose Drivers and Sensitivity Parameters

The impact of specific sensitivity parameters is dependent on the radionuclides that contribute the majority of the dose to the receptor. Due to limited site data, a full evaluation cannot be performed until additional site characterization data is available. In the interim, Table C-117 presented below identifies the primary dose pathways for each radionuclide and indicates which of the sensitivity parameters have significant impact on the dose. This evaluation would be refined as additional site data are collected.

Table C-117 Summary of Primary Dose Pathways

Nuclide	Primary Pathway for Dose	Key Parameters(1)	Year of Peak Dose
		Surface Soil	
Am-241	Water independent (plant uptake)	plant transfer factors, source thickness	0.00E+00
C-14	Water independent (plant uptake)	source thickness	0.00E+00
Cm-243	External Exposure, Water independent (plant uptake)	plant transfer factors, source thickness	0.00E+00

Table C-117 Summary of Primary Dose Pathways

Nuclide	Primary Pathway for Dose	Key Parameters[(1)]	Year of Peak Dose
Cm-244	Water independent (plant uptake)	plant transfer factors, source thickness	0.00E+00
Cs-137	External Exposure	outdoor fraction, plant transfer factors	0.00E+00
I-129	Water dependent (water ingestion, plant and milk uptake)	K, Kd, runoff/evap coefficients, well intake depth, groundwater model	9.21E+00
Np-237	Water dependent (water ingestion, plant uptake)	hydraulic conductivity, Kd, runoff/evap coefficients, well intake depth, groundwater model	2.01E+01
Pu-238	Water independent (plant uptake)	Kd, plant transfer factors	0.00E+00
Pu-239	Water independent (plant uptake)	Kd, plant transfer factors	0.00E+00
Pu-240	Water independent (plant uptake)	Kd, plant transfer factors	0.00E+00
Pu-241	Water independent (plant uptake)	Kd, plant transfer factors	5.52E+01
Sr-90	Water independent (plant uptake)	source thickness, plant transfer factors, Kd, groundwater model	0.00E+00
Tc-99	Water dependent (water ingestion, plant uptake), independent (plant uptake)	source thickness, well intake depth, plant transfer factors, length parallel to flow, Kd, K, groundwater model	1.54E+00
U-232	External Exposure	outdoor fraction, plant transfer factors	8.17E+00
U-233	Water dependent (water ingestion, plant uptake)	irrigation/pump rate, Kd, runoff/evap coefficients, groundwater model	2.96E+02
U-234	Water dependent (water ingestion, plant uptake)	irrigation/pump rate, Kd, runoff/evap coefficients, groundwater model	2.96E+02
U-235	Water dependent (water ingestion, plant uptake)	irrigation/pump rate, Kd, runoff/evap coefficients, groundwater model	2.96E+02
U-238	Water dependent (water ingestion, plant uptake)	irrigation/pump rate, Kd, runoff/evap coefficients, groundwater model	2.96E+02
Subsurface Soil			
Am-241	External Exposure, Water independent (plant uptake)	source thickness, plant transfer factors	0.00E+00
C-14	Water independent (plant uptake)	source thickness	0.00E+00
Cm-243	External Exposure	outdoor fraction, source thickness	0.00E+00
Cm-244	Water independent (plant uptake)	source thickness, plant transfer factors	0.00E+00
Cs-137	External Exposure	outdoor fraction, source thickness	0.00E+00
I-129	Water dependent (water ingestion)	source thickness, irrigation/pump rate, Kd, runoff/evap coefficients	6.32E+00
Np-237	Water independent (soil ingestion, plant uptake)	source thickness, Kd, runoff/evap coefficients	1.37E+01
Pu-238	Water independent (plant uptake, soil ingestion and inhalation)	source thickness, Kd, plant transfer factors	0.00E+00
Pu-239	Water independent (plant uptake, soil	source thickness, Kd, plant transfer factors	0.00E+00

Table C-117 Summary of Primary Dose Pathways

Nuclide	Primary Pathway for Dose	Key Parameters[1]	Year of Peak Dose
	ingestion and inhalation)		
Pu-240	Water independent (plant uptake, soil ingestion and inhalation)	source thickness, Kd, plant transfer factors	0.00E+00
Pu-241	Water independent (plant uptake)	source thickness, Kd, plant transfer factors	6.14E+01
Sr-90	Water independent (plant uptake)	source thickness, Kd, plant transfer factors	0.00E+00
Tc-99	Water dependent (plant uptake)	source thickness, plant transfer factors	0.00E+00
U-232	External Exposure	outdoor fraction, source thickness	4.60E+00
U-233	Water dependent (water ingestion)	Kd, runoff/evap coefficients	1.97E+02
U-234	Water dependent (water ingestion)	Kd, runoff/evap coefficients	1.97E+02
U-235	External Exposure	outdoor fraction, source thickness, Kd	0.00E+00
U-238	Water dependent (water ingestion)	source thickness, irrigation/pump rate, Kd, runoff/evap coefficients, groundwater model	1.98E+02
Sediment			
Am-241	External Exposure, Soil ingestion, Water independent (meat uptake)	outdoor fraction	0.00E+00
C-14	Water independent (meat uptake), Water dependent (fish uptake)	source thickness, unsaturated thickness, Kd	0.00E+00
Cm-243	External Exposure	outdoor fraction	0.00E+00
Cm-244	Soil ingestion	outdoor fraction	0.00E+00
Cs-137	External Exposure	outdoor fraction	0.00E+00
I-129	Water independent (meat uptake), Water dependent (fish uptake)	unsaturated thickness, Kd, fish transfer factors	0.00E+00
Np-237	External Exposure, Water independent (meat uptake), Water dependent (fish uptake)	unsaturated thickness, Kd, fish transfer factors	0.00E+00
Pu-238	Water independent (meat uptake), Soil ingestion	outdoor fraction, Kd	0.00E+00
Pu-239	Water independent (meat uptake), Soil ingestion	outdoor fraction, Kd	2.82E-01
Pu-240	Water independent (meat uptake), Soil ingestion	outdoor fraction, Kd	1.18E-01
Pu-241	External Exposure, Water independent (meat uptake), Soil ingestion	outdoor fraction, Kd	5.78E+01
Sr-90	Water independent (meat uptake)	plant and fish transfer factors	0.00E+00
Tc-99	Water independent (meat uptake)	Kd, plant and fish transfer factors	0.00E+00
U-232	External Exposure	outdoor fraction, Kd	7.72E+00
U-233	External Exposure, Water independent (meat uptake), Water dependent (fish uptake)	outdoor fraction, unsaturated thickness, Kd, plant and fish transfer factors	1.56E-01

Table C-117 Summary of Primary Dose Pathways

Nuclide	Primary Pathway for Dose	Key Parameters(1)	Year of Peak Dose
U-234	Water independent (meat uptake), Water dependent (fish uptake)	outdoor fraction, unsaturated thickness, Kd, fish transfer factors	1.81E-01
U-235	External Exposure	outdoor fraction	0.00E+00
U-238	External Exposure	outdoor fraction, fish transfer factors	0.00E+00

NOTE: (1) Key parameters identified in sensitivity runs. As additional site characterization data becomes available, the radionuclides driving dose and parameters most critical to calculating dose can be used to refine the sensitivity analysis.

3.0 References

Beyeler, et al. 1999, *Residual Radioactivity from Decommissioning, Parameter Analysis*, NUREG/CR-5512, Vol 3, Draft Report for Comment. Beyeler, W. E., W. A. Hareland, F. A. Duran, T. J. Brown, E. Kalinina, D. P. Gallegos, and P. A. Davis, Sandia National Laboratories, Albuquerque, New Mexico, October 1999.

Dames and Moore, 1995a, *Testing and Characterization of Glacial Deposits: Geochemical and Radionuclide Adsorption Data*, Project 10805-953-8251. Dames and Moore, Orchard Park, New York, June 26, 1995.

Dames and Moore, 1995b, *Investigation of Strontium Behavior in the Surficial Sand and Gravel-Groundwater System*, Project 10805-953-8251. Dames and Moore, Orchard Park, New York, June 9, 1995.

EPA 1997, *Exposure Factors Handbook*. National Center for Environmental Assessment, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D.C., 1997.

NRC 1997, *Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities; Final Policy Statement*. NUREG-1496, Vol. 1. U.S. Nuclear Regulatory Commission, Office of Regulatory Research, Division of Regulatory Applications, Washington, D.C., July 1997.

Sheppard and Thibault 1990, "Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium," Sheppard, M.I., and D.H. Thibault, *Health Physics*, 59:471-482, 1990.

Sheppard, et. al., 2006, "Revision and meta-analysis of selected biosphere parameter values for chlorine, iodine, neptunium, radium, radon, and uranium", Journal of Environmental Radioactivity, 89:115-137, 2006.

Yu, et al. 1993, *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil*. Yu, C., et al., Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Illinois, April 1993.

Yu, et al. 2000, *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, NUREG/CR-6697, ANL/EAD/TM-98. Yu, C., et al., Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois, November 2000.

Yu, et al. 2001, *User's Manual for RESRAD Version 6*, ANL/EAD-4. Yu, C., et al., Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois, July 2001.

WVNSCO 1993a, *Environmental Information Document, Volume I, Geology*, WVDP-EIS-004, Rev. 0. West Valley Nuclear Services Company, West Valley, New York, 1993.

WVNSCO 1993b, *Environmental Information Document, Volume III, Hydrology: Part 4, Groundwater Hydrology and Geochemistry*, WVDP-EIS-009, Rev. 0. West Valley Nuclear Services Company, West Valley, New York, 1993.

WVNSCO 1993c, *Environmental Information Document, Volume III, Hydrology: Part 5, Vadose Zone Hydrology*, WVDP-EIS-009, Rev. 0. West Valley Nuclear Services Company, West Valley, New York, 1993.

WVNSCO 1993d, *Environmental Information Document, Volume VIII, Air Resources: Part 2, Meteorology*, WVDP-EIS-014, Rev. 0. West Valley Nuclear Services Company, West Valley, New York, 1993.

Attachments

1. Electronic Files Described in Section 2 (provided separately)
2. Electronic File Described in Section 1 (provided separately)
3. Electronic Files for Multisource Analysis of Lavery till as a continuing source.

RAI 5C15 (20)

Subject: Conservatism in model input parameters

RAI: DOE did not provide sufficient support that the selection of parameter values in the deterministic analysis is sufficiently conservative to demonstrate compliance with LTR criteria. (Section 5.2.4)

Basis: When performing deterministic analysis to demonstrate compliance with radiological criteria for license termination it is important to demonstrate that the selection of parameter values does not lead to a significant under-prediction of the potential risk to the average member of the critical group for a 1000 year compliance period. Due to the large number of radionuclides and limited characterization, it is difficult to select a global parameter set that is demonstrably conservative for the actual mix of radionuclides expected to remain at the site following remediation. For example, if water-dependent pathways dominate the dose, then distribution coefficients (K_ds) on the low end of the distribution (lower quartile) may be conservative. But, if water-independent pathways dominate the dose, then K_ds on the high end of the distribution (upper quartile) may be conservative. Several important parameter values were identified in the sensitivity analysis (e.g., distribution coefficients, various parameters/model affecting groundwater dilution, bioaccumulation factors); however, DOE did not evaluate the sensitivity of the results to all parameter values and it is not clear how DOE made changes to its selection of parameter values to ensure that the deterministic analysis is sufficiently conservative.

Path Forward: DOE should provide support that the selection of parameter values in the deterministic analysis does not significantly under-predict the potential risk associated with residual material remaining at the site following remediation. Using what limited characterization data is available, DOE should identify the key risk drivers and indicate how the parameter selection is conservative for these radionuclides. In the absence of sufficient information on radionuclide distributions, DOE should consider use of pathway- or radionuclide-dependent parameter sets that would tend to over-estimate rather than under-estimate the potential dose when considering the potential uncertainty associated with the dose calculations.

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DOE Response: The DOE letter that forwarded Revision 0 of the DP to NRC for review (DOE 2008) noted that the issue regarding the sufficiency of conservatism in conceptual model input parameters was still under evaluation when Revision 0 was completed. To address this issue, DOE has performed probabilistic uncertainty analyses to evaluate the degree of conservatism in key input parameters for the conceptual models used in developing DCGLs for surface soil, subsurface soil, and streambed sediment. DOE has also changed some of the input parameters in the conceptual models.

Input Parameter Changes and the Effects on the Deterministic Model Results

The input parameter changes apply to both the deterministic models and the probabilistic analyses. These parameter changes and the reasons for them are identified in the response to RAI 5C12, which provides a revised version of Appendix C.

The results of these changes on the deterministic DCGLs were as follows:

- The revised deterministic surface soil DCGLs were generally slightly lower than the original DCGLs, as indicated in the response to RAI 5C4;

- The revised subsurface soil DCGLs were generally slightly higher than the original DCGLs, as indicated in the response to RAI 5C6; and
- The streambed sediment DCGLs were essentially the same as before, as indicated in the response to RAI 5C12.

Note that the multi-source evaluation for subsurface soil DCGLs described in the updated response to RAI 5C9 produced generally lower DCGLs as discussed below.

Probabilistic Uncertainty Analyses

The probabilistic uncertainty analyses supplement the deterministic sensitivity analyses described in Section 5 of the DP. These analyses generated results that quantify the total uncertainty in the DCGLs resulting from the variability of key input parameters, and also provide perspective regarding the relative importance of the contributions of different input parameters to the total uncertainty in the DCGLs. Note that probabilistic evaluation of the multi-source model was not practical due to the complexities of such an analysis considering the need to integrate the probabilistic analytic capabilities of RESRAD with the FORTRAN program used to develop the DCGLs.

These analyses thereby provide additional perspective on the relationships between conceptual model input parameters and estimated dose, along with sets of DCGLs expressed in probabilistic terms. This information supports a risk-informed approach to establishing cleanup goals for Phase 1 of the decommissioning.

The analyses were performed using the probabilistic modules of RESRAD version 6.4, which utilize Latin hypercube sampling, a modified Monte Carlo method, allowing for the generation of representative input parameter values from all segments of the input distributions. Input variables for the models were selected randomly from probability distribution functions for each parameter of interest. A new appendix was prepared for the DP to provide details of the analyses; a copy of this appendix is provided below following a description of the other changes being made to the DP as a result of the analyses.

Table 5C15-1 identifies the input parameters treated in a probabilistic manner during the analyses and the distribution used for each parameter.

Table 5C15-1. Probabilistic Parameter Distributions

Parameter	Distribution	Conceptual Model		
		Surface	Subsurface	Streambed Sediment
Contamination zone thickness	triangular	√		
Length parallel to aquifer flow	triangular	√		
Saturated zone hydraulic conductivity	triangular	√		
Well pumping rate	bounded normal	√	√	
Irrigation rate	bounded normal	√	√	
Indoor time fraction	triangular	√	√	
Outdoor time fraction	triangular	√	√	√

Table 5C15-1. Probabilistic Parameter Distributions

Parameter	Distribution	Conceptual Model		
Unsaturated zone hydraulic conductivity	triangular	√		
Contaminated zone hydraulic conductivity	triangular	√		√
Root depth	uniform	√	√	
Precipitation rate	bounded normal	√	√	√
External gamma shielding factor(1)	triangular	√	√	
Biotransfer factors (plant/meat/milk)	triangular	√	√	√(2)
Kd values for each zone	bounded lognormal	√	√	√

NOTES: (1) Cs-137 and U-232 only.
(2) Fish transfer factor applies to the sediment model, but not milk transfer factor.

Table 5C15-2 summarizes the results of the analyses.

Table 5C15-2. Summary of Results of Probabilistic Uncertainty Analyses(1)

Nuclide	Surface Soil DCGLs (pCi/g)		Subsurface Soil DCGLs (pCi/g)		Streambed Sediment DCGLs (pCi/g)	
	Determ(2)	Peak-of-the-Mean(3)	Limiting Determ(4)	Peak-of-the-Mean(3)	Determ(5)	Peak-of-the-Mean(3)
Am-241	4.3E+01	2.9E+01	7.1E+03	6.8E+03	1.6E+04	1.0E+04
C-14	2.0E+01	1.6E+01	3.7E+05	7.2E+05	3.4E+03	1.8E+03
Cm-243	4.1E+01	3.5E+01	1.2E+03	1.1E+03	3.6E+03	3.1E+03
Cm-244	8.2E+01	6.5E+01	2.3E+04	2.2E+04	4.8E+04	3.8E+04
Cs-137(6)	2.4E+01	1.5E+01	4.4E+02	3.0E+02	1.3E+03	1.0E+03
I-129	3.5E-01	3.3E-01	5.2E+01	6.7E+02	3.7E+03	7.9E+02
Np-237	9.5E-02	2.6E-01	4.3E+00	9.3E+01	5.2E+02	3.3E+02
Pu-238	5.0E+01	4.0E+01	1.5E+04	1.4E+04	2.0E+04	1.2E+04
Pu-239	4.5E+01	2.5E+01	1.3E+04	1.2E+04	1.8E+04	1.2E+04
Pu-240	4.5E+01	2.6E+01	1.3E+04	1.2E+04	1.8E+04	1.2E+04
Pu-241	1.4E+03	1.2E+03	2.4E+05	2.5E+05	5.1E+05	3.4E+05
Sr-90(6)	6.4E+00	4.1E+00	3.2E+03	3.4E+03	9.5E+03	4.7E+03
Tc-99	2.6E+01	2.1E+01	1.1E+04	1.4E+04	2.2E+06	6.6E+05
U-232	5.9E+00	1.5E+00	1.0E+02	7.4E+01	2.6E+02	2.2E+02
U-233	1.9E+01	8.3E+00	1.9E+02	9.9E+03	5.7E+04	2.2E+04
U-234	2.0E+01	8.5E+00	2.0E+02	1.3E+04	6.0E+04	2.2E+04
U-235	1.9E+01	3.5E+00	2.1E+02	9.3E+02	2.9E+03	2.3E+03
U-238	2.1E+01	9.8E+00	2.1E+02	4.6E+03	1.2E+04	8.2E+03

NOTES: (1) Values shown in green are lower of the pair.
(2) Revised deterministic DCGLs based on parameter changes described in RAI 5C12.
(3) Probabilistic peak-of-the-mean DCGLs bases on analyses described in the new Appendix E.

(4) These values are the limiting DCGLs for subsurface soil from the penultimate column of Table 5C18-3 in the response to RAI 5C18. The subsurface soil peak-of-the-mean DCGLs and the multi-source deterministic DCGLs are not directly comparable because of conceptual model differences, i.e., the releases from the bottom of the deep excavations not being accounted for in the probabilistic analysis. However, Table 5C9-2 in the updated response to RAI 5C9 compares the multi-source analysis DCGLs to all other sets of subsurface soil DCGLs for information purposes.

(5) These are the revised DCGLs based on parameter changes described in RAI 5C12.

(6) These values reflect 30 years decay.

Table 5C15-2 shows that:

- For surface soil, the peak-of-the-mean probabilistic DCGLs are lower than the revised deterministic DCGLs for all radionuclides except Np-237.
- For subsurface soil, the limiting deterministic analysis results are more limiting than the peak-of-the-mean DCGLs for eight of the 18 radionuclides; and
- For streambed sediment, the peak-of-the-mean DCGLs are more limiting than the revised deterministic DCGLs.

For most radionuclides, the 95th percentile probabilistic DCGLs are lower than the peak-of-the-mean DCGLs. The peak-of-the-mean DCGLs are considered to be appropriate to compare with the deterministic DCGLs because NRC indicates that when using probabilistic dose modeling, the peak-of-the-mean dose distribution should be used for demonstrating compliance with its License Termination Rule in 10 CFR 20, Subpart E (NRC 2006).

The updated response to RAI 5C9 provides information on a multi-source analysis for development of subsurface soil DCGLs that took into account contaminant releases from the unweathered Lavery till at the bottom of the remediated deep excavations by diffusion. This analysis produced subsurface soil DCGLs that were lower than the probabilistic peak-of-the-mean DCGLs for most radionuclides of interest. Table 5C9-2 included in the updated response to RAI 5C9 compares the subsurface soil DCGLs produced by different conceptual models to the peak-of-the-mean probabilistic DCGLs.

Revised Cleanup Goals

Section 5.4.1 of the DP describes how the cleanup goals were developed for Phase 1 of the decommissioning. Table 5-14 describes these cleanup goals, which serve as the soil and streambed sediment remediation criteria for the project.

To determine whether to revise these goals, DOE has considered the following information:

- The results of the probabilistic uncertainty analysis;
- The revised deterministic DCGLs resulting from the parameter changes described in the response to RAI 5C12;
- The results of alternative scenario analyses performed as recommended by NRC, especially the residential gardener analysis described in the response to RAI 5C18;
- The results of additional groundwater modeling to estimate the magnitude of potential releases of residual radioactivity from the bottoms of the remediated WMA 1 and WMA 2 excavations described in the updated response to RAI 5C9; and
- The results of additional groundwater modeling to estimate the potential impact of flow field changes associated with installation of WMA 1 and WMA 2 hydraulic barriers on the DCGLs as described in the response to RAI 5C3.

The surface soil cleanup goals are being revised based on the peak-of-the-mean DCGLs. These values are being reduced by 10 percent following the limited site-wide dose assessment apportionment process described in Section 5.4.1 of the DP. The resulting cleanup goals thus reflect a maximum dose of 22.5 mrem per year to a receptor exposed only to contamination in surface soil at the cleanup goal concentrations.

The subsurface soil cleanup goals are being revised based on the smallest of the DCGLs produced in multi-source analysis described in the updated response to RAI 5C9, the limiting resident farmer-residential gardener deterministic analysis results, and the peak-of-the-mean DCGLs. These values are being reduced by 10 percent following the process described in Section 5.3.2 of the DP and then by 50 percent more following the process described in Section 5.4.1 of the DP. The resulting cleanup goals equate to a maximum dose of 11.25 mrem per year to a receptor exposed only to radioactivity associated with contamination in subsurface soil at the bottom of the large WMA 1 or WMA 2 excavations at the cleanup goal concentrations.

The streambed sediment cleanup goals are being revised based on the peak-of-the-mean DCGLs. These values are being reduced by 90 percent following the process of Section 5.4.1 of the DP. The resulting cleanup goals equate to a maximum 2.5 mrem per year to an individual exposed only to contamination in the area of the streams.

Table 5C15-3 shows the resulting cleanup goals compared to those in Revision 1 of the DP.

Table 5C15-3. Cleanup Goals to be Used in Remediation in pCi/g(1)

Nuclide	Surface Soil		Subsurface Soil		Streambed Sediment	
	CG_w (old)	CG_w (new)	CG_w (old)	CG_w (new)(3)	CG_w (old)	CG_w (new)
Am-241	4.9E+01	2.6E+01	2.9E+03	2.8E+03	1.6E+03	1.0E+03
C-14	3.1E+01	1.5E+01	1.9E+05	4.5E+02	3.4E+02	1.8E+02
Cm-243	4.2E+01	3.1E+01	5.1E+02	5.0E+02	3.6E+02	3.1E+02
Cm-244	9.4E+01	5.8E+01	8.8E+03	9.9E+03	4.7E+03	3.8E+02
Cs-137(2)	2.7E+01	1.4E+01	2.0E+02	1.4E+02	1.3E+02	1.0E+02
I-129	5.8E-01	2.9E-01	1.9E+02	3.4E+00	3.7E+02	7.9E+01
Np-237	9.6E-02	2.3E-01	1.7E+01	4.5E-01	5.4E+01	3.2E+01
Pu-238	5.8E+01	3.6E+01	5.5E+03	5.9E+03	2.0E+03	1.2E+03
Pu-239	5.2E+01	2.3E+01	5.0E+03	1.4E+03	1.8E+03	1.2E+03
Pu-240	5.2E+01	2.4E+01	5.0E+03	1.5E+03	1.8E+03	1.2E+03
Pu-241	1.6E+03	1.0E+03	9.8E+04	1.1E+05	5.2E+04	3.4E+04
Sr-90(2)	8.7E+00	3.7E+00	1.4E+03	1.3E+02	9.5E+02	4.7E+02
Tc-99	2.9E+01	1.9E+01	5.0E+03	2.7E+02	2.2E+05	6.6E+04
U-232	5.6E+00	1.4E+00	5.3E+01	3.3E+01	2.7E+01	2.2E+01
U-233	2.0E+01	7.5E+00	7.5E+02	8.6E+01	5.8E+03	2.2E+03
U-234	2.1E+01	7.6E+00	7.7E+02	9.0E+01	6.1E+03	2.2E+03
U-235	1.4E+01	3.1E+00	4.3E+02	9.5E+01	2.9E+02	2.3E+02
U-238	2.2E+01	8.9E+00	8.2E+02	9.5E+01	1.3E+03	8.2E+02

NOTES (1) The old cleanup goals are from Table 5-14 of Revision 1 to the DP. Green signifies the lower value.
(2) These cleanup goals apply in the year 2041 and later.
(3) Developed as described in the updated response to RAI 5C9.

Changes to the Plan:

Add the following new subsection just before Section 5.3 on page 5-43:

5.2.5 Probabilistic Uncertainty Analysis

The probabilistic uncertainty analysis has been performed for each of the three conceptual models to supplement the deterministic sensitivity analyses just described. These probabilistic analyses generated results that quantify the total uncertainty in the DCGLs resulting from the variability of key input parameters, and also provide perspective regarding the relative importance of the contributions of different input parameters to the total uncertainty in the DCGLs. This information supports a risk-informed approach to establishing cleanup goals for Phase 1 of the decommissioning.

These analyses were performed using the probabilistic modules of RESRAD version 6.4, which utilize Latin hypercube sampling, a modified Monte Carlo method, allowing for the generation of representative input parameter values from all segments of the input distributions. Input variables for the models were selected randomly from probability distribution functions for each parameter of interest. The number of parameters treated probabilistically for each conceptual model was as follows: surface soil 102, subsurface soil 67, and streambed sediment 63, with these figures including the biotransfer factors and the K_d values for the 18 radionuclides of interest for each zone (contaminated, saturated, unsaturated) and media each model. Appendix E provides details of the analyses.

Table 5-11a summarizes the results of the analyses.

Table 5-11a. Summary of Results of Probabilistic Uncertainty Analyses(1)

Nuclide	Surface Soil DCGLs (pCi/g)		Subsurface Soil DCGLs (pCi/g)		Streambed Sediment DCGLs (pCi/g)	
	Determ(2)	Peak-of-the-Mean(3)	Limiting Determ(4)	Peak-of-the-Mean(3)	Determ(5)	Peak-of-the-Mean(3)
Am-241	4.3E+01	**2.9E+01**	7.1E+03	**6.8E+03**	1.6E+04	**1.0E+04**
C-14	2.0E+01	**1.6E+01**	**3.7E+05**	7.2E+05	3.4E+03	**1.8E+03**
Cm-243	4.1E+01	**3.5E+01**	1.2E+03	**1.1E+03**	3.6E+03	**3.1E+03**
Cm-244	8.2E+01	**6.5E+01**	2.3E+04	**2.2E+04**	4.8E+04	**3.8E+03**
Cs-137*	2.4E+01	**1.5E+01**	4.4E+02	**3.0E+02**	1.3E+03	**1.0E+03**
I-129	3.5E-01	**3.3E-01**	**5.2E+01**	6.7E+02	3.7E+03	**7.9E+02**
Np-237	**9.5E-02**	2.6E-01	**4.3E+00**	9.3E+01	5.2E+02	**3.3E+02**
Pu-238	5.0E+01	**4.0E+01**	1.5E+04	**1.4E+04**	2.0E+04	**1.2E+04**
Pu-239	4.5E+01	**2.5E+01**	1.3E+04	**1.2E+04**	1.8E+04	**1.2E+04**
Pu-240	4.5E+01	**2.6E+01**	1.3E+04	**1.2E+04**	1.8E+04	**1.2E+04**
Pu-241	1.4E+03	**1.2E+03**	**2.4E+05**	2.5E+05	5.1E+05	**3.4E+05**
Sr-90*	6.4E+00	**4.1E+00**	**3.2E+03**	3.4E+03	9.5E+03	**4.7E+03**

Table 5-11a. Summary of Results of Probabilistic Uncertainty Analyses(1)

Nuclide	Surface Soil DCGLs (pCi/g)		Subsurface Soil DCGLs (pCi/g)		Streambed Sediment DCGLs (pCi/g)	
	Determ(2)	Peak-of-the-Mean(3)	Limiting Determ(4)	Peak-of-the-Mean(3)	Determ(5)	Peak-of-the-Mean(3)
Tc-99	2.6E+01	**2.1E+01**	**1.1E+04**	1.4E+04	2.2E+06	**6.6E+05**
U-232	5.9E+00	**1.5E+00**	1.0E+02	**7.4E+01**	2.6E+02	**2.2E+02**
U-233	1.9E+01	**8.3E+00**	**1.9E+02**	9.9E+03	5.7E+04	**2.2E+04**
U-234	2.0E+01	**8.5E+00**	**2.0E+02**	1.3E+04	6.0E+04	**2.2E+04**
U-235	1.9E+01	**3.5E+00**	**2.1E+02**	9.3E+02	2.9E+03	**2.3E+03**
U-238	2.1E+01	**9.8E+00**	**2.1E+02**	4.6E+03	1.2E+04	**8.2E+03**

NOTES: (1) Values shown in boldface are lower of the pair of values being compared.
(2) Revised deterministic DCGLs based on parameter changes described in Appendix C.
(3) Probabilistic peak-of-the-mean DCGLs bases on analyses described in Appendix E.
(4) These values are the limiting DCGLs for subsurface soil from the residential gardener alternate scenario analysis discussed above. Subsurface soil DCGLs are discussed further in Section 5.2.6, which describes the results of an analysis that takes into account continuing releases from the bottoms of the remediated deep excavations.
(5) These are the revised DCGLs based on parameter changes described in Appendix C.

Table 5-11a shows that:

- For surface soil, the peak-of-the-mean probabilistic DCGLs are lower than the revised deterministic DCGLs for all radionuclides except Np-237.
- For subsurface soil, the limiting deterministic analysis results from the residential gardener alternative scenario described above are more limiting than the peak-of-the-mean DCGLs for 10 of the 18 radionuclides. (However, the additional deterministic multi-source analysis that includes continuing releases from the bottoms of the remediated deep excavations as discussed in Section 5.2.6 results in even lower DCGLs from many of the radionuclides of interest.)
- For streambed sediment, the peak-of-the-mean DCGLs are more limiting than the revised deterministic DCGLs.

For most radionuclides, the 95th percentile probabilistic DCGLs are lower than the peak-of-the-mean DCGLs as shown in Appendix E. The peak-of-the-mean DCGLs are considered to be appropriate to compare with the deterministic DCGLs because NRC indicates that when using probabilistic dose modeling, the peak-of-the-mean dose distribution should be used for demonstrating compliance with its License Termination Rule in 10 CFR 20, Subpart E (NRC 2006).

After consideration of the results of the probabilistic uncertainty analysis and the analyses of alternate exposures discussed previously, DOE has determined that it is appropriate to use the peak-of-the-mean DCGLs for surface soil and for streambed sediment and the lowest DCGLs of the various subsurface soil evaluations. Subsurface soil DCGLs are addressed in Section 5.2.6.

Change Table 5-12 on page 5-45 as follows:

Table 5-12. Limited Site-Wide Dose Assessment 1 Results (DCGLs in pCi/g)

Nuclide	Subsurface Soil $DCGL_W$ Values		Streambed Sediment $DCGL_W$ Values	
	Base Case(1)	Assessment(2)	Base Case(1)	Assessment(2)
Am-241	6.3E+03	5.7E+03	1.0E+04	1.0E+03
C-14	9.9E+02	8.9E+02	1.8E+03	1.8E+02
Cm-243	1.1E+03	9.9E+02	3.1E+03	3.1E+02
Cm-244	2.2E+04	2.0E+04	3.8E+04	3.8E+03
Cs-137(3)	3.0E+02	2.7E+02	1.0E+03	1.0E+02
I-129	7.5E+00	6.8E+00	7.9E+02	7.9E+01
Np-237	1.0E+00	9.0E-01	3.2E+02	3.2E+01
Pu-238	1.3E+04	1.2E+04	1.2E+04	1.2E+03
Pu-239	3.1E+03	2.8E+03	1.2E+04	1.2E+03
Pu-240	3.4E+03	3.1E+03	1.2E+04	1.2E+03
Pu-241	2.4E+05	2.2E+05	3.4E+05	3.4E+04
Sr-90(3)	2.8E+02	2.5E+02	4.7E+03	4.7E+02
Tc-99	5.9E+02	5.3E+02	6.6E+05	6.6E+04
U-232	7.4E+01	6.7E+01	2.2E+02	2.2E+01
U-233	1.9E+02	1.7E+02	2.2E+04	2.2E+03
U-234	2.0E+02	1.8E+02	2.2E+04	2.2E+03
U-235	2.1E+02	1.9E+02	2.3E+03	2.3E+02
U-238	2.1E+02	1.9E+02	8.2E+03	8.2E+02

NOTES: (1) The base-case values are the lowest values from Table 5-11c.
(2) The results for the analysis of the combined base case in this table (the lowest DCGLs in the various analyses for subsurface soil) and the recreationist in the area of the streams.
(3) These DCGLs apply in the year 2041 and later.

Change Table 5-13 on page 5-46 as follows:

Table 5-13. Limited Site-Wide Dose Assessment 2 Results (DCGLs in pCi/g)

Nuclide	Surface Soil $DCGL_W$ Values		Streambed Sediment $DCGL_W$ Values	
	Base Case(1)	Assessment(2)	Base Case(1)	Assessment(2)
Am-241	2.9E+01	2.6E+01	1.0E+04	1.0E+03
C-14	1.6E+01	1.5E+01	1.8E+03	1.8E+02
Cm-243	3.5E+01	3.1E+01	3.1E+03	3.1E+02
Cm-244	6.5E+01	5.8E+01	3.8E+04	3.8E+03

Table 5-13. Limited Site-Wide Dose Assessment 2 Results (DCGLs in pCi/g)

Nuclide	Surface Soil $DCGL_W$ Values		Streambed Sediment $DCGL_W$ Values	
	Base Case[1]	Assessment[2]	Base Case[1]	Assessment[2]
Cs-137[3]	1.5E+01	1.4E+01	1.0E+03	1.0E+02
I-129	3.3E-01	2.9E-01	7.9E+02	7.9E+01
Np-237	2.6E-01	2.3E-01	3.2E+02	3.2E+01
Pu-238	4.0E+01	3.6E+01	1.2E+04	1.2E+03
Pu-239	2.5E+01	2.3E+01	1.2E+04	1.2E+03
Pu-240	2.6E+01	2.4E+01	1.2E+04	1.2E+03
Pu-241	1.2E+03	1.0E+03	3.4E+05	3.4E+04
Sr-90[3]	4.1E+00	3.7E+00	4.7E+03	4.7E+02
Tc-99	2.1E+01	1.9E+01	6.6E+05	6.6E+04
U-232	1.5E+00	1.4E+00	2.2E+02	2.2E+01
U-233	8.3E+00	7.5E+00	2.2E+04	2.2E+03
U-234	8.4E+00	7.6E+00	2.2E+04	2.2E+03
U-235	3.5E+00	3.1E+00	2.3E+03	2.3E+02
U-238	9.8E+00	8.9E+00	8.2E+03	8.2E+02

NOTES: (1) The base case values from Table 5-11a.
(2) The results for the analysis of the combined resident farmed located in the area of remediated surface soil and the recreationist in the area of the streams.
(3) These DCGLs apply in the year 2041 and later.

Change Table 5-14 on page 5-48 as follows:

Table 5-14. Cleanup Goals to be Used in Remediation in pCi/g[1]

Nuclide	Surface Soil[2]		Subsurface Soil[3]		Streambed Sediment[2]	
	CG_w	CG_{EMC}	CG_w	CG_{EMC}	CG_w	CG_{EMC}
Am-241	2.6E+01	3.9E+03	2.8E+03	1.2E+04	1.0E+03	3.3E+04
C-14	1.5E+01	2.0E+06	4.5E+02	8.0E+04	1.8E+02	1.1E+06
Cm-243	3.1E+01	7.6E+02	5.0E+02	4.0E+03	3.1E+02	3.2E+03
Cm-244	5.8E+01	1.2E+04	9.9E+03	4.5E+04	3.8E+03	4.5E+05
Cs-137[4]	1.4E+01	3.0E+02	1.4E+02	1.7E+03	1.0E+02	1.2E+03
I-129	2.9E-01	2.9E+03	3.4E+00	3.4E+02	7.9E+01	9.3E+04
Np-237	2.3E-01	3.1E+02	4.5E-01	4.3E+01	3.2E+01	1.7E+03
Pu-238	3.6E+01	7.6E+03	5.9E+03	2.8E+04	1.2E+03	2.7E+05
Pu-239	2.3E+01	6.9E+03	1.4E+03	2.6E+04	1.2E+03	2.5E+05
Pu-240	2.4E+01	6.9E+03	1.5E+03	2.6E+04	1.2E+03	2.5E+05
Pu-241	1.0E+03	1.3E+05	1.1E+05	6.8E+05	3.4E+04	1.1E+06

Table 5-14. Cleanup Goals to be Used in Remediation in pCi/g[(1)]

Nuclide	Surface Soil[(2)]		Subsurface Soil[(3)]		Streambed Sediment[(2)]	
	CG_w	CG_{EMC}	CG_w	CG_{EMC}	CG_w	CG_{EMC}
Sr-90[(4)]	3.7E+00	1.1E+04	1.3E+02	7.3E+03	4.7E+02	1.4E+05
Tc-99	1.9E+01	6.1E+04	2.7E+02	1.5E+04	6.6E+04	1.4E+07
U-232	1.4E+00	5.9E+01	3.3E+01	4.2E+02	2.2E+01	2.5E+02
U-233	7.5E+00	1.1E+04	8.6E+01	9.4E+03	2.2E+03	1.2E+05
U-234	7.6E+00	2.3E+04	9.0E+01	9.4E+03	2.2E+03	5.9E+05
U-235	3.1E+00	6.1E+02	9.5E+01	3.3E+03	2.3E+02	2.5E+03
U-238	8.9E+00	2.9E+03	9.5E+01	9.9E+03	8.2E+02	1.3E+04

NOTE: (1) These cleanup goals (CGs) are to be used as the criteria for the remediation activities described in Section 7 of this plan. The $DCGL_{EMC}$ values were calculated using a contamination zone area of 1 m^2 and apply to 1 m^2 areas of elevated concentration.

(2) The CG_W values for surface soil and streambed sediment are the same as the limited dose assessment DCGL values in Table 5-11.

(3) These CG_W values are the assessment values in the third column of Table 5-12 reduced by a factor of 0.50 as discussed below. The CG_{EMC} values are the limiting values from the multi-source analysis or the deterministic resident farmer analysis.

(4) These cleanup goals apply in the year 2041 and later.

Insert new Appendix E (copy provided below). Since the appendix is entirely new, a black font is used with no change bars.

References:

DOE 2008, Letter from DOE (C.V. Anderson) to NRC (K.I. McConnell), submitting Revision 0 of the WVDP Phase 1 Decommissioning Plan for NRC review, December 3, 2008.

NRC 2006, *Consolidated NMSS Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria, Final Report,* NUREG 1757 Volume 2, Revision 1. NRC, Office of Nuclear Material Safety and Safeguards, Washington, DC, September, 2006.

APPENDIX E

DOSE MODELING PROBABILISTIC UNCERTAINTY ANALYSES

PURPOSE OF THIS APPENDIX

The purpose of this appendix is to describe probabilistic uncertainty analyses performed to evaluate the degree of conservatism in key input parameters for the conceptual models used to develop derived concentration guideline levels (DCGLs) for surface soil, subsurface soil, and streambed sediment, along with the results of these analyses.

INFORMATION IN THIS APPENDIX

This appendix provides the following information:

- Section 1 provides introductory information to help place the discussions that follow into context.
- Section 2 defines key terms used in the discussions.
- Section 3 summarizes the probabilistic analysis capabilities of the RESRAD computer code used in the analyses.
- Section 4 describes criteria used for selecting parameters for uncertainty analysis.
- Section 5 describes how parameter distributions were selected.
- Section 6 describes correlation of parameters.
- Section 7 describes the uncertainty analysis results for each of the three conceptual models, including DCGLs expressed as the peak-of-the-mean (50^{th} percentile) and 95^{th} percentile.
- Section 8 describes parameter output rank correlations.
- Section 9 provides conclusions and describes actions taken on the analysis results.
- Attachment 1 contains copies of representative probabilistic output plots.
- Attachment 2 contains the electronic files developed in performing the analyses.

RELATIONSHIP TO OTHER PLAN SECTIONS

This appendix provides supporting information for Section 5. Information provided in Section 5 and in Section 1 on the project background will help place the information in this appendix into context.

1.0 Introduction

1.1 Purpose

The probabilistic uncertainty analyses discussed in this appendix were performed to evaluate the degree of conservatism in key input parameters for the conceptual models used in developing DCGLs for surface soil, subsurface soil, and streambed sediment that are described in Section 5 of this plan. The DOE letter that forwarded Revision 0 of this plan to NRC for review (DOE 2008) noted that this matter was still under evaluation when Revision 0 was completed.

These probabilistic uncertainty analyses supplement the deterministic sensitivity analyses described in Section 5 of this plan. They compute the total uncertainty in the DCGLs resulting from the uncertainty in or the variability of the input parameters. They also help determine the relative importance of the contributions of different input parameters to the total uncertainty in the DCGLs.

These analyses thereby provide additional perspective on the relationships between conceptual model input parameters and estimated dose, along with sets of DCGLs expressed in probabilistic terms. This information supports a risk-informed approach to establishing cleanup goals for Phase 1 of the decommissioning.

1.2 Background

The DCGLs for surface soil, subsurface soil, and streambed sediment were developed using the basic RESRAD deterministic approach in which the analysis is performed by assigning each parameter a single value, as described in Section 5 of this plan. As noted in Section 5, RESRAD was selected as the mathematical model for DCGL development due to its extensive use by DOE and by NRC licensees in developing DCGLs and evaluating doses from residual radioactivity at decommissioned sites.

General NRC Guidance on Uncertainty and Sensitivity Analyses

NRC guidance on uncertainty and sensitivity analyses appears in Appendix I to NUREG-1757, Volume 2 (NRC 2006). NRC concludes that while the deterministic modeling approach has the advantage of being simple to implement and easy to communicate to a non-specialist audience, it has significant limitations:

- It does not allow consideration of the effects of unusual combinations of input parameters;
- It does not provide information on uncertainty in the results, which would be helpful to the decision-maker; and
- It often leads to overly conservative evaluations because it has to rely on the use of pessimistic estimates of each parameter of the model to ensure a bounding dose estimate, that is, results that are likely to overestimate the actual peak dose.

The first two limitations apply to the deterministic dose analysis described in Section 5, which did not include evaluation of different parameter combinations or estimates of uncertainty. And while DOE used conservative model input parameters in many cases, it is difficult to demonstrate that the results of the deterministic dose analysis are bounding.

NRC encourages the use of probabilistic techniques to evaluate and quantify the magnitude and effect of uncertainties in dose assessments, and the sensitivity of the calculated risks from individual parameter values and modeling assumptions. Probabilistic uncertainty analysis provides more information to the decision-maker than deterministic analysis, as it characterizes a range of potential doses and the likelihood that a particular dose may be exceeded. (NRC 2006)

Uncertainty analyses in the RESRAD probabilistic modules use Latin hypercube sampling[1], a modified Monte Carlo method, allowing for the generation of representative input parameter values from all segments of the input distributions. Input variables for the models are selected randomly from probability distribution functions for each parameter of interest. Parameter distribution functions may be either independent or correlated to other input variable distributions. The analysis is then performed hundreds of times to obtain a distribution of doses resulting from each set of randomly selected input parameters.

The results of a probabilistic uncertainty analysis provide a distribution of doses illustrating the effects of random combinations of input parameters. It should be recognized that some percentage of the calculated distribution of doses may exceed the regulatory limit, which is expressed as a (deterministic) single value. Compliance can be stated in terms of a metric of the distribution such as the mean falling below the limit, or only a percentage of calculated doses exceeding the limit. (NRC 2006)

NRC indicates that when using probabilistic dose modeling, the "peak-of-the-mean" dose distribution should be used for demonstrating compliance with its License Termination Rule in 10 CFR Part 20, Subpart E (NRC 2006).

Specific NRC Guidance for Phase 1 of the WVDP Decommissioning

DOE and NRC held two scoping meeting on DOE's dose modeling plans. The NRC summary of the second meeting (NRC 2008) included the following statements:

> "NRC indicated that it might not be acceptable to use the mean or most likely value for those parameters that have the largest impact on dose in a deterministic analysis (e.g., for parameters such as K_ds that have a large parameter range and uncertainty)."
>
> "NRC warned of the potential pitfalls of performing a deterministic analysis with a sensitivity analysis in lieu of a probabilistic assessment. Depending on the combination and range of parameter values selected and models employed (e.g., mass balance versus non-dispersion model in RESRAD), key radionuclides and pathways, the results of the sensitivity analysis could be misleading and the full range of uncertainty difficult to determine. Selection of parameter values should be guided by conservative assumptions when uncertainty is large and cannot be reduced. To determine the impact of a particular parameter value on the dose results, DOE must identify key risk drivers and perform a comprehensive sensitivity analysis to ensure that its selection of parameter values in its deterministic analysis errors on the side of conservatism."

DOE identified key risk (i.e., dose) drivers and included a comprehensive sensitivity analysis in Section 5.2.4 of Revision 1 to the plan. The analyses described in this appendix, complete DOE actions on these matters.

1.3 Analyses and Associated Electronic Files

The probabilistic dose analyses discussed herein were performed using the probabilistic modules of RESRAD Version 6.4 (LePoire, et al. 2000; Yu, et al. 2000; Yu, et al. 2001) making use of the stratified sampling of the Latin hypercube method.

[1] The Latin hypercube method is a modified Monte Carlo method; see Section 2 below for definitions of terms such as these. NRC supported development of the probabilistic version of RESRAD for use in determining compliance with its License Termination Rule (Yu, et al. 2000). RESRAD probabilistic modeling capabilities are discussed in Section 3 below.

For the surface soil model, three groups of results were generated for 1000 sets of input parameters, with calculated statistical parameters (minimum, maximum, mean, percentiles) output by RESRAD for each of the three input parameter datasets. For the subsurface and streambed sediment models, use of the mass balance groundwater option results in long computation times for multiple parameter input sets. Therefore, only a single set of 1000 input values for each parameter was used for the subsurface soil and sediment evaluation where simulation times were extensive.

Included in the electronic files of Attachment 1 are the RESRAD input and output files for surface soil ("RESRAD PROB SURF.zip"), subsurface soil ("RESRAD PROB SUBS.zip"), and sediment ("RESRAD PROB SED.zip"), and a Word file containing output plots of dose over time for each radionuclide in each media ("PROB Dose Plots.doc").

1.4 Products of the Probabilistic Uncertainty Analyses

The primary products of these analyses are as follows:

- Sets of peak-of-the-mean $DCGL_W$ values for surface soil, subsurface soil, and streambed sediment, that is, values that have a 50 percent probability that the specified concentration for each radionuclide would correspond to a dose of 25 mrem in the year of peak dose;
- Sets of 95th percentile $DCGL_W$ values for surface soil, subsurface soil, and streambed sediment, that is, values that have a 95 percent probability that the specified concentration for each radionuclide would correspond to a dose of 25 mrem in the year of peak dose;
- Preliminary dose estimates for the remediated Waste Management Area (WMA) 1 excavation expressed as the peak of the mean (50th percentile) and the 95th percentile; and
- Preliminary dose estimates for the remediated WMA 2 excavation expressed as the peak of the mean and the 95th percentile.

As discussed in Section 9.2 of this appendix, the results of the probabilistic uncertainty analyses indicate that some input parameters used in the deterministic modeling to develop DCGLs may not be sufficiently conservative to ensure bounding results.

2.0 Key Terms

Because of the technical nature of the discussions in this appendix, some readers may find the following definitions to be useful. These definitions are tailored to the use of the terms in this appendix.

Behavioral parameter. Any conceptual model input parameter whose value would depend on the receptor's behavior within the scenario definition. For the same group of receptors, a behavioral parameter value could change if the scenario changed, e.g., parameters for recreational use could be different from those for residential use. (See also **metabolic parameter** and **physical parameter**.)

Correlation. A measure of the strength of the relationship between two variables (e.g., conceptual model input parameters) used to predict the value of one variable given the value of the other.

Correlation coefficient. Correlation coefficients (R values) are expressed on a scale from -1.0 to +1.0, with the strongest correlations being at both extremes and providing the best predictions. Negative values reflect inverse relationships. (See also **partial rank correlation coefficient.**)

Deterministic analysis. In a deterministic analysis, each input parameter is assumed to be an exactly known single value, as are the analysis results.

Empirical distribution. An empirical distribution is a parameter distribution well defined by available data to the extent that additional sampling would not be expected to significantly change the distribution's shape.

Latin hypercube sampling. A modified **Monte Carlo method** used to generate random samples of input parameters in the probabilistic version of RESRAD.

Lognormal distribution. In a lognormal distribution, the logarithm of the parameter has a **normal distribution**. A lognormal distribution is defined by two parameters, the logarithmic mean and its standard deviation.

Mean. The arithmetic mean as used here is the mathematical average of a set of numbers. The mean is calculated by adding a set of values and dividing the total by the number of values in the set.

Metabolic parameter. A parameter representing the metabolic characteristics of the potential receptor that is independent of scenario. (Metabolic parameters were not included in the evaluation discussed in this appendix.)

Monte Carlo method. A technique which obtains a probabilistic approximation to the solution of a problem by using statistical sampling techniques. Monte Carlo methods rely on repeated random sampling to compute their results, and are often used to simulate complex physical and mathematical systems.

Normal distribution. Probability values in a normal distribution follow a bell shaped curve centered about a mean value with the width of the "bell" described by the standard deviation. In a bounded normal distribution, upper and lower limits to the range are specified.

Overall coefficient of determination. This coefficient, denoted by R^2, provides an indication of the variability in the overall radionuclide dose accounted for by the selected input parameters. It varies between 0 and 1; the higher the value, the greater the influence. A value of 0 indicates the selected parameters do not influence the calculated dose at all.

Partial rank correlation coefficient. The partial rank correlation coefficient measures the strength of the relationship between variables after any confounding influences of other variables have been removed. (See also **rank correlation coefficient.**)

Peak of the mean. The highest dose value in a plot of the estimated mean dose over time.

Physical parameter. Any parameter whose value would not change if a different group of receptors was considered. Physical parameters are site-specific factors determined by the source, its location, and geological or physical characteristics of the site.

Probabilistic analysis. In a probabilistic analysis, statistical distributions are defined for input parameters to account for their uncertainty, and the analysis results reflect the resulting uncertainty, e.g., a distribution of values rather than a single value. Such analyses use a random sampling method to select parameter values from a distribution. Results of the calculations appear in the form of a distribution of values.

Probability density function. A graphical representation of the probability distribution of a continuously random variable illustrating the range of possible values and the relative frequency (probability) of each value within the range. Uncertainty in a conceptual model input parameter is represented by the probability density function for that parameter. Probability distribution functions provided for in RESRAD include empirical, uniform, triangular, normal, and lognormal.

Rank correlation coefficient. A correlation coefficient between two variables that is used for determining the relative importance of input parameters in influencing the resultant dose.

Regression analysis. A mathematical method of modeling the relationships among three or more variables used to predict the value of one variable given the values of the others.

Triangular distribution. In a triangular distribution of a continuous random variable, the graph of the probability density function forms a triangle, with a range defined by minimum and maximum values and a mode value which is the most frequent (probable) value.

Uniform distribution. In a uniform distribution, each value within the range has the same probability of occurrence.

3.0 The Probabilistic Version of RESRAD

The probabilistic RESRAD code is an extended and enhanced version of RESRAD. RESRAD Version 6.4, which was used for the dose analyses described in Section 5 of this plan, provides both deterministic and probabilistic analysis capabilities.

The probabilistic version of RESRAD was developed for use in site-specific dose modeling in support of NRC's License Termination Rule compliance process for decontamination and decommissioning of NRC-licensed sites. Probabilistic analysis capabilities were incorporated into RESRAD in external software modules integrated into the code. Three reports describe these probabilistic analyses capabilities and how they are applied:

- NUREG/CR-6676, *Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes* (Kamboj, et al. 2000);
- NUREG/CR-6692, *Probabilistic Modules for the RESRAD and RESRAD-Build Computer Codes, User Guide* (LePoire, et al. 2000); and
- NUREG/CR-6697, *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes* (Yu, et al. 2000).

Three basic types of input parameters are considered in probabilistic analyses: physical parameters, behavioral parameters, and metabolic parameters[2]. Certain parameters fall into more than one category, e.g., inhalation rate is both a behavioral parameter and a metabolic parameter.

The probabilistic modules in RESRAD Version 6.4 provide default values and distributions for various parameters. Default probability distributions include normal, lognormal, uniform, triangular, and empirical. These default distributions are based primarily on the quantity of relevant data available in reviewed technical literature.[3] For three parameters of interest in this plan – cover depth, precipitation rate, and well pumping rate – a default distribution type is not provided.

In a RESRAD probabilistic analysis, the results from all input samples are analyzed and presented in a statistical format in terms of the average value, standard deviation, minimum value, and maximum value. The cumulative probability distribution of the output is presented in both tabular and graphical forms.

The basic process includes the following steps:

- Identifying parameters for probabilistic evaluation;
- Defining distributions of key parameters;
- Assigning correlations between input parameters, which is done to limit the occurrence of unrealistic physical conditions;
- Verifying that simulation input values reflect the desired correlations by visual inspection of scatter plots of correlated parameters;
- Determining parameters with highest rank correlation coefficients in the results, i.e., those that most influence dose; and
- Confirming output parameter correlations with scatter plots of parameter input values versus calculated dose.

Figure E-1 illustrates the process.

[2] Metabolic parameters were not included in this evaluation because the deterministic values represent means for the generic population, which would be independent of site conditions (Kamboj, et al. 2000).

[3] Parameter distributions developed for use with RESRAD and RESRAD-BUILD and their bases are described in Attachment C to NUREG/CR-6697 (Yu, et al. 2000).

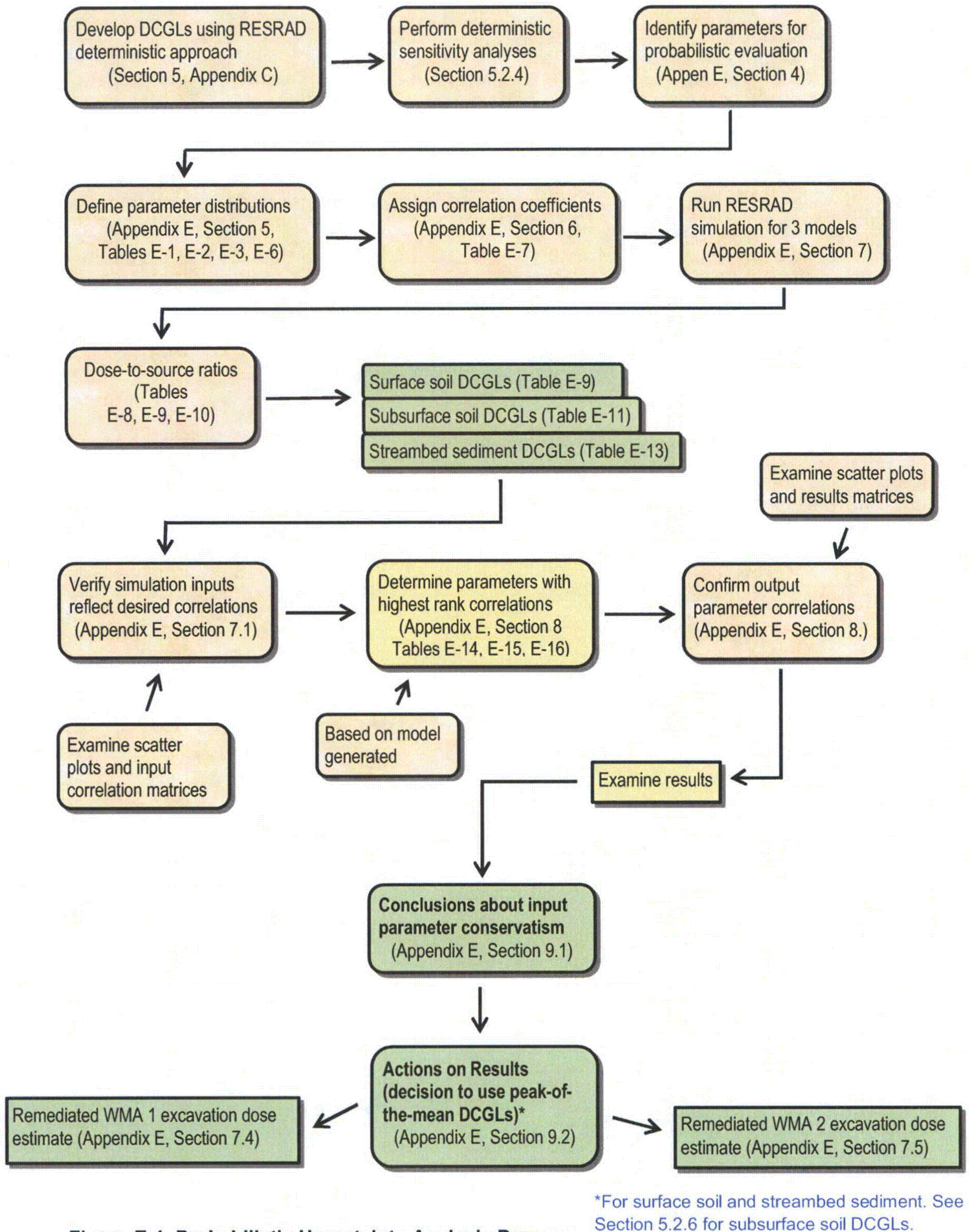

Figure E-1. Probabilistic Uncertainty Analysis Process

4.0 Key Parameter Selection

The main criteria used for identifying key parameters to be evaluated involved the expected parameter influence on dose variability. That is, key parameters are those that have the largest effect on the dose analysis results.

Section 5.2.4 of this plan describes the results of sensitivity analyses for key input parameters for each of the three conceptual models. Tables E-1, E-2, and E-3 identify key parameters for the three conceptual models described in Section 5 of the plan, along with their assigned distributions, which are discussed in the next section.

Section 5.2.4 identifies Sr-90 and Cs-137 as likely to be the primary dose drivers for surface soil, subsurface soil and sediment exposure pathways. However, all eighteen radionuclides of interest were evaluated in the probabilistic analyses for the sake of completeness.

Other factors considered in parameter selection included the availability of site-specific information that could be used to define the distributions and NRC guidance on potentially significant parameters. Preference was also given to including parameters for which input correlations with other input variables could be defined, and where ambiguous input correlations with other input parameters was limited. Additionally, a number of parameters were used to establish a site-specific dilution factor (See Appendix C) corroborated by the detailed three dimensional flow model. These parameters were not varied with the exception of hydraulic conductivity, well pumping rate and length parallel to aquifer flow. For these parameters the probabilistic evaluation included values that would vary the dilution factor within a reasonable site-specific range.

Initial probabilistic simulations included parameters such as soil density, total porosity, and effective porosity for the contaminated, unsaturated, and saturated zones. These parameters consistently had correlation coefficients below 0.25. Because the correlation of these parameters with other more significant input parameters (i.e. hydraulic conductivity) was not clear, these parameters were dropped from subsequent analysis. Additional information regarding parameter input correlation is provided in Section 6.0.

5.0 Parameter Distribution Selection

This section first addresses the statistical distributions of model input parameters other than K_d values and then addresses K_d values.

5.1 Parameters Other Than Distribution Coefficients

Distributions selected for the input parameters are presented in Tables E-1, E-2, and E-3, and were based on applicable guidance in NUREG/CR-6676 (Kamboj, et al. 2000) and NUREG/CR-6697 (Yu, et al. 2000). Site specific parameters were generally assigned triangular distributions centered on the most likely value (e.g., source thickness, contaminated length parallel to aquifer flow).

Table E-1 identifies parameters of interest and their assigned distributions for the surface soil conceptual model that were varied during the analyses and the distribution used for each parameter, except for distribution coefficients and the plant, meat and milk biotransfer factors. The distribution coefficients for all ten elements associated with the radionuclides of interest were also varied using bounded lognormal distributions.

Table E-1. Input Parameter Distributions for Surface Soil Model (Other than K_d and Biotransfer Factor Values)(1)(2)

RESRAD Parameter	Parameter Description	Units	Distribution	Parameters(3)			
THICK0	Contaminated zone thickness	m	triangular	0.5	1	3	
LCZPAQ	Length parallel to aquifer flow	m	triangular	100	165	200	
HCSZ	Saturated zone hydraulic conductivity	m/y	triangular	630	1400	2200	
UW	Well pumping rate	m^3/y	bounded normal	5900	1270	2618	7586
RI	Irrigation rate	m/y	bounded normal	0.47	0.12	0.14	0.64
FIND	Indoor time fraction	none	triangular	0.45	0.66	0.8	
FOTD	Outdoor time fraction	none	triangular	0.1	0.25	0.45	
HCUZ(1)	Unsaturated zone hydraulic conductivity	m/y	triangular	63	140	220	
HCCZ	Contaminated zone hydraulic conductivity	m/y	triangular	63	140	220	
DROOT	Root depth	m	triangular	0.3	0.9	3	
PRECIP	Precipitation rate	m/y	bounded normal	1.03	0.13	0.86	1.36
THICK0	Contaminated zone thickness	m	triangular	0.5	1	3	
SHF1	External gamma shielding factor	none	triangular	(4)	(4)	(4)	

NOTES: (1) Values in RESRAD file "SUMMARY.REP".

(2) Radionuclide specific K_d values were varied (see Table E-6) and plant, meat, milk transfer factors were assigned the RESRAD default distribution.

(3) Parameters for the distributions are: TRIANGULAR - minimum, mode, maximum and BOUNDED NORMAL - mean, standard deviation, minimum, maximum.

(4) Radionuclide specific distribution. Dose drivers Cs-137 and U-232 were evaluated.

In general, site-specific physical parameters in Table E-1 were described with triangular distributions across the range of values associated with the site, including hydraulic conductivity, and indoor/outdoor time fraction, etc. Depth of roots was assigned a triangular distribution ranging from 0.3 meter (onions, lettuce) to three meters (alfalfa), centered on 0.9 m (corn).

Precipitation was based on a normal distribution described by statistical parameters (mean = 1.03 meter, standard deviation = 0.13 meter) that were calculated from meteorological data collected over the last 30 years in Buffalo, New York (http://www.weatherexplained.com/Vol-4/2001-Buffalo-New-York-BUF.html). The precipitation data was then used to assign a distribution for the irrigation rate, assuming that a total of 1.5 m/y of applied water was needed, and the well pumping rate was assigned a distribution based on the irrigation volume needed. These parameters were also correlated to ensure this relationship in the input values.

The total onsite fraction of 0.91 equates to a total of 33 days each year, or 15 hours each week, away from the site inclusive of time spent taking livestock/crops to market, assisting on neighboring farms, or other travel off-site (vacation, family occasions, religious services, etc.).

The plant-soil, meat-soil, and milk-soil bioaccumulation factors were simulated using the RESRAD default lognormal-N distributions, and were correlated (R = -0.87) with the K_d as described in Section 6.0.

Table E-2 identifies parameters of interest and their assigned distributions for the subsurface soil conceptual model, except for distribution coefficients and the plant, meat and milk biotransfer factors, that were varied during the analyses and the distribution used for each parameter. The distribution coefficients for all ten elements associated with the radionuclides of interest were also varied using bounded lognormal distributions.

Table E-2. Input Parameter Distributions for Subsurface Soil Model (Other than K_d and Biotransfer Factor Values)(1)(2)

RESRAD Parameter	Parameter Description	Units	Distribution	Parameters(3)			
UW	Well pumping rate	m^3/y	bounded normal	5900	1270	2618	7586
RI	Irrigation rate	m/y	bounded normal	0.47	0.12	0.14	0.64
FIND	Indoor time fraction	none	triangular	0.45	0.66	0.8	
FOTD	Outdoor time fraction	none	triangular	0.1	0.25	0.45	
DROOT	Root depth	m	triangular	0.3	0.9	3	
PRECIP	Precipitation rate	m/y	bounded normal	1.03	0.13	0.86	1.36
SHF1	External gamma shielding factor	none	triangular	(4)	(4)	(4)	

NOTES: (1) Values in RESRAD file "SUMMARY.REP".

(2) Radionuclide specific K_d values were varied (see Table E-6) and plant, meat, milk transfer factors were assigned the RESRAD default distribution.

(3) Parameters for the distributions are: TRIANGULAR - minimum, mode, maximum and BOUNDED NORMAL - mean, standard deviation, minimum, maximum.

(4) Radionuclide specific distribution. Dose drivers Cs-137 and U-232 were evaluated

Because the subsurface soil model is based on the well drilling scenario, only a limited amount of material is available from the excavation (approximately 30 m^3). The parameter ranges and correlation described below were selected assuming deterministic values for the contaminated zone area and depth. The sensitivity of the models to specific area and thickness combinations was evaluated in Section 5 of the body of this plan. Note that the subsurface soil evaluation is based on the mass balance groundwater model.

The plant-soil, meat-soil, and milk-soil bioaccumulation factors were simulated using the RESRAD default lognormal-N distributions, and were correlated (R = -0.87) with the K_d as described in Section 6.0.

Table E-3 identifies parameters of interest and their assigned distributions for the streambed sediment conceptual model, except for distribution coefficients and the plant and meat biotransfer factors, that were varied during the analyses and the distribution used for each parameter. The distribution coefficients for all ten elements associated with the radionuclides of interest were also varied using bounded lognormal distributions.

Table E-3. Input Parameter Distributions for Streambed Sediment Model (Other than K_d and Biotransfer Factor Values)(1)(2)

RESRAD Parameter	Parameter Description	Units	Distribution	Parameters(3)			
HCCZ	Contaminated zone hydraulic conductivity	m/y	triangular	63	140	220	
PRECIP	Precipitation rate	m/y	bounded normal	1.03	0.13	0.86	1.36
FOTD	Outdoor time fraction	none	triangular	0.006	0.012	0.024	

NOTES: (1) Values in RESRAD file "SUMMARY.REP"..

(2) Radionuclide specific K_d values were varied (see Table E-6) and plant, meat, fish transfer factors were assigned the RESRAD default distribution.

(3) Parameters for the distributions are: TRIANGULAR - minimum, mode, maximum and BOUNDED NORMAL - mean, standard deviation, minimum, maximum.

Soil parameters were varied over the same ranges used for the soil models. Parameter values for the fraction of time outdoors were taken from the deterministic sensitivity analysis described in Section 5 of the plan for likely recreational exposures.

The plant-soil and meat-soil bioaccumulation factors were simulated using the RESRAD default lognormal-N distributions, and were correlated (R = -0.87) with the K_d as described previously. Fish transfer factors were also simulated using the RESRAD default lognormal-N distributions, however no correlations were included.

5.2 Distribution Coefficients

Table C-2 of this plan identifies the distribution coefficients (K_d values) used in the dose analyses described in Section 5 of the body of this plan. Section 3.7.8 and Table 3-20 of this plan provide information on measurements of the distribution coefficients in soils at the site. However, these data are not sufficient to establish a site-specific distribution of the K_d parameter for each of the 10 chemical elements represented in the 18 radionuclides of interest in dose modeling.

Sheppard and Thibault (Sheppard and Thibault 1990) and NUREG/CR-6697 (Yu, et al. 2000) recommend that the K_d parameter be described as a lognormal distribution. Table E-4 summarizes data on K_d values from two key sources compared to the values used in the dose modeling described in Section 5 of this plan. Table E-5 provides a summary of the parameters describing the lognormal distributions as given in these reports.

Consideration of the data in Table E-5 from the two sources led to the distribution parameters in Table E-6, which were used in the uncertainty analyses. The distributions were bounded based on the values presented in Table E-6 to constrain unreasonably large or small values, which is consistent with the approach suggested in NUREG-6697 (Attachment C). The values in the table were established as follows:

- When Sheppard and Thibault sand values were used for K_d in the basic RESRAD analysis, then the Sheppard and Thibault sand distribution was used in the uncertainty analysis; and
- For cases when WVDP site-specific values are available, a distribution was selected so that the distribution mean [exp(μ)] provides a closer approximation to the K_d used in the basic RESRAD analyses.

Table E-4. Summary of Data on K_d Parameter (mL/g) for the 10 Elements of Interest

Element	RESRAD Default	Geometric Mean and Range [Sheppard and Thibault 1990]				Range [EPA 1999] [EPA 2004]	Values Used in Section 5 Modeling	
		Sand	Loam	Clay	Organic		Surface Soil, Unsaturated Zone, Saturated Zone	Subsurface Soil and Sediment in Contaminated Zone
Am	20	1,900 8.2 – 300,000	9,600 400 – 48,309	8,400 25 – 400,000	112,000 6,398 – 450,000	8.2 - 2,270,000	1900 (1) (420 - 111,000)	4000 (2) (420 - 111,000)
C	0	5	20	1	7	not addressed	5 (1) (0.7 - 12)	7 (2) (0.7 - 12)
Cm	calculated	4,000 780 – 22,970	18,000 7,666 – 44,260	6,000 ND	6,000 0	93 – 51,900	calculated	calculated
Cs	460	280 0.2 – 10,000	4,600 560 – 61,287	1,900 37 – 31,500	270 0.4 – 145,000	10 – 66,700	280 (1) (48 - 4800)	480 (2) (48 - 4800)
I	calculated	1 0.04 - 81	5 0.1 - 43	1 0.2 - 29	25 1.4 - 368	0.05 – 10,200	1 (1) (0.4 - 3.4)	2 (3) (0.4 - 3.4)
Np	calculated	5 0.5-390	25 1.3-79	55 0.4-2,575	1200 857-1,900	0.36 – 50,000	2.3 (4) (0.5 - 5.2)	3 (2) (0.5 - 5.2)
Pu	2,000	550 27-36,000	1200 100-5,933	5100 316-190,000	1900 60-62,000	5 – 2,550	2600 (4) (5 - 27,900)	3000 (2) (5 - 27,900)
Sr	30	15 0.05-190	20 0.01-300	110 3.6-32,000	150 8-4800	1 -1,700	5 (5) (1 - 32)	15 (2) (1 - 32)
Tc	0	0.1 0.01-16	0.1 0.01-0.4	1 1.16-1.32	1 0.02-340	0.01 – 340	0.1 (1) (0.01 - 4.1)	4.1 (3) (1 - 10)
U	50	35 0.03-2,200	15 0.2-4,500	1600 46-395,100	410 33-7,350	0.4 – 1,000,000	35 (1) (15 - 350)	10 (3) (1 - 100)

NOTES: (1) From Sheppard and Thibault 1990, for sand.
(2) Site specific value for the unweathered Lavery till (see Section 3.7.8, Table 3-20).
(3) Site specific value for the Lavery till (see Section 3.7.8, Table 3-20).
(4) Site specific value for the sand and gravel unit (see Section 3.7.8, Table 3-20).
(5) Dames and Moore (1995a, 1995b).

Table E-5. Lognormal Distribution Parameters for K_d Values from Literature

Element	Sand Soil[1]				Clay Soil[2]				RESRAD Default[3]			
	No. of Obs.	μ[4]	σ[5]	exp(μ)[6]	No. of Obs.	μ[4]	σ[5]	exp(μ)[6]	No. of Obs.	μ[4]	σ[5]	exp(μ)[6]
Am	29	7.6	2.6	1,998	11	9.0	2.6	8,100	219	7.28	3.15	1,451
C	3	1.1	0.8	3	0[7]	0.8		2.2	NA	2.40	3.22[8]	11
Cm	2	8.4	2.4	4,447	0[7]	8.7		6,000	23	8.82	1.82	6,761
Cs	81	5.6	2.5	270	28	7.5	1.6	1,810	564	6.10	2.33	446
I	22	0.04	2.2	1.0	8	0.5	1.5	1.7	109	1.52	2.19	4.6
Np	16	1.4	1.7	4.1	4	4.0	3.8	55	77	2.84	2.25	17
Pu	39	6.3	1.7	545	18	8.5	2.1	4,920	205	6.86	1.89	953
Sr	81	2.6	1.6	13.5	24	4.7	2.0	110	539	3.45	2.12	32
Tc	19	-2.0	1.8	0.1	4	0.2	0.06	1.2	59	-0.67	3.16	0.51
U	24	3.5	3.2	33	7	7.3	2.9	1,480	60	4.84	3.13	126

NOTES: (1) From Sheppard and Thibault 1990, Table A-1.
(2) From Sheppard and Thibault 1990, Table A-3.
(3) From Yu, et al. 2000, Table 3.9-1.
(4) The mean of the underlying normal distribution after taking natural logarithm of the K_d values.
(5) The standard deviation of the underlying normal distribution after taking natural logarithm of the K_d values.
(6) Exponential of the mean value [mL/g] or the geometric mean K_d.
(7) Default values for μ and exp(μ) have been predicted using soil-to-plant concentration ratios for nuclides with 0 observations.
(8) Standard deviation for data obtained from using the RESRAD default root uptake transfer factor and the correlation between K_d and the concentration ratio for loamy soil was set to 3.22 to consider a potential wide range of distribution.

LEGEND: NA = not available

Table E-6. Lognormal Distribution Parameters Used for K_d Uncertainty Analyses

Element	Surface Soil, Unsaturated Zone Saturated Zone					Subsurface Soil and Sediment in Contaminated Zone					Bounding Range
	Source(1)	μ(2)	σ(3)	exp(μ)(4)	DP K_d	Source(1)	μ(2)	σ(3)	exp(μ)(4)	DP K_d	
Am	S&T Sand	7.6	2.6	1,900	1,900	S&T Sand	7.6	2.6	1,900	4,000	0.5 - 390
C	S&T Sand	1.1	0.8	5	5	S&T Sand	1.1	0.8	5	7	0.7 - 12
Cm	RESRAD	8.82	1.82	6,761	6760	RESRAD	8.82	1.82	6,761	6760	780 - 22970
Cs	S&T Sand	5.6	2.5	280	280	RESRAD	6.10	2.33	446	480	10 - 10000
I	S&T Sand	0.04	2.2	1.0	1	S&T Clay	0.5	1.5	1	2	0.4 - 81
Np	S&T Sand	1.4	1.7	5	2.3	S&T Sand	1.4	1.7	5	3	0.5 - 390
Pu	RESRAD	6.86	1.89	953	2,600	S&T Clay	8.5	2.1	5,100	3,000	27 - 2550
Sr	S&T Sand	2.6	1.6	15	5	D&M	2.6	1.6	15	15	1 - 190
Tc	S&T Sand	-2.0	1.8	0.1	0.1	RESRAD	-0.67	3.16	0.51	4.1	0.01 - 16
U	S&T Sand	3.5	3.2	35	35	S&T Sand	3.5	3.2	35	10	0.4 - 2200

NOTES: (1) Sources: S&T Sand is Table A-1, Sheppard and Thibault 1990; S&T Clay is Table A-3, Sheppard and Thibault 1990; D&M from Dames and Moore, 1995a, 1995b, and RESRAD is Table 3.9-1, Attachment C, NUREG/CR-6697 (Yu, et al. 2000)

(2) The mean of the underlying normal distribution after taking natural logarithm of the K_d values.

(3) The standard deviation of the underlying normal distribution after taking natural logarithm of the K_d values.

(4) Exponential of the mean value [mL/g] or the geometric mean.

6.0 Parameter Correlation

The RESRAD code allows correlation of input parameters to limit the occurrence of unrealistic physical conditions (e.g., high outdoor and also high indoor time fractions). Parameters were correlated in pairs based on the user specified rank correlation coefficient as presented in Table E-7. The basis for the correlation coefficients for each conceptual model is discussed following the table.

Table E-7. Input Correlations for Probabilistic Evaluation(1)

Parameter 1	Parameter 2	Correlation Coefficient	Basis	Surface Soil Model	Subsurface Model	Sediment Model
Indoor time fraction	Outdoor time fraction	-0.95	Continuity of onsite time	•	•	
Contaminated zone hydraulic conductivity	Unsaturated zone hydraulic conductivity	0.95	Homogeneity in soil column	•		
Contaminated zone hydraulic conductivity	Saturated zone hydraulic conductivity	0.95	Homogeneity in soil column	•		
Unsaturated zone hydraulic conductivity	Saturated zone hydraulic conductivity	0.95	Homogeneity in soil column	•		
Precipitation rate	Rate of irrigation	-0.95	Less irrigation when rainy	•	•	
Precipitation rate	Well pumping rate	-0.95	Less pumping for irrigation when rainy	•	•	
Rate of irrigation	Well pumping rate	0.95	Pumping volume due mainly to irrigation	•	•	
Contaminated zone K_d	Unsaturated zone K_d	0.95	Homogeneity in soil column	•		
Unsaturated zone K_d	Saturated zone K_d	0.95	Homogeneity in soil column	•		
Contaminated zone K_d	Saturated zone K_d	0.95	Homogeneity in soil column	•		
Contaminated zone K_d	Plant transfer factor	-0.87	Baes, et. al. 1984	•	•	•
Contaminated zone K_d	Meat transfer factor	-0.87	Plant correlation used for meat	•	•	•
Contaminated zone K_d	Milk transfer factor	-0.87	Plant correlation used for milk	•	•	
Unsaturated zone K_d	Plant transfer factor	-0.87	Baes, et. al. 1984	•		
Unsaturated zone K_d	Meat transfer factor	-0.87	Plant correlation used for meat	•		
Unsaturated zone K_d	Milk transfer factor	-0.87	Plant correlation used for milk	•		
Saturated zone K_d	Plant transfer factor	-0.87	Baes, et. al. 1984	•		
Saturated zone K_d	Meat transfer factor	-0.87	Plant correlation used for meat	•		
Saturated zone K_d	Milk transfer factor	-0.87	Plant correlation used for milk	•		

NOTES: (1) Presented in the RESRAD probabilistic output files "LHS.REP" for each media.

6.1 Surface Soil Model

This section discusses the parameters correlated in the surface soil model, including distribution coefficients, plant transfer factors, hydraulic conductivities, as well as irrigation, precipitation, and well pumping rates.

The strongly negative correlation (R = -0.87) of K_d with plant transfer factors is based on regression results obtained from computer simulation for a range of elements (Baes, et. al. 1984). This Oak Ridge National Laboratory investigation included all areas of the country and therefore represents average results, which are used in lieu of site-specific correlations. Similarly, the meat and milk transfer coefficients were strongly correlated with the contaminated zone K_d for the principal radionuclides. Transfer factors for principal radionuclide daughter products were not correlated. As each additional parameter requires cross correlating with transfer factors for each soil layer, reducing the number of required correlations allows for reasonable code execution times.

The rate of irrigation and the well pumping rate were strongly correlated (R = 0.95) since the majority of water pumped by the well is used for irrigation. The precipitation rate was strongly negatively correlated (R = -0.95) with the irrigation and well pumping rate, assuming less groundwater will be needed to adequately water crops during wet years.

To ensure that the soils reflect relative homogeneity, the hydraulic conductivity in the three zones (contaminated, unsaturated and saturated) were correlated (R = 0.95).

6.2 Subsurface Soil Model

The subsurface soil model is based on a cistern excavation scenario, and is therefore based on a limited volume of source material brought to the surface. The potential configurations of contaminated zone area and thickness were evaluated in the deterministic sensitivity analysis presented in Section 5. Alternate parameters were selected for probabilistic evaluation.

6.3 Streambed Sediment Model

Parameters correlated in the streambed sediment model included:

- Contaminated zone and saturated zone hydraulic conductivity (0.95), and
- Contaminated zone K_d and plant/meat transfer factors (-0.87).

To ensure that intended correlations were reflected in the RESRAD model input vectors, values were viewed graphically to verify the parameter relationships for each media and radionuclide.

7.0 RESRAD Output

7.1 Basic Approach

The results of the probabilistic evaluation are output from RESRAD in numerous summary data files and graphic displays. As suggested in NUREG/CR-6676 (Kamboj, et al. 2000), the input values generated by the specified distributions and correlations were graphically viewed to verify parameter associations. RESRAD output was tabulated and probabilistic-based DCGLs were calculated as described below.

Additionally, the tabulated output parameter correlation ranks were used to identify the parameters most significantly associated with the modeled dose, as described in subsequent sections. Plots of the modeled dose over time are included in Attachment 1 for each radionuclide and media model. DCGLs were calculated from the RESRAD DSRs in the same manner as described in Appendix C to this plan.

7.2 Surface Soil

Key results of the surface soil evaluation are presented in Table E-8. Table E-9 compares the resulting probabilistic DCGLs with the DCGLs developed using the deterministic method.

As can be seen in Table E-9, key dose drivers Cs-137, Sr-90, I-129 and U-232 had probabilistic peak-of-the-mean DCGLs below the deterministic values, as did all radionuclides except Np-237. Radionuclides were identified as key dose drivers based on preliminary characterization data in WMA1 and WMA2 (See Attachment 1, Tables Att-1 and Att-2). Cs-137, Sr-90, I-129 and U-232 are discussed below (See also Table E-14).

- The Cs-137 dose is due primarily to external exposure in the initial years of exposure. However the depth of source thickness and exposure time fractions were the probabilistic parameters that are directly related to the external pathway, and were not highly correlated with resulting dose.
- The Sr-90 dose is due primarily to plant uptake in the initial years of exposure. Plant uptake factors and depth of roots were highly correlated with the resulting dose.
- I-129 dose is primarily due to ingestion of water and milk in the initial decades of exposure. Length parallel to groundwater flow and contaminated zone thickness were the most highly correlated parameters with the resulting dose.
- U-232 dose is primarily due to external exposure during the initial years of the simulation. The gamma shielding factor, and indoor/outdoor time fractions were most highly correlated with the resulting dose.

Attachment 1 presents plots of the probabilistic (peak-of-the-mean and 95th percentile) and deterministic dose-source ratios (DSRs) for comparison, for the radionuclides listed above. Also presented are plots of deterministic results compared with the cumulative probability derived from the probabilistic modeling. For all radionuclides (with the exception of Np-237) the peak-of-the-mean DCGLs were smaller than the deterministic DCGLs.

Table E-8. Key Output Dose Statistics (DSRs) – Surface Soil Model (mrem/y per pCi/g)[(1)]

Radionuclide	Year of Peak Dose	Minimum	Maximum	Mean	95th Percentile
Am-241	2.01E+02	4.04E-02	3.49E+01	8.68E-01	1.32E+00
C-14	0.00E+00	2.12E-01	2.83E+00	1.53E+00	2.56E+00
Cm-243	0.00E+00	2.70E-01	4.69E+00	7.21E-01	1.60E+00
Cm-244	0.00E+00	4.94E-02	7.38E+00	3.85E-01	1.04E+00
Cs-137	0.0E+00	1.8E+00	2.2E+01	3.3E+00	6.3E+00
I-129	3.43E+00	3.31E-01	1.86E+03	7.68E+01	4.68E+02
Np-237	1.18E+01	9.16E-01	1.02E+03	9.59E+01	5.17E+02
Pu-238	0.00E+00	8.51E-02	8.10E+00	6.26E-01	1.78E+00
Pu-239	8.84E+02	2.73E-02	1.48E+01	9.86E-01	5.83E+00

Table E-8. Key Output Dose Statistics (DSRs) – Surface Soil Model (mrem/y per pCi/g)[1]

Radionuclide	Year of Peak Dose	Minimum	Maximum	Mean	95th Percentile
Pu-240	7.81E+02	5.28E-02	1.32E+01	9.48E-01	5.84E+00
Pu-241	5.18E+01	3.34E-03	2.47E-01	2.15E-02	6.00E-02
Sr-90	0.00E+00	2.12E-01	2.11E+02	1.22E+01	4.17E+01
Tc-99	0.00E+00	2.30E-02	1.39E+01	1.19E+00	3.64E+00
U-232	1.2E+01	1.5E+00	5.6E+02	1.7E+01	1.1E+02
U-233	1.51E+01	2.07E-02	8.61E+01	3.02E+00	2.96E+01
U-234	1.33E+01	1.41E-02	1.35E+02	2.96E+00	2.60E+01
U-235	6.63E+01	7.77E-01	2.20E+01	7.20E+00	1.60E+01
U-238	1.33E+01	3.34E-02	6.82E+01	2.54E+00	2.27E+01

NOTE: (1) From RESRAD probabilistic output file "MCSUMMARY.REP".

Table E-9. Surface Soil $DCGL_W$ Values for 25 mrem in Peak Year in pCi/g

Nuclide	Deterministic[1]	Probabilistic[2]		Percent Difference Deterministic and Peak of the Mean
		Peak-of-the-Mean	95th Percentile	
Am-241	4.31E+01	2.88E+01	1.89E+01	-33%
C-14	2.00E+01	1.63E+01	9.77E+00	-18%
Cm-243	4.06E+01	3.47E+01	1.56E+01	-15%
Cm-244	8.22E+01	6.49E+01	2.40E+01	-21%
Cs-137[3][4]	**2.43E+01**	**1.52E+01**	**7.95E+00**	-37%
I-129[4]	3.47E-01	3.26E-01	5.34E-02	-6%
Np-237	9.42E-02	2.61E-01	4.84E-02	177%
Pu-238	5.03E+01	3.99E+01	1.40E+01	-21%
Pu-239	4.53E+01	2.54E+01	4.29E+00	-44%
Pu-240	4.53E+01	2.64E+01	4.28E+00	-42%
Pu-241	1.42E+03	1.16E+03	4.17E+02	-18%
Sr-90[3][4]	**6.25E+00**	**4.10E+00**	**1.20E+00**	-34%
Tc-99	2.37E+01	2.10E+01	6.87E+00	-11%
U-232[4]	5.84E+00	1.51E+00	2.23E-01	-74%
U-233[4]	1.90E+01	8.28E+00	8.45E-01	-56%
U-234[4]	1.97E+01	8.45E+00	9.62E-01	-57%
U-235[4]	1.87E+01	3.47E+00	1.79E+00	-81%
U-238[4]	2.06E+01	9.84E+00	1.10E+00	-52%

NOTES: (1) From Table 5-8 of Section 5.
(2) From RESRAD probabilistic output file "MCSUMMARY.REP".
(3) DCGLs for these radionuclides are multiplied by a factor of two to account for decay during 30 year institutional control period.
(4) Dose driver radionuclide (see Section 5.2.4 of the plan).

7.3 Subsurface Soil

Key results of the subsurface soil evaluation are presented in Table E-10. Table E-11 compares the resulting probabilistic DCGLs with the DCGLs developed using the deterministic method. Note that the deterministic DCGLs used in this table for comparison purposes are the DCGLs from Table 5-8, which are based on the original base-case conceptual model. The DCGLs from the multi-source analysis that takes into account continuing releases from the bottom of the deep excavations are not directly comparable with the peak-of-the-mean DCGLs because the model used in development of the latter does not account for this secondary source. Table 5-11c in Section 5 of this plan compares all of the different subsurface soil DCGLs.

Note also that the DCGLs presented in Table E-11 reflect a 10 fold dilution of the source term (i.e. using 1/10th the DSRs presented in Table E-10) as described in Section 5 of the DPlan.

As can be seen in Table E-11, only Sr-90, Tc-99, and U-232 had probabilistic peak-of-the-mean DCGLs at least 10 percent below the deterministic values. These radionuclides are discussed below (See also Table E-15).

- The Sr-90 dose is due primarily to plant uptake in the initial years of exposure. Depth of roots and plant uptake factors were highly correlated with the resulting dose.
- The Tc-99 dose is due primarily to plant uptake in the initial years of exposure. Depth of roots and plant uptake factors were highly correlated with the resulting dose.
- The U-232 dose is due primarily to external exposure in the initial years of the simulation. The contaminated zone K_d and gamma shielding factors were most highly correlated with the resulting dose.

Attachment 1 presents the plots of the probabilistic (peak-of-the-mean and 95th percentile) and deterministic DSRs for comparison, for the key dose drivers Sr-90, Cs-137, and U-232. Also presented are plots of deterministic results compared with the cumulative probability derived from the probabilistic modeling. For seven other radionuclides, the peak-of-the-mean DCGLs were greater than or equal to the deterministic.

Table E-10. Key Output Dose Statistics (DSRs) – Subsurface Soil Model (mrem/y per pCi/g)(1)

Radionuclide	Year of Peak Dose	Minimum	Maximum	Mean	95th Percentile
Am-241	0.0E+00	2.4E-02	2.4E-01	3.7E-02	5.8E-02
C-14	0.0E+00	1.4E-04	1.2E-03	3.5E-04	6.9E-04
Cm-243	0.0E+00	1.6E-01	3.8E-01	2.2E-01	2.7E-01
Cm-244	0.0E+00	6.0E-03	7.3E-02	1.1E-02	2.3E-02
Cs-137	0.0E+00	1.4E+00	2.4E+00	1.7E+00	1.8E+00
I-129	1.2E+01	2.1E-03	1.7E+00	3.7E-01	9.6E-01
Np-237	2.5E+01	6.5E-08	2.3E+01	2.7E+00	8.5E+00

Table E-10. Key Output Dose Statistics (DSRs) – Subsurface Soil Model (mrem/y per pCi/g)(1)

Radionuclide	Year of Peak Dose	Minimum	Maximum	Mean	95th Percentile
Pu-238	0.0E+00	9.7E-03	1.6E-01	1.8E-02	3.7E-02
Pu-239	0.0E+00	1.1E-02	1.9E-01	2.0E-02	4.1E-02
Pu-240	0.0E+00	1.1E-02	4.7E-01	2.1E-02	3.9E-02
Pu-241	5.2E+01	2.0E-04	7.7E-03	1.0E-03	1.6E-03
Sr-90	0.0E+00	1.3E-02	5.0E+00	1.5E-01	4.8E-01
Tc-99	0.0E+00	5.5E-04	5.2E-01	1.7E-02	5.7E-02
U-232	6.4E+00	5.4E-03	5.1E+00	3.4E+00	4.6E+00
U-233	3.7E+02	2.3E-14	6.3E-01	2.5E-02	7.4E-02
U-234	3.7E+02	4.5E-07	1.3E+00	2.0E-02	6.7E-02
U-235	0.0E+00	1.5E-01	3.6E-01	2.7E-01	3.3E-01
U-238	0.0E+00	3.3E-02	1.1E-01	5.4E-02	6.6E-02

NOTE: (1) From RESRAD probabilistic output file "MCSUMMARY.REP".

Table E-11. Subsurface Soil $DCGL_W$ Values for 25 mrem in Peak Year in pCi/g

Nuclide	Deterministic(1)	Probabilistic(2)		Percent Difference Deterministic and Peak-of-the-Mean
		Peak-of-the-Mean	95th Percentile	
Am-241	7.16E+03	6.81E+03	4.30E+03	-5%
C-14	5.59E+05	7.18E+05	3.64E+05	28%
Cm-243	1.15E+03	1.12E+03	9.33E+02	-3%
Cm-244	2.37E+04	2.21E+04	1.08E+04	-7%
Cs-137(3)(4)	**4.36E+02**	**3.01E+02**	**2.72E+02**	-31%
I-129(4)	6.46E+02	6.70E+02	2.60E+02	4%
Np-237	5.77E+01	9.33E+01	2.95E+01	62%
Pu-238	1.47E+04	1.37E+04	6.83E+03	-7%
Pu-239	1.33E+04	1.23E+04	6.11E+03	-7%
Pu-240	1.33E+04	1.21E+04	6.44E+03	-9%
Pu-241	2.41E+05	2.50E+05	1.59E+05	4%
Sr-90(3)(4)	**4.36E+03**	**3.42E+03**	**1.03E+03**	-21%
Tc-99	1.59E+04	1.44E+04	4.36E+03	-10%
U-232(4)	1.06E+02	7.40E+01	5.43E+01	-30%
U-233(4)	2.72E+03	9.92E+03	3.39E+03	264%
U-234(4)	2.81E+03	1.26E+04	3.75E+03	349%
U-235(4)	9.41E+02	9.33E+02	7.60E+02	-1%

Table E-11. Subsurface Soil $DCGL_W$ Values for 25 mrem in Peak Year in pCi/g

Nuclide	Deterministic(1)	Probabilistic(2)		Percent Difference Deterministic and Peak-of-the-Mean
		Peak-of-the-Mean	95th Percentile	
U-238(4)	2.94E+03	4.60E+03	3.79E+03	57%

NOTES: (1) From Table 5-8 of Section 5. More limiting deterministic values for the resident gardener are available as an alternative comparison for some radionuclides. Refer to Section 5.2.6 for a comparison between the probabilistic DCGLs and all other sets of subsurface soil DCGLs.

(2) From RESRAD probabilistic output file "MCSUMMARY.REP" for the resident farmer with a contamination zone of 100 m^2.

(3) DCGLs for these radionuclides are multiplied by a factor of two to account for decay during 30 year institutional control period.

(4) Dose driver radionuclide (see Section 5.2.4 of the plan).

7.3 Streambed Sediment

Key results of the streambed sediment evaluation are presented in Table E-12. Table E-13 compares the resulting probabilistic DCGLs with the DCGLs developed using the deterministic method.

As can be seen in Table E-13, all radionuclides had probabilistic peak-of-the-mean DCGLs at least 10 percent below the deterministic values. Key dose drivers for sediment are Sr-90 and Cs-137. These radionuclides are discussed below (See also Table E-16).

- Sr-90 dose is due primarily to ingestion of venison in the initial years of exposure. The resulting dose is highly correlated to the contaminated zone K_d value; however, the plant and fish biotransfer factors were more closely correlated than the meat biotransfer factors.
- Cs-137 dose is primarily due to external exposure in the initial years of exposure. As expected, the outdoor time fraction was highly correlated with dose.

Attachment 1 presents the plots of the probabilistic (peak-of-the-mean and 95th percentile) and deterministic DSRs for comparison. Also presented are plots of deterministic results compared with the cumulative probability derived from the probabilistic modeling.

Table E-12. Key Output Dose Statistics (DSRs) – Streambed Sediment Model (mrem/y per pCi/g)(1)

Radionuclide	Year of Peak Dose	Minimum	Maximum	Mean	95th Percentile
Am-241	1.0E+00	9.1E-04	5.7E-02	2.5E-03	4.8E-03
C-14	0.0E+00	5.8E-03	4.5E-01	1.4E-02	3.4E-02
Cm-243	0.0E+00	3.7E-03	1.4E-02	8.2E-03	1.2E-02
Cm-244	0.0E+00	2.6E-04	2.4E-03	6.5E-04	9.9E-04
Cs-137	0.0E+00	2.3E-02	8.8E-02	4.8E-02	6.9E-02
I-129	0.0E+00	6.1E-03	6.6E-01	3.2E-02	7.2E-02
Np-237	0.0E+00	1.0E-02	2.2E+00	7.7E-02	2.3E-01
Pu-238	1.0E+00	6.9E-04	1.4E-01	2.0E-03	3.6E-03
Pu-239	1.0E+00	8.8E-04	2.3E-02	2.1E-03	4.1E-03

Table E-12. Key Output Dose Statistics (DSRs) – Streambed Sediment Model (mrem/y per pCi/g)[(1)]

Radionuclide	Year of Peak Dose	Minimum	Maximum	Mean	95th Percentile
Pu-240	1.0E+00	9.0E-04	1.6E-02	2.1E-03	4.2E-03
Pu-241	5.2E+01	2.8E-05	1.9E-03	7.3E-05	1.3E-04
Sr-90	0.0E+00	1.4E-03	1.5E-01	1.1E-02	3.0E-02
Tc-99	0.0E+00	3.4E-06	1.1E-03	3.8E-05	1.1E-04
U-232	7.2E+00	4.6E-02	9.3E-01	1.1E-01	1.7E-01
U-233	0.0E+00	1.1E-04	5.2E-02	1.2E-03	3.9E-03
U-234	0.0E+00	1.2E-04	2.9E-02	1.2E-03	4.2E-03
U-235	0.0E+00	4.9E-03	4.0E-02	1.1E-02	1.6E-02
U-238	0.0E+00	1.1E-03	9.0E-02	3.1E-03	5.5E-03

NOTE: (1) From RESRAD probabilistic output file "MCSUMMARY.REP".

Table E-13. Streambed Sediment $DCGL_W$ Values for 25 mrem in Peak Year in pCi/g

Nuclide	Deterministic[(1)]	Probabilistic[(2)]		Percent Difference Deterministic and Peak-of-the-Mean
		Peak-of-the-Mean	95th Percentile	
Am-241	1.55E+04	1.02E+04	5.19E+03	-34%
C-14	3.44E+03	1.84E+03	7.42E+02	-46%
Cm-243	3.59E+03	3.06E+03	2.08E+03	-15%
Cm-244	4.84E+04	3.83E+04	2.52E+04	-21%
Cs-137[(3)(4)]	**1.29E+03**	**1.04E+03**	**7.24E+02**	-19%
I-129	3.69E+03	7.91E+02	3.49E+02	-79%
Np-237	5.19E+02	3.25E+02	1.11E+02	-37%
Pu-238	1.99E+04	1.24E+04	7.02E+03	-38%
Pu-239	1.79E+04	1.19E+04	6.08E+03	-33%
Pu-240	1.79E+04	1.20E+04	5.98E+03	-33%
Pu-241	5.11E+05	3.44E+05	1.92E+05	-33%
Sr-90[(3)(4)]	**9.49E+03**	**4.72E+03**	**1.67E+03**	-50%
Tc-99	2.17E+06	6.61E+05	2.38E+05	-70%
U-232	2.61E+02	2.23E+02	1.49E+02	-15%
U-233	5.75E+04	2.16E+04	6.38E+03	-62%
U-234	6.04E+04	2.16E+04	5.94E+03	-64%
U-235	2.89E+03	2.34E+03	1.58E+03	-19%
U-238	1.25E+04	8.17E+03	4.55E+03	-34%

NOTES: (1) From Table 5-8 of Section 5.
(2) From RESRAD probabilistic output file "MCSUMMARY.REP".

(3) DCGLs for these radionuclides are multiplied by a factor of two to account for decay during 30 year institutional control period.
(4) Dose driver radionuclide (see Section 5.2.4 of the plan).

7.4 Preliminary Dose Assessment for Remediated WMA 1 Excavation

As indicated in Section 5.4.4 of this plan, the preliminary dose assessment for the remediated WMA 1 excavated area estimated by using information from the multi-source deterministic analysis was a maximum of approximately 8 mrem per year. Using the probabilistic modeling results, the estimates are as follows:

- A peak-of-the-mean estimate of 1.9 mrem per year
- A 95th percentile value of 2.8 mrem per year

Table Att-1 of Attachment 1 shows the calculations of these values. The probabilistic results were not used because they were lower than the 8 mrem per year estimate produced using information from the multi-source deterministic analysis.

7.5 Preliminary Dose Assessment for Remediated WMA 2 Excavation

As indicated in Section 5.4.4 of this plan, the preliminary dose assessment for the remediated WMA 2 excavated area estimated by using information from the multi-source deterministic analysis was a maximum of approximately 0.2 mrem per year. Using the probabilistic modeling results, the estimates are as follows:

- A peak-of-the-mean estimate of 0.11 mrem per year
- A 95th percentile value of 0.13 mrem per year

Table Att-2 of Attachment 1 shows the calculations of these values. The probabilistic results were not used because they were lower than the 0.2 mrem per year estimate produced using information from the multi-source deterministic analysis.

8.0 Parameter Output Rank Correlations

The RESRAD results include several correlations of input parameters with the output modeled dose. Several correlations are available based on actual numerical calculated values and relative rankings.

Guidance for RESRAD probabilistic modeling in NUREG/CR-6676 (Kamboj, et al. 2000) indicates that correlation coefficients based on relative rankings are preferable where nonlinear relationships, widely disparate scales, or long tails are present in the input and outputs. Therefore, determinations of parameter significance presented in this section are based on the partial rank correlation coefficient (PRCC). Where strong correlations between an input parameter and the dose were indicated in the output ranking, scatter plots were inspected to confirm the conclusion.

RESRAD also calculates the overall coefficients of determination (R^2) for each model, which provides an indication of the variability in the overall radionuclide dose accounted for by the selected input parameters.

As described previously, numerous parameters were selected for probabilistic evaluation for each radionuclide. The tables presented and discussed below focus on the three highest ranked parameter correlations for all included parameters for each radionuclide in each media.

To ensure sufficient model iterations were being used to allow for convergence of the results, three sets of 1,000 iterations were selected. This was considered to be appropriate as the peak-of-the-mean doses for the three datasets were within approximately +/-10 percent. The run with the largest peak-of-the-mean dose was selected as the basis for the information in the summary tables.

8.1 Surface Soil Model

Table E-14 presents a summary of the parameters which correlate most closely with the overall dose for each radionuclide. In general, K_d, plant transfer factors, and root zone depth were most strongly correlated with dose. The plant transfer factors have the higher correlations (mostly >0.7) when compared with K_d (<0.7).

The R^2 values ranged from 0.71 (U-232) to 0.99 (I-129). Where the overall correlation is low, identification of additional probabilistic parameters for these radionuclides may better describe the variability in the model output.

Table E-14. Summary of Parameter Rankings – Surface Soil Model[1]

Nuclide	Parameter Ranking			Simulation No. (R^2)
	1	2	3	
Am-241	Plant transfer factor for Am (0.78)	Contaminated zone Thickness (0.54)	Depth of roots (-0.49)	3 (0.93)
C-14	Contaminated zone thickness (0.98)	Depth of roots (-0.79)	Plant transfer factor for C (0.08)	3 (0.96)
Cm-243	Plant transfer factor for Cm (0.86)	Contaminated zone Thickness (0.65)	Depth of roots (-0.64)	2 (0.96)
Cm-244	Plant transfer factor for Cm (0.87)	Contaminated zone Thickness (0.68)	Depth of roots (-0.67)	3 (0.96)
Cs-137	Plant transfer factor for Cs (0.71)	Depth of roots (-0.56)	Contaminated zone Thickness (0.52)	3 (0.95)
I-129	Length parallel to groundwater flow (0.64)	Contaminated zone Thickness (0.62)	Irrigation rate (0.34)	2 (0.99)
Np-237	Length parallel to groundwater flow (0.73)	Contaminated zone Thickness (0.60)	Saturated zone hydraulic conductivity (-0.45)	2 (0.99)
Pu-238	Plant transfer factor for Pu (0.86)	Depth of roots (-0.67)	Contaminated zone Thickness (0.66)	3 (0.96)
Pu-239	Plant transfer factor for Pu (0.72)	Depth of roots (-0.44)	Contaminated zone Thickness (0.43)	1 (0.91)
Pu-240	Plant transfer factor for Pu (0.74)	Depth of roots (-0.44)	Contaminated zone Thickness (0.43)	1 (0.91)
Pu-241	Plant transfer factor for Am (0.81)	Contaminated zone Thickness (0.39)	Depth of roots (-0.37)	1 (0.75)
Sr-90	Plant transfer factor for Sr (0.84)	Depth of roots (-0.62)	Contaminated zone thickness (0.60)	3 (0.96)

Table E-14. Summary of Parameter Rankings – Surface Soil Model[1]

Nuclide	Parameter Ranking			Simulation No. (R^2)
	1	2	3	
Tc-99	Contaminated zone Thickness (0.67)	Plant transfer factor for Tc (0.55)	Depth of roots (-0.33)	3 (0.92)
U-232	Gamma shileding factor (0.38)	Outdoor time fraction (0.34)	Indoor time fraction (0.21)	1 (0.67)
U-233	Contaminated zone Thickness (0.23)	Meat transfer factor for U (-0.19)	Plant transfer factor for Th (0.18)	3 (0.92)
U-234	Contaminated zone Thickness (0.32)	Meat transfer factor for U (-0.15)	Depth of roots (-0.13)	3 (0.95)
U-235	Length parallel to groundwater flow (0.78)	Contaminated zone Thickness (0.77)	Saturated zone Kd (-0.46)	3 (0.93)
U-238	Contaminated zone Thickness (0.23)	Length parallel to groundwater flow (0.16)	Depth of roots (-0.16)	1 (0.96)

NOTE: (1) From RESRAD probabilistic output file "MCSUMMARY.REP". Simulation (out of three) with largest peak-of-the-mean dose was used to determine the parameter ranking, based on the PRCCs with statistic (either R or R2) in parentheses.

8.2 Subsurface Soil Model

As shown in Table E-15, the most highly correlated parameters for the subsurface model, like with the surface soil model, are the K_d, plant transfer coefficients, and root depth. The highest correlations (-0.99) were calculated for the depth of roots; however the K_d correlations were generally lower than those for the plant transfer factors. The R^2 values ranged from 0.17 (U-233) to 1.00 (Np-237).

Table E-15. Summary of Parameter Rankings - Subsurface Soil Model[1]

Nuclide	Parameter Ranking			Simulation No. (R^2)
	1	2	3	
Am-241	Depth of roots (-0.82)	Plant transfer factor for Am (0.76)	Outdoor time fraction (0.58)	1 (0.93)
C-14	Depth of roots (-0.99)	Meat transfer factor for C (0.18)	Plant transfer factor for C (0.17)	2 (0.98)
Cm-243	Outdoor time fraction (0.91)	Indoor time fraction (0.53)	Plant transfer factor for Cm (-0.44)	1 (0.96)
Cm-244	Depth of roots (-0.93)	Plant transfer factor for Cm (0.89)	Indoor time fraction (0.40)	1 (0.97)
Cs-137	Outdoor time fraction (0.93)	Gamma shielding factor (0.92)	Indoor time fraction (0.81)	3 (0.96)
I-129	Contaminated zone K_d for I (-0.94)	Well pumping rate (-0.56)	Irrigation rate (0.27)	1 (0.99)
Np-237	Contaminated zone K_d for Np (-0.95)	Well pumping rate (-0.55)	Irrigation rate (0.29)	3 (1.00)
Pu-238	Depth of roots (-0.93)	Plant transfer factors for Pu (0.32)	Outdoor time fraction (0.32)	1 (0.97)
Pu-239	Depth of roots (-0.93)	Plant transfer factor for Pu (0.89)	Outdoor time fraction (0.29)	2 (0.97)

Table E-15. Summary of Parameter Rankings - Subsurface Soil Model[1]

Nuclide	Parameter Ranking			Simulation No. (R^2)
	1	2	3	
Pu-240	Depth of roots (-0.93)	Plant transfer factor for Pu (0.90)	Indoor time fraction (0.33)	1 (0.97)
Pu-241	Plant transfer factor for Am (0.81)	Depth of roots (-0.62)	Contaminated zone K_d for Am (0.52)	1 (0.77)
Sr-90	Depth of roots (-0.94)	Plant transfer factor for Sr (0.91)	Contaminated zone K_d for Cs (-0.10)	1 (0.98)
Tc-99	Depth of roots (-0.93)	Plant transfer factor for Tc (0.90)	Well pumping rate (-0.10)	1 (0.97)
U-232	Contaminated zone K_d for U (0.49)	Gamma shielding factor (0.48)	Outdoor time fraction (0.41)	3 (0.87)
U-233	Contaminated zone K_d for U (-0.34)	Milk transfer factor for U (-0.31)	Plant transfer factor for U (-0.29)	3 (0.17)
U-234	Contaminated zone K_d for U (-0.31)	Milk transfer factor for U (-0.24)	Meat transfer factor for U (-0.22)	3 (0.25)
U-235	Outdoor time fraction (0.71)	Indoor time fraction (0.28)	Meat transfer factor for U (-0.15)	2 (0.85)
U-238	Outdoor time fraction (0.48)	Milk transfer factor for U (-0.22)	Meat transfer factor for U (-0.21)	1 (0.62)

NOTE: (1) From RESRAD probabilistic output file "MCSUMMARY.REP". Simulation (out of three) with largest peak-of-the-mean dose was used to determine the parameter ranking, based on the Partial Rank Correlation Coefficients (PRCC) with statistic (either R or R2) in parentheses.

8.3 Streambed Sediment Model

Table E-16 shows the correlation coefficients and highest ranked sediment parameters for streambed sediment. Fourteen radionuclides have a correlation coefficient greater than or equal to 0.85 and one radionuclide has a coefficient below 0.5. The R^2 values ranged from 0.23 (U-233) to 0.99 (Cm-243). The outdoor time fraction accounted for the majority of the highest correlations.

Table E-16. Summary of Parameter Rankings – Streambed Sediment Model[1]

Nuclide	Parameter Ranking			Simulation No. (R^2)
	1	2	3	
Am-241	Outdoor time fraction (0.86)	Fish transfer factor for Am (0.43)	Meat transfer factor for Am (0.13)	1 (0.81)
C-14	Fish transfer factor for C (0.98)	Contaminated zone K_d for C (-0.43)	Meat transfer factor for C (0..07)	1 (0.97)
Cm-243	Outdoor time fraction (1.00)	Contaminated zone K_d for Cm (-0.14)	Fish transfer factor for Cm (0.11)	1 (0.99)
Cm-244	Outdoor time fraction (0.92)	Fish transfer factor for Cm (0.29)	Meat transfer factor for Cm (0.26)	1 (0.89)
Cs-137	Outdoor time fraction (0.99)	Meat transfer factor for Cs (0.33)	Plant transfer factor for Cs (0.18)	1 (0.98)
I-129	Fish transfer factor for I (0.81)	Contaminated zone K_d for I (-0.48)	Meat transfer factor for I (0.44)	1 (0.95)

Table E-16. Summary of Parameter Rankings – Streambed Sediment Model(1)

Nuclide	Parameter Ranking			Simulation No. (R^2)
	1	2	3	
Np-237	Fish transfer factor for Np (0.89)	Outdoor time fraction (0.52)	Contaminated zone K_d for Np (-0.47)	1 (0.93)
Pu-238	Outdoor time fraction (0.82)	Fish transfer factor for Pu (0.74)	Contaminated zone K_d for Pu (-0.23)	1 (0.87)
Pu-239	Outdoor time fraction (0.81)	Fish transfer factor for Pu (0.74)	Contaminated zone K_d for Pu (-0.27)	1 (0.86)
Pu-240	Outdoor time fraction (0.81)	Fish transfer factor for Pu (0.74)	Contaminated zone K_d for Pu (-0.30)	1 (0.96)
Pu-241(2)	Outdoor time fraction (0.79)	Contaminated zone K_d for Am (-0.58)	Fish transfer factor for Am (0.38)	1 (0.72)
Sr-90	Contaminated zone K_d for Sr (-0.73)	Fish transfer factor for Sr (0.59)	Plant transfer factor for Sr (0.30)	1 (0.97)
Tc-99	Fish transfer factor for Tc (0.91)	Plant transfer factor for Tc (0.17)	Meat transfer factor for Tc (0.13)	1 (0.86)
U-232	Outdoor time fraction (0.96)	Fish transfer factor for U (0.27)	Plant transfer factor for U (-0.14)	1 (0.93)
U-233	Contaminated zone K_d for Th (-0.21)	Outdoor time fraction (0.26)	Meat transfer factor for Tc (0.20)	1 (0.23)
U-234	Fish transfer factor for U (0.45)	Outdoor time fraction (0.28)	Contaminated zone K_d for U (-0.26)	3 (0.78)
U-235	Outdoor time fraction (0.94)	Fish transfer factor for U (0.35)	Meat transfer factor for U (0.20)	1 (0.90)
U-238	Outdoor time fraction (0.85)	Fish transfer factor for U (0.41)	Contaminated zone K_d for U (-0.23)	1 (0.85)

NOTES: (1) From RESRAD probabilistic output file "MCSUMMARY.REP". Simulation (out of three) with largest peak-of-the-mean dose was used to determine the parameter ranking, based on the Partial Rank Correlation Coefficients (PRCC) with statistic (either R or R2) in parentheses.
(2) This analog was assumed give the decay of Pu-241 to Am-241.

9.0 Conclusions from the Uncertainty Analyses and Related Actions

9.1 Conclusions

The following conclusions can be drawn from the results of the probabilistic modeling described above.

Surface Soil DCGLs

Table E-9 shows that deterministic DCGLs for 17 of the 18 radionuclides of interest are not bounding because they are greater than the peak-of-the mean probabilistic DCGLs. Parameters highly correlated with the output are plant transfer factors, depth of roots, and length parallel to aquifer flow.

The length parallel to aquifer flow is a parameter selected to vary the dilution factor in groundwater.

These input parameters therefore lack sufficient conservatism insofar as the 17 radionuclides are concerned. This group of radionuclides includes three that have been identified as dose drivers: Sr-90, Cs-137, and U-235.

The lack of conservatism in these surface soil criteria can be quantified in another manner by considering the average soil concentrations at the deterministic DCGLs. If the average residual concentration of Sr-90, for example, were to be 6.25 pCi/g (the deterministic DCGL for surface soil), then the probabilistic modeling would indicate that the probability that the resulting dose would not exceed 25 mrem in the peak year would be approximately 55 percent (see Figure Att-2 in Attachment 1).

The primary conclusion for the surface soil model is that some input parameters used in the deterministic modeling are not sufficiently conservative and, consequently, the deterministic DCGLs for 17 radionuclides are not bounding.

Subsurface Soil DCGLs

Table E-11 shows that 10 of the deterministic DCGLs are not bounding because they exceed the peak-of-the mean probabilistic DCGLs, however only three radionuclides were below the deterministic DCGL by more than 10 percent. The comparisons above are based on the deterministic values for the resident farmer scenario, however more limiting values are available for the resident gardener scenario for comparison. The most limiting of all deterministic and probabilistic scenarios will be used to establish the cleanup levels (See Section 5). Parameters highly correlated with the output are depth of roots, contaminated zone K_d, and outdoor time fraction. The outdoor time fraction is based on assumptions of anticipated activity and may be refined with additional site-specific considerations. Refer to Section 5.2.6 for comparisons between the probabilistic DCGLs and other sets of subsurface soil DCGLs.

Streambed Sediment DCGLs

Table E-13 indicates that none of the deterministic DCGLs are bounding because they all exceed the peak-of-the-means DCGLs. For the key sediment dose drivers Sr-90 and Cs-137, the probabilistic values less than the deterministic by 50 percent and 19 percent respectively. The outdoor time fraction is most highly correlated with the dose for Cs-137, and Sr-90 was most highly correlated with the contaminated zone K_d. The outdoor time fraction is based on assumptions of anticipated activity and may be refined with additional site-specific considerations.

Preliminary Dose Assessments

The probabilistic dose estimates for the WMA 1 excavation area show that doses are likely to be less than 1.9 mrem/y, due primarily to Sr-90. The probabilistic dose estimates for the WMA 2 excavation area show that the doses are likely to be less than 0.11 mrem/y, due primarily to Cs-137.

Based on these results, it is anticipated that a small number of radionuclides will account for the majority of the dose.

Input Parameters and Dose Variability

The determination of which input parameters account for the majority of variability in the output was accomplished by inspection of the output correlation coefficients, which indicated the following:

- For surface soil, output dose results were well described by the input parameters, as only two radionuclides (Pu-241 and U-232) had coefficients of determination <+/-0.9. The highest parameter correlations (>+/-0.7) were for plant transfer factors and contaminated zone thickness.
- For subsurface soil, the variability in the calculated dose was moderately well described by the input parameters (six radionuclides with R^2 <+/-0.9). The highest correlations for individual parameters (>+/-0.9) were the depth of roots, contaminated zone K_d, and outdoor time fraction
- Sediment dose variability was well described by the input parameters (nine radionuclides with R^2 <+/-0.9), with the highest correlations (>+/-0.9) observed for the outdoor time fraction and fish transfer factor.

The probabilistic evaluation has identified parameters that are well correlated with the calculated dose. Based on these results, the input parameters that account for the majority of variability in the output are plant transfer factors, contaminated zone thickness, depth of roots, contaminated zone K_d , outdoor time fraction, and fish transfer factors.

9.2 Actions

The conclusions on the probabilistic uncertainty analysis results just described led to the decision to make use of the probabilistic peak-of-the-mean DCGLs in place of the deterministic DCGLs provided in Revision 0 to this plan for surface soil and streambed sediment. The probabilistic peak-of-the-mean DCGLs were used for subsurface soil for three radionuclides as discussed in Section 5.2.6. Changes in Section 5 made as part of Revision 2, including changes to the cleanup goals, reflect these decisions.

10.0 References

Baes. et.al. 1984, *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*, ORNL-5786. Base, C.F. III, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September, 1984.

DOE 2008, DOE letter from Cynthia Anderson (Deputy Chief Operations Officer) to Keith McConnell of NRC (Deputy Director, Decommissioning and Uranium Recovery Licensing Directorate) dated December 3, 2008.

EPA 1999, *UNDERSTANDING VARIATION IN PARTITION COEFFICIENT, K_d, VALUES, Volume II: Review of Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (^3H), and Uranium*, Report EPA 402-R-99-004B. US Environmental Protection Agency, Washington, D.C., August 1999.

EPA 2004, *UNDERSTANDING VARIATION IN PARTITION COEFFICIENT, K_d, VALUES, Volume III: Review of Geochemistry and Available K_d Values for Americium,* *Arsenic, Curium, Iodine, Neptunium, Radium, and Technetium,* Report EPA 402-R-99-004C. US Environmental Protection Agency, Washington, D.C., July 2004.

Kamboj, et al. 2000, *Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes*, NUREG/CR-6676, ANL/EAD/TM-89. Kamboj, S. et al. Environmental Assessment Division, Argonne National Laboratory, Chicago, Illinois, May 2000.

LePoire, et al. 2000, *Probabilistic Modules for the RESRAD and RESRAD-Build Computer Codes, User Guide*, NUREG-CR-6692, ANL/EAD/TM-91. LePoire, D., et al. Environmental Assessment Division, Argonne National Laboratory, Chicago, Illinois, November 2000.

NRC 2006, *Consolidated NMSS Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria, Final Report*, NUREG 1757 Volume 2, Revision 1. NRC, Office of Nuclear Material Safety and Safeguards, Washington, DC, September, 2006.

NRC 2008, *Report of October 21, 2008 Meeting With U.S. Department of Energy on Dose Modeling Approach for Phase 1 Decommissioning Plan*. Forwarded by letter from NRC (Rebecca Tadesse, Chief, Materials Decommissioning Branch, Decommissioning and Uranium Recovery Licensing Directorate) to DOE (Bruce Bower, WVDP) dated November 18, 2008.

Sheppard and Thibault 1990, "Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium," Sheppard, M.I., and D.H. Thibault, *Health Physics*, 59:471-482, 1990.

Yu, et al. 2000, *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, NUREG/CR-6697, ANL/EAD/TM-98. Yu, C., et al., Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois, November 2000.

Yu, et al. 2001, *User's Manual for RESRAD Version 6*, ANL/EAD-4. Yu, C., et al., Environmental Assessment Division, Argonne National Laboratory, Argonne, Illinois, July 2001.

11.0 ATTACHMENTS

(1) Plots of Probabilistic and Deterministic Results

(2) Electronic Files Described in Section 1.3 (provided separately)

ATTACHMENT 1

Plots of Probabilistic and Deterministic Results

Note that the deterministic results used in this attachment are the deterministic results based on the original base-case conceptual model. The multi-source analysis results were not used because they are not directly comparable with the probabilistic results.

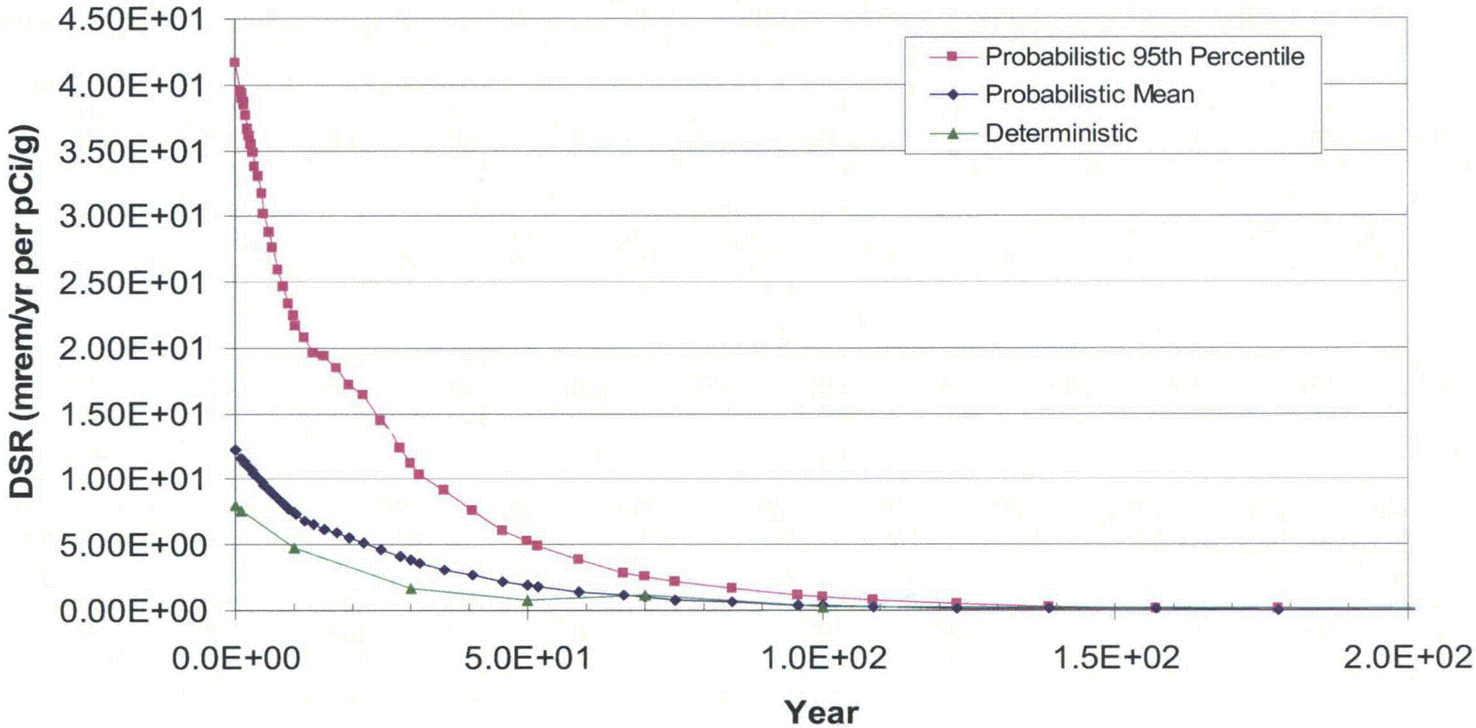

Figure Att-1. Probabilistic and Deterministic Dose-Source Ratio vs. Time, Sr-90 – Surface Soil

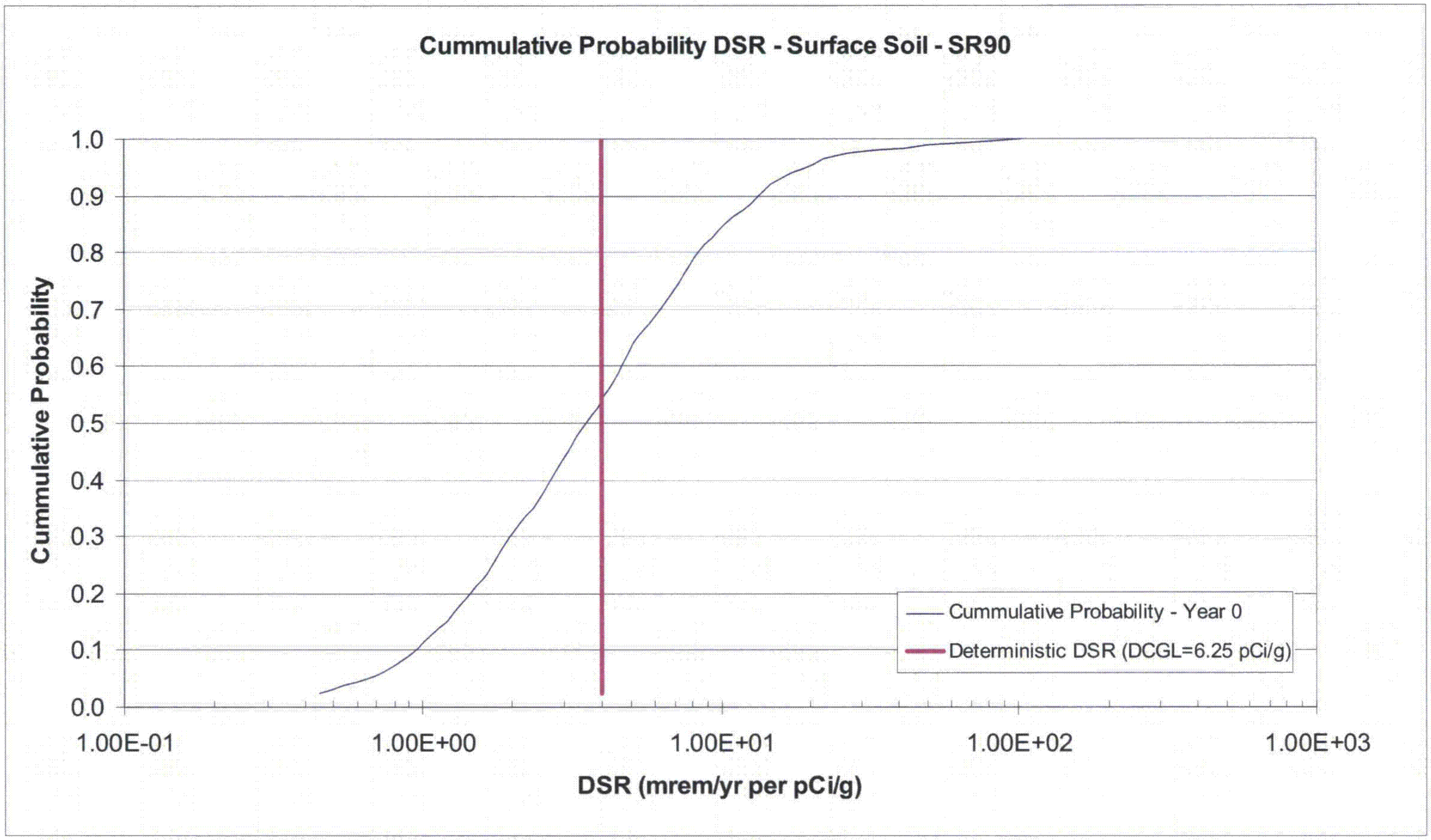

Figure Att-2. Cumulative Probability Dose-Source Ratio, Sr-90 – Surface Soil

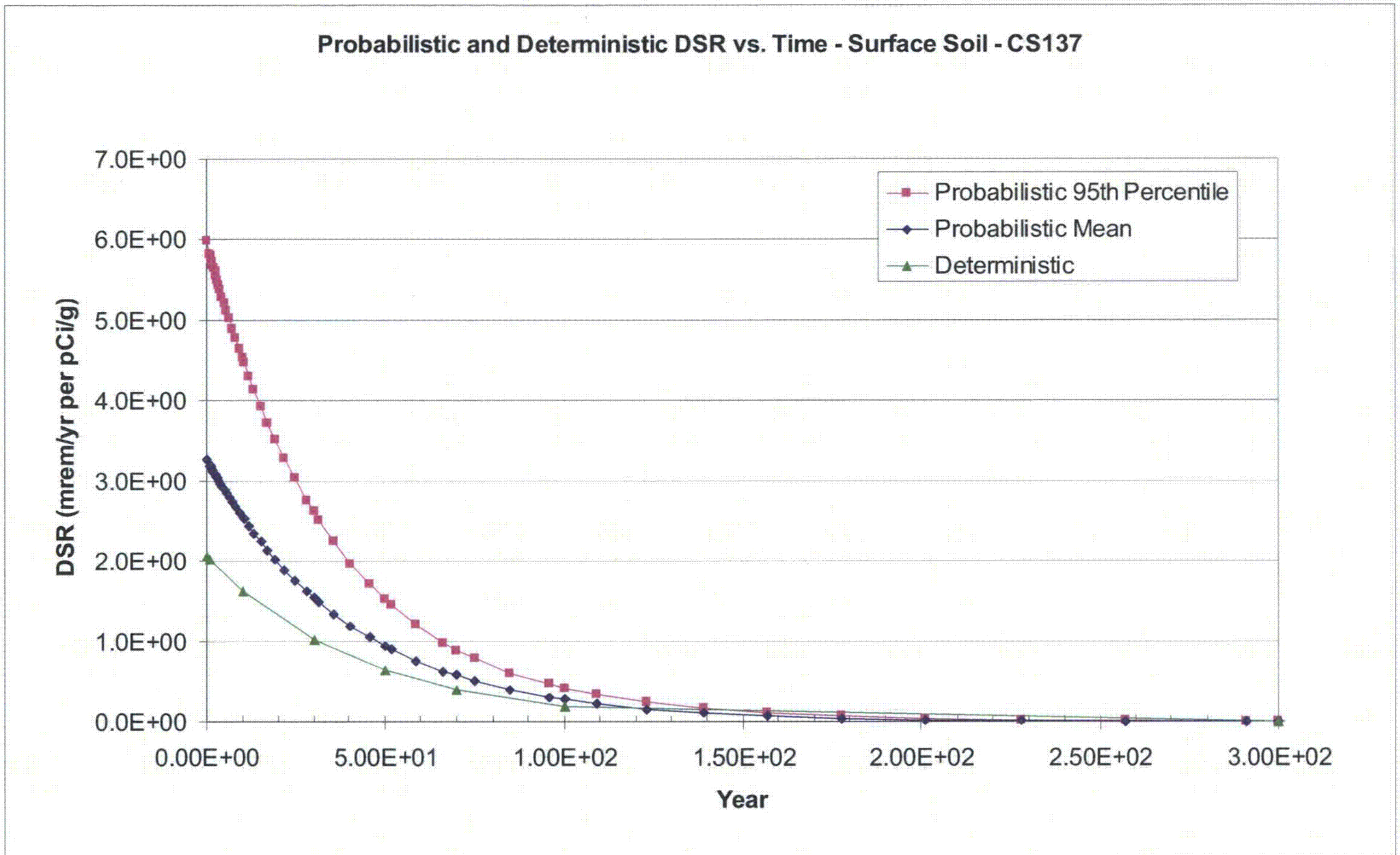

Figure Att-3. Probabilistic and Deterministic Dose-Source Ratio, Cs-137 – Surface Soil

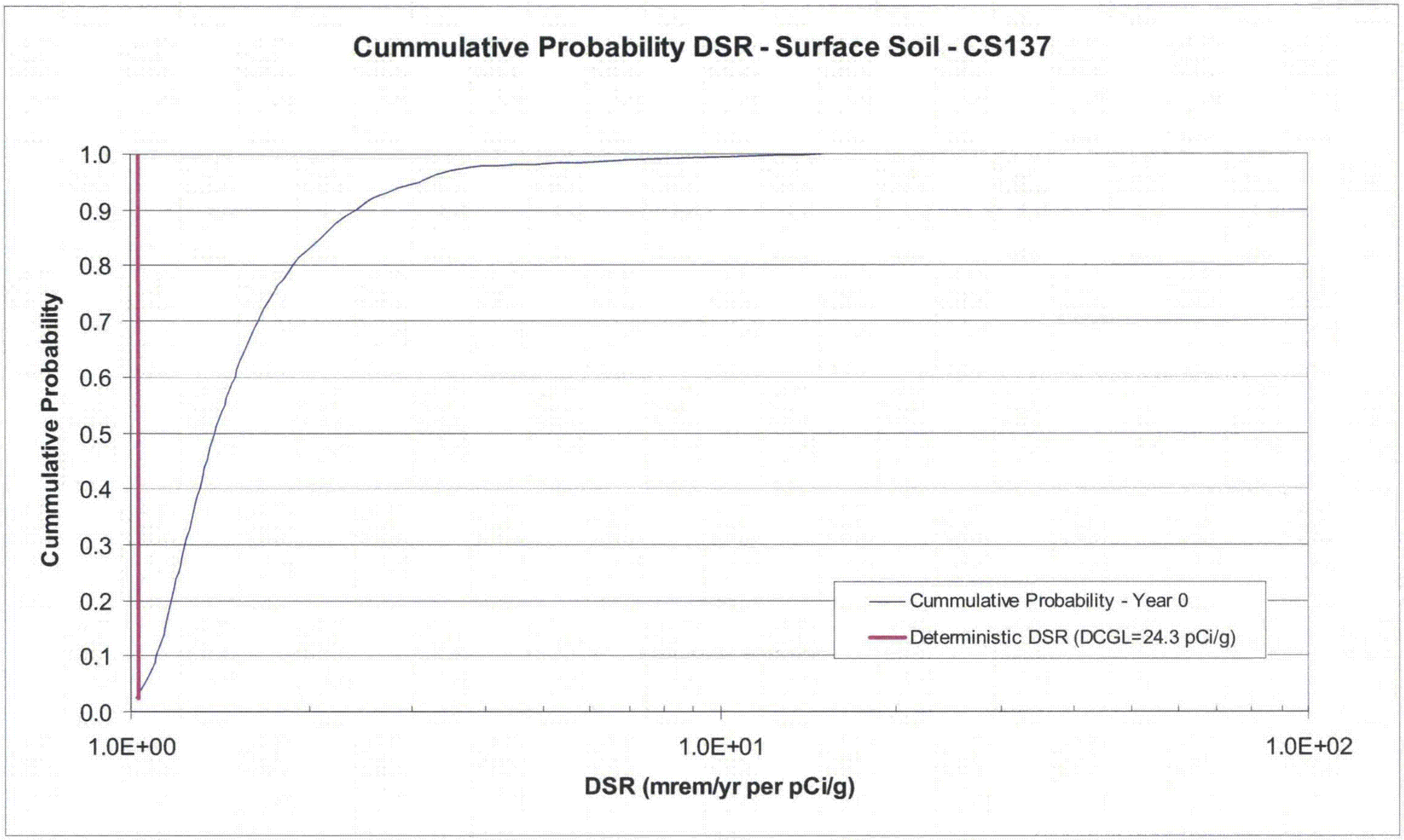

Figure Att-4. Cumulative Probability Dose-Source Ratio, Cs-137 – Surface Soil

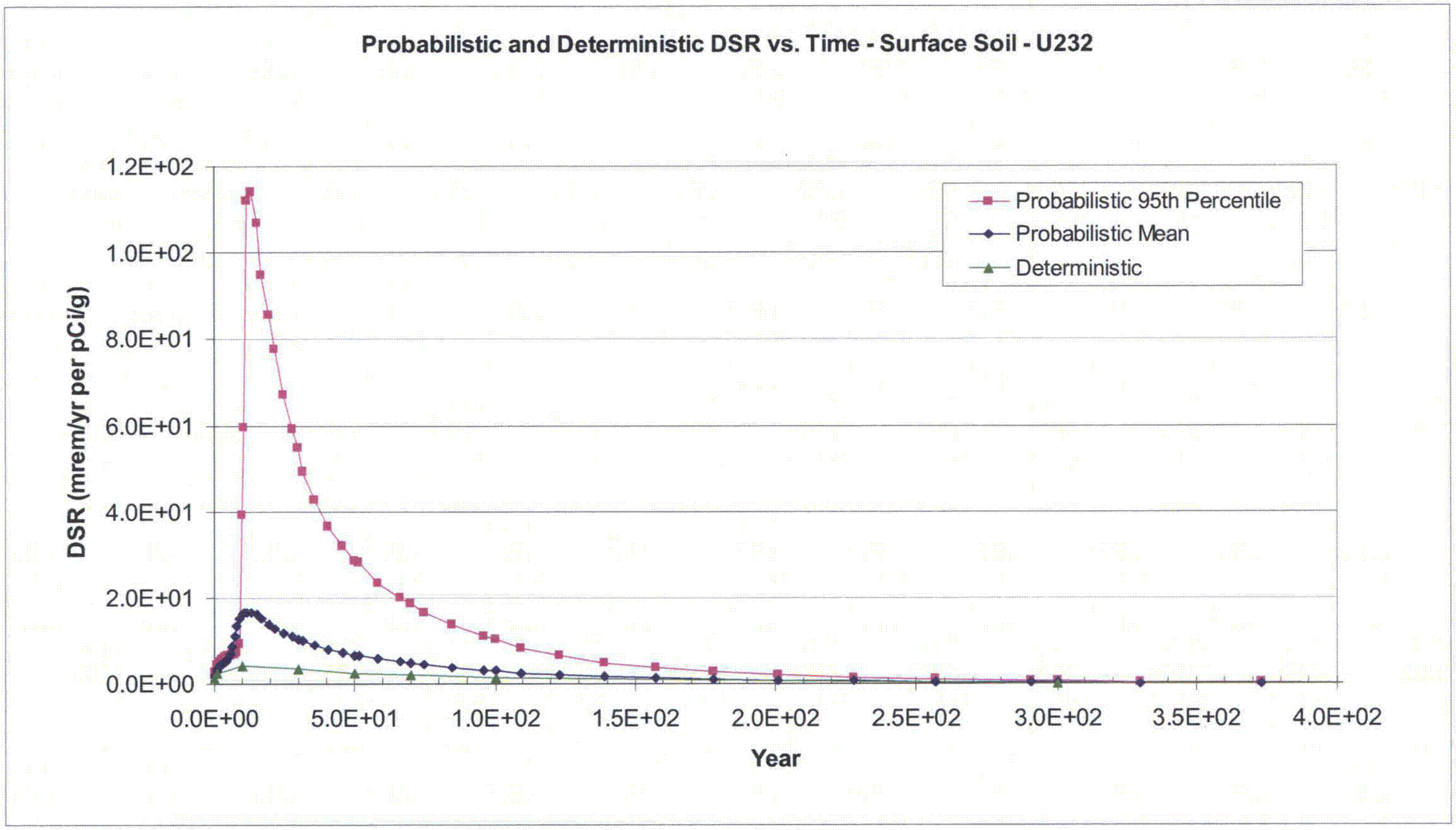

Figure Att-5. Probabilistic and Deterministic Dose-Source Ratio vs. Time, U-232 – Surface Soil

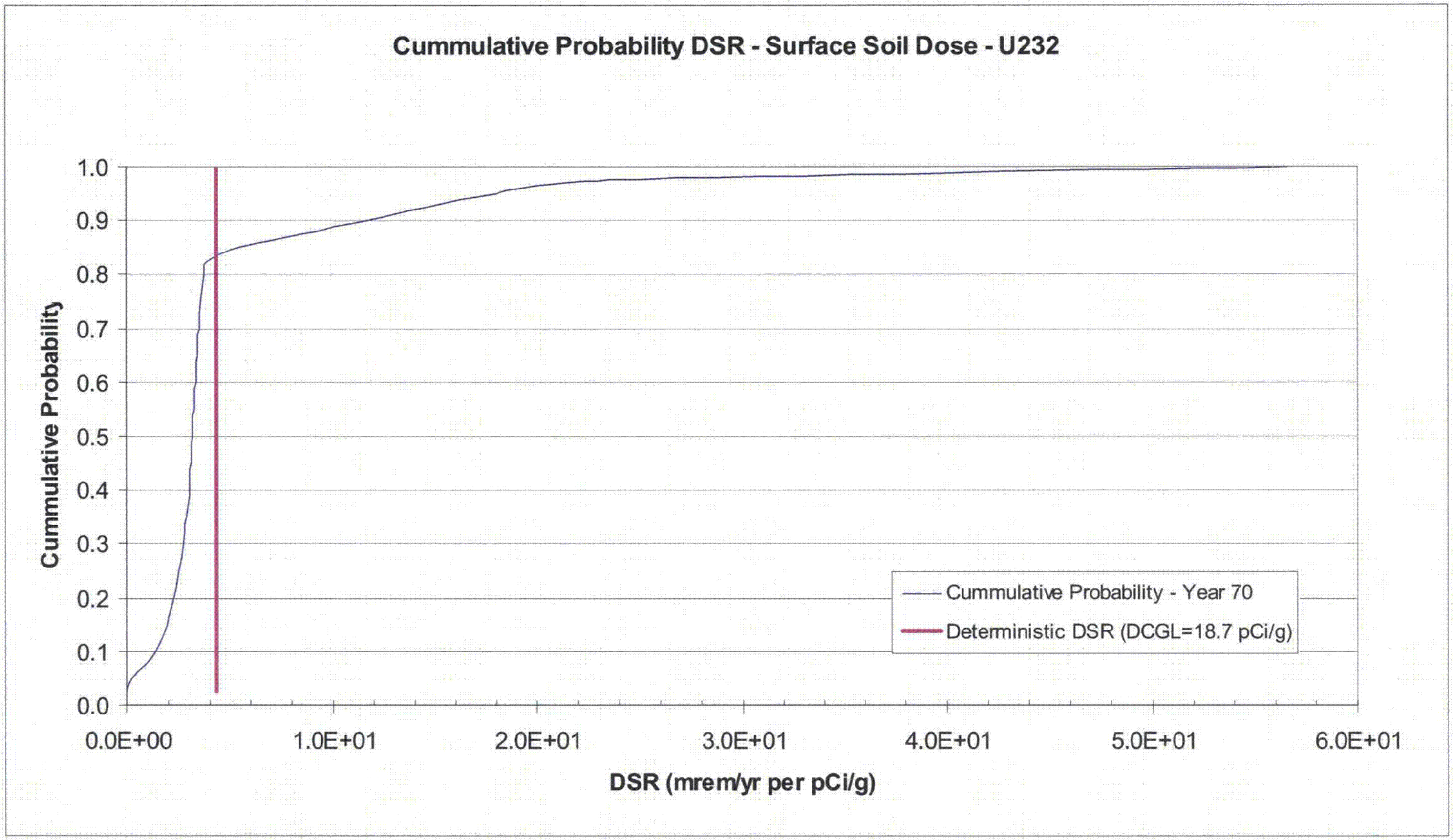

Figure Att-6. Cumulative Probability Dose-Source Ratio, U-232 – Surface Soil

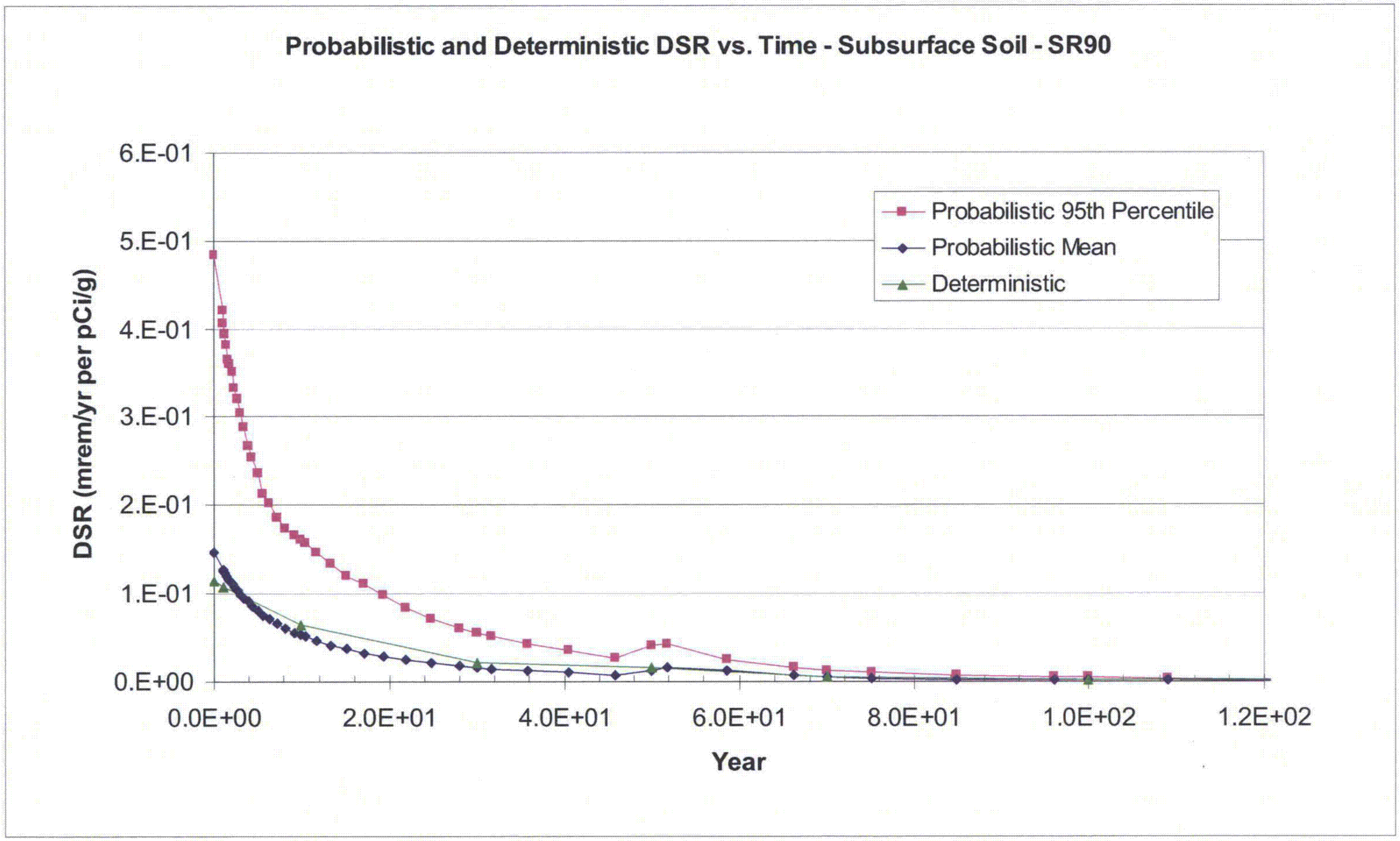

Figure Att-7. Probabilistic and Deterministic Dose-Source Ration vs. Time, Sr-90 – Subsurface Soil

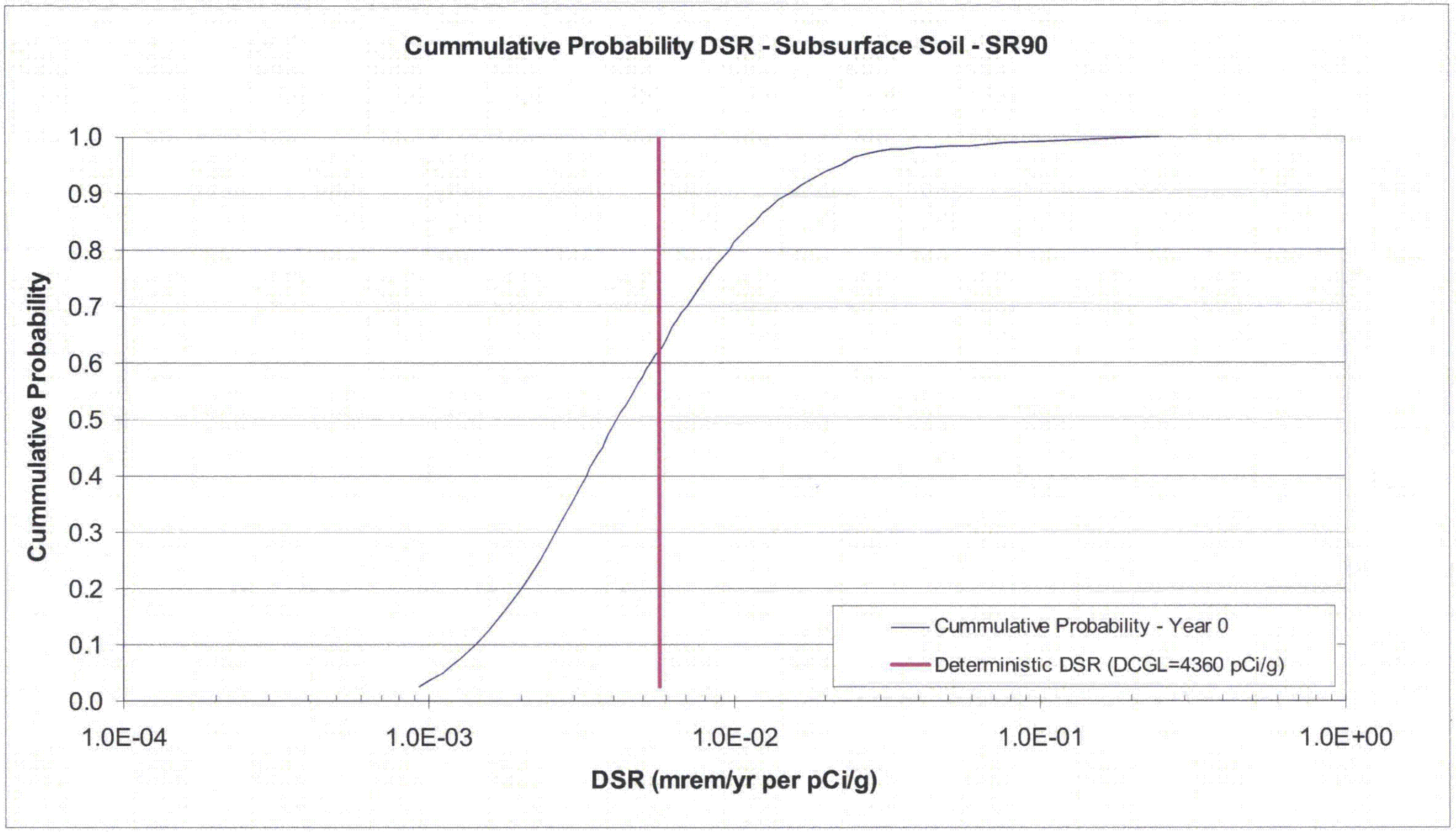

Figure Att-8. Cumulative Probability Dose-Source Ratio, Sr-90 – Subsurface Soil

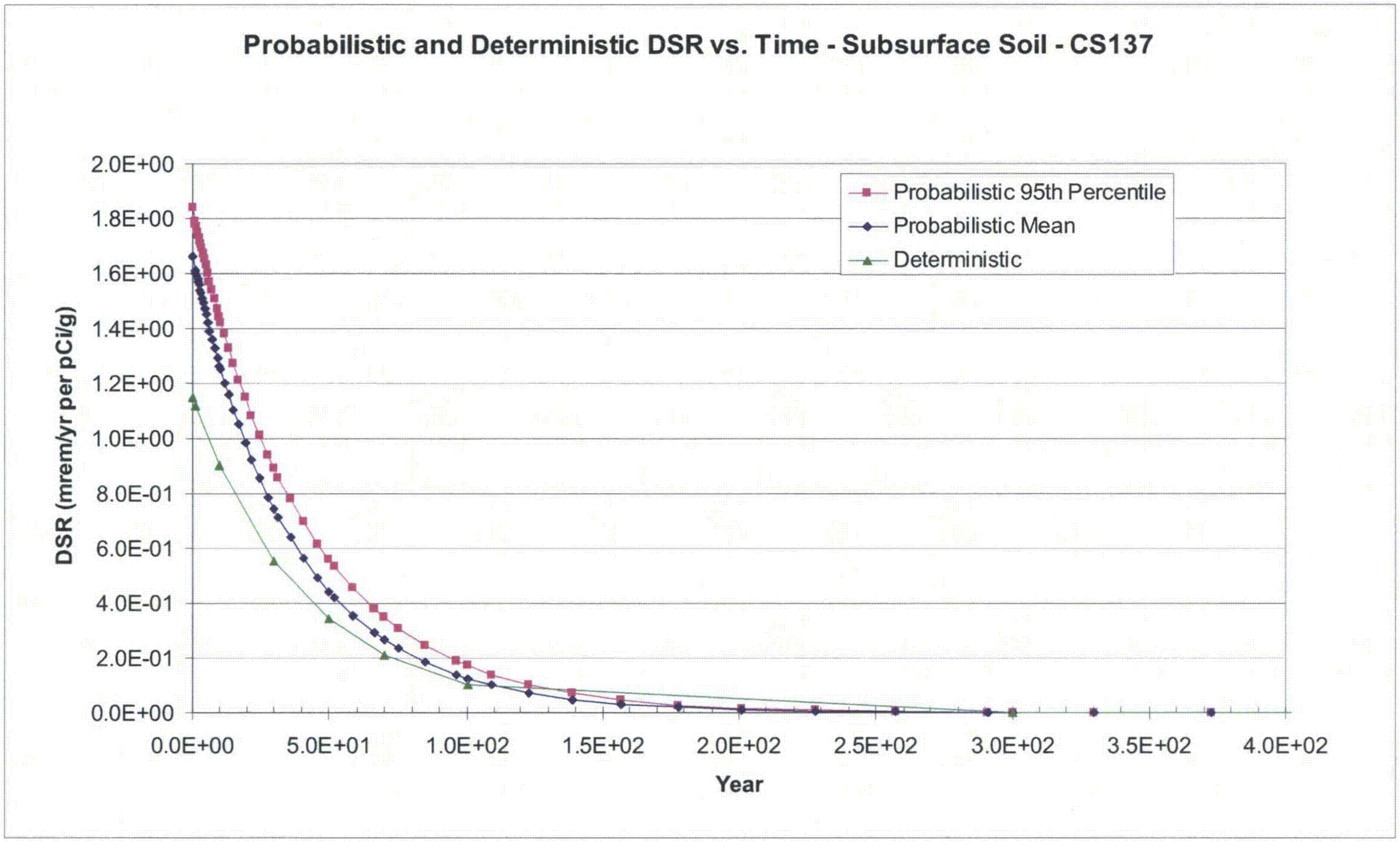

Figure Att-9. Probabilistic and Deterministic Dose-Source Ratio vs. Time, Cs-137 – Subsurface Soil

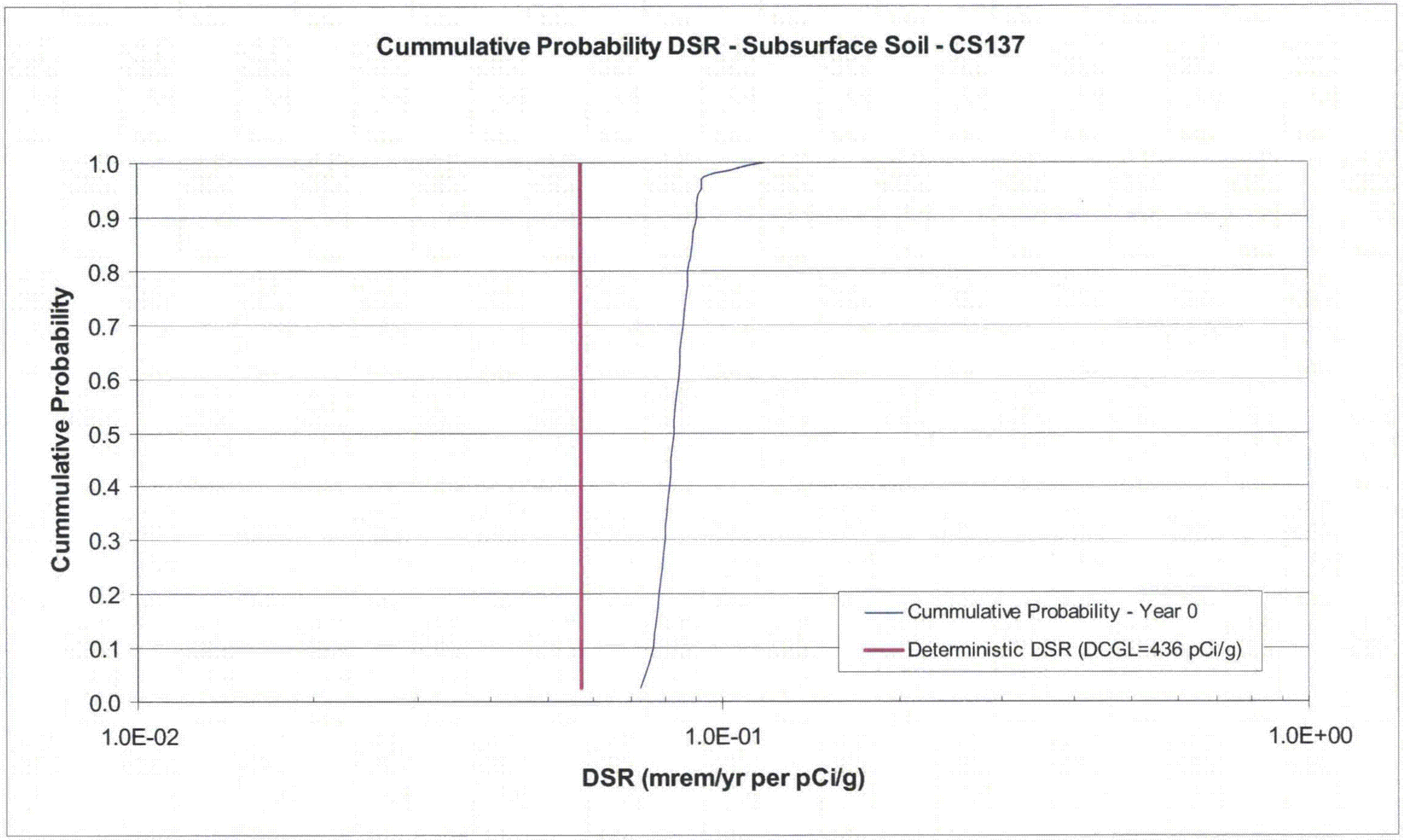

Figure Att-10. Cumulative Probability Dose-Source Ratio, Cs-137 – Subsurface Soil

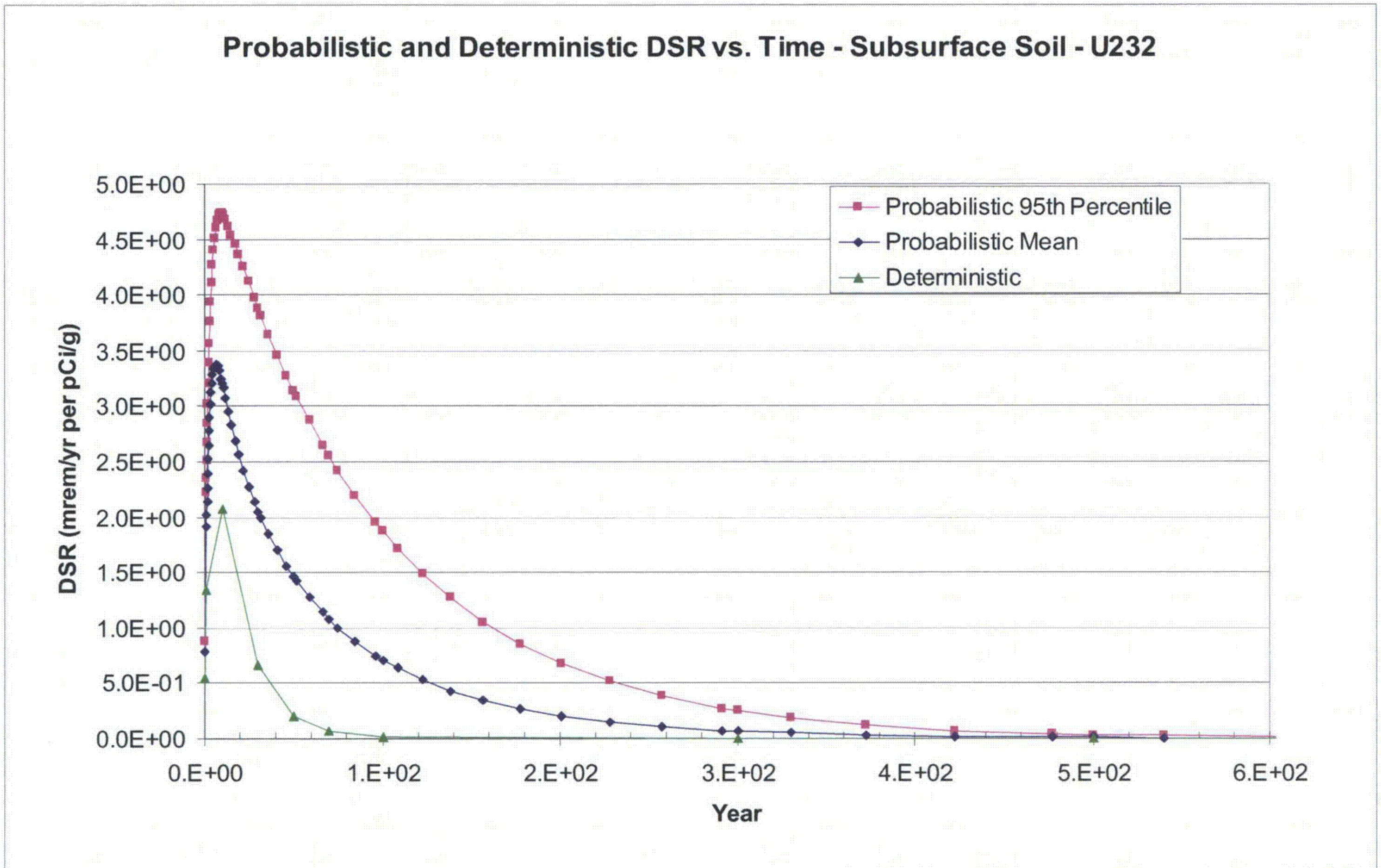

Figure Att-11. Probabilistic and Deterministic Dose-Source Ration vs. Time, U-232 – Subsurface Soil

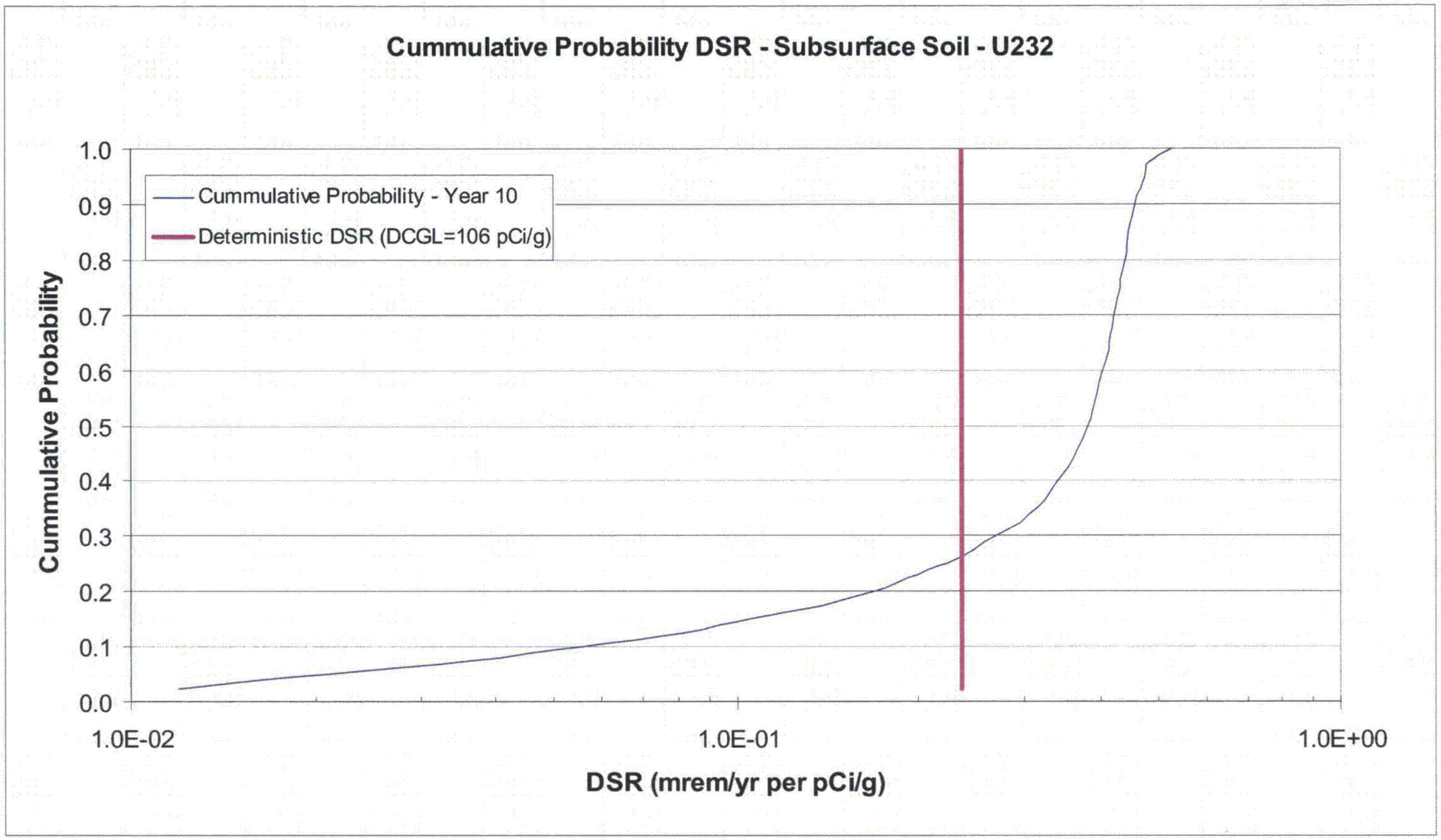

Figure Att-12. Cumulative Probability Dose-Source Ratio, U-232, Subsurface Soil

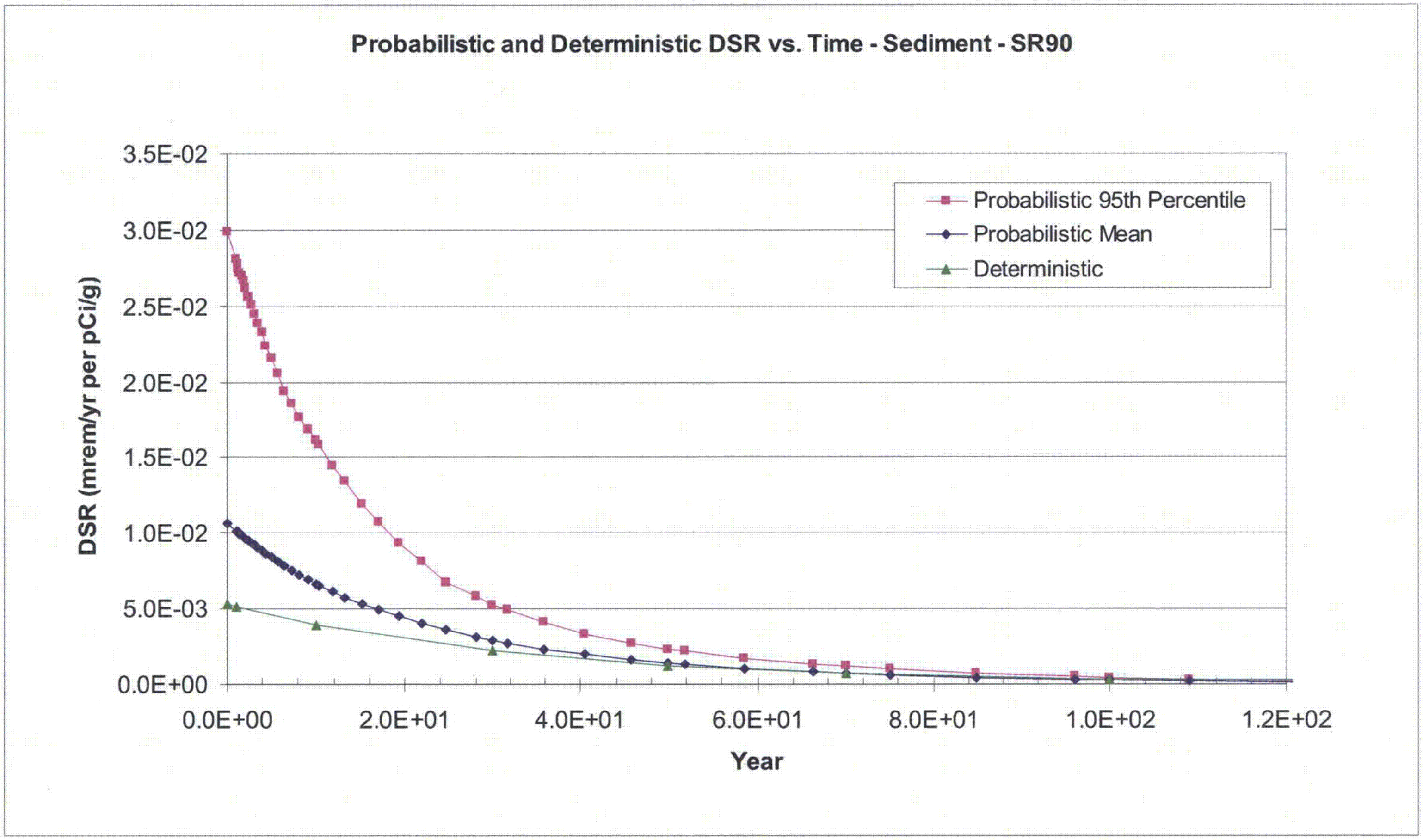

Figure Att-13. Probabilistic and Deterministic Dose-Source Ratio vs. Time, Sr-90 – Streambed Sediment

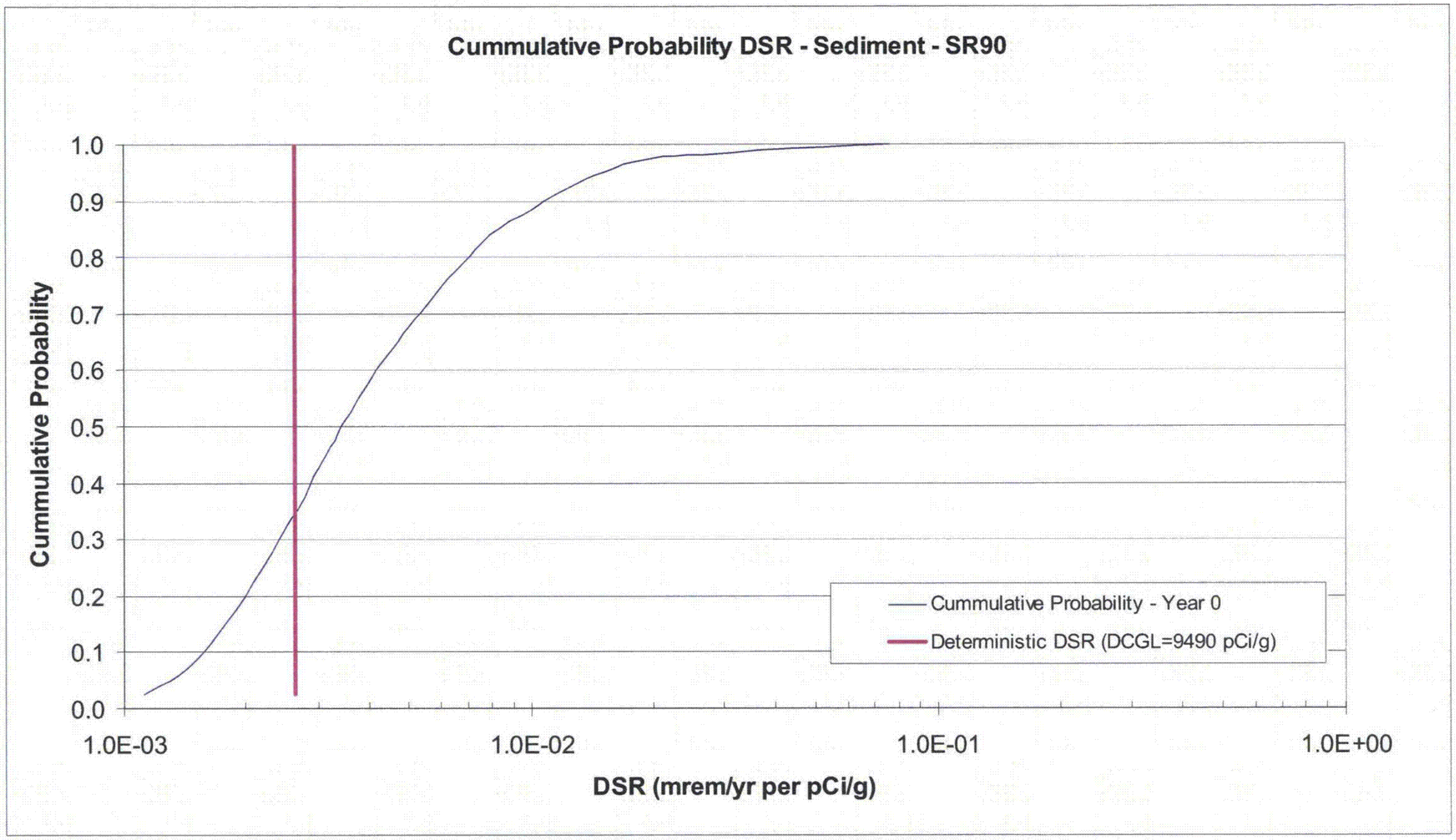

Figure Att-14. Cumulative Probability Dose-Source Ratio, Sr-90 – Streambed Sediment

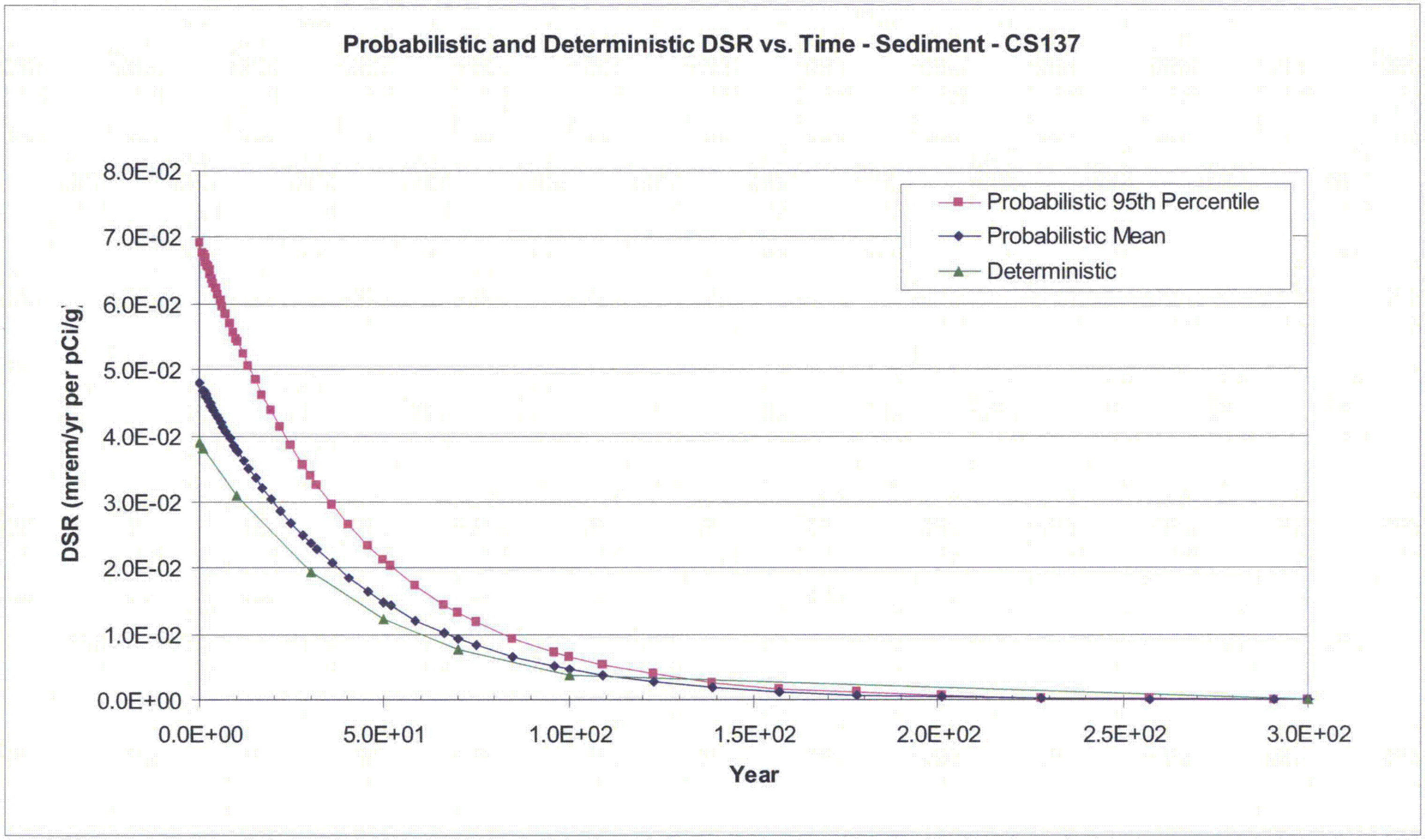

Figure Att-15. Probabilistic and Deterministic Dose-Source Ratio vs. Time, Cs-137 – Streambed Sediment

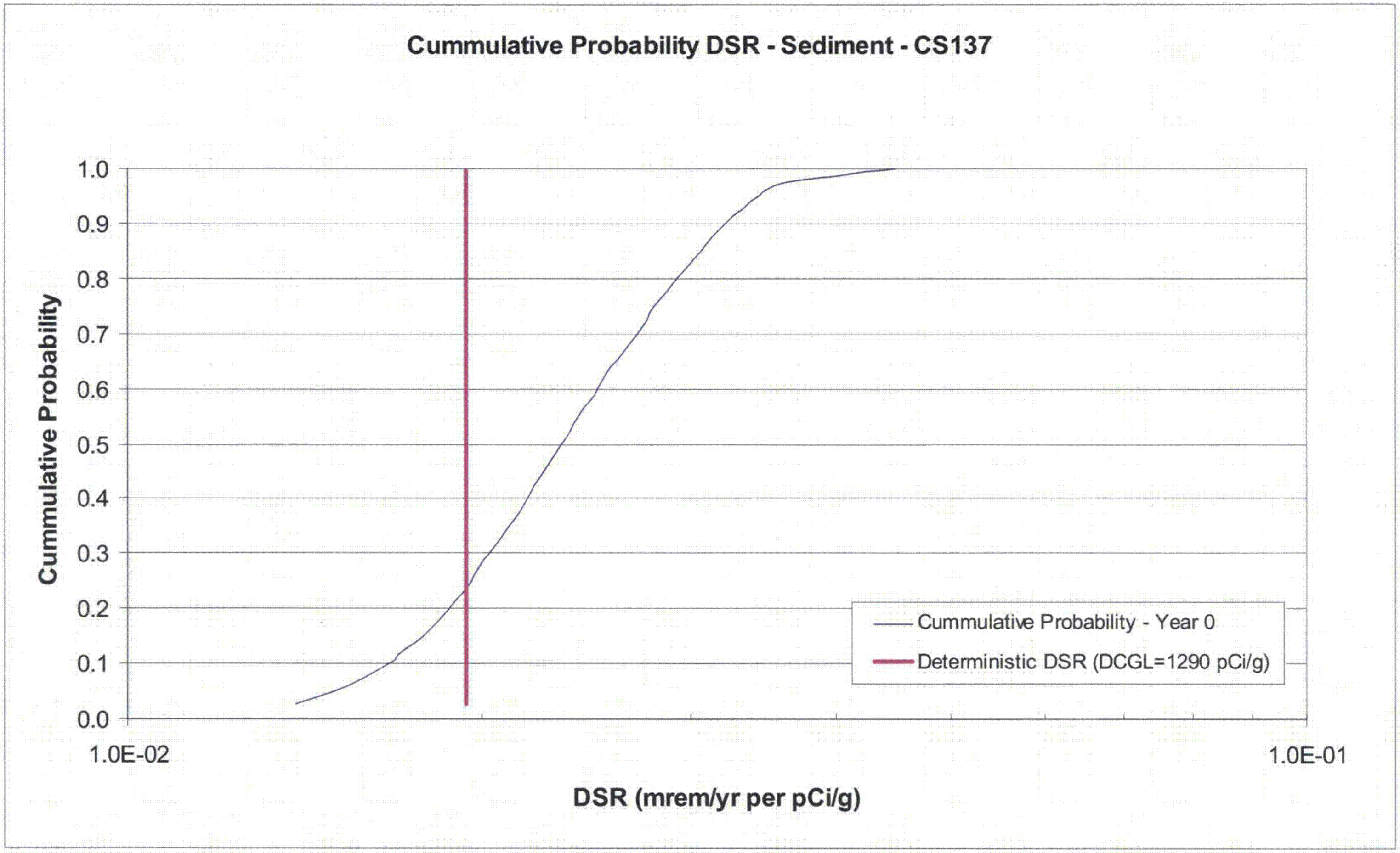

Figure Att-16. Cumulative Probability Dose-Source Ratio, Cs-137 – Streambed Sediment

Table Att-1. Estimated WMA 1 Doses from Observed Maximum Radionuclide Concentrations in the Lavery Till

Radionuclide	Maximum Detection *(pCi/g)*(1)	Depth (ft)	Peak-of-the-Mean Subsurface Soil *$DCGL_w$ (pCi/g)*(2)	95th Percentile Subsurface Soil *$DCGL_w$ (pCi/g)*	Peak-of-the-Mean Estimated *Dose (mrem/y)*(3)	95th Percentile Estimated *Dose (mrem/y)*(3)
Am-241	1.3E-01	38-40	6.8E+03	4.3E+03	4.8E-04	7.6E-04
C-14	1.1E-01	38-40	3.7E+05	3.6E+05	7.3E-06	7.5E-06
Cs-137	3.9E+00	38-40	3.0E+02	2.7E+02	3.6E-01	3.6E-01
Cm-243	2.3E-02	38-40	1.1E+03	9.3E+02	6.2E-04	6.2E-04
Cm-244	2.3E-02	38-40	2.2E+04	1.1E+04	5.3E-05	5.3E-05
I-129	2.9E-01	38-40	5.2E+01	5.2E+01	1.4E-01	1.4E-01
Np-237	2.1E-02	37-39	4.3E+00	4.3E+00	1.2E-01	1.2E-01
Pu-238	2.3E-02	38-40	1.4E+04	6.8E+03	4.2E-05	8.4E-05
Pu-239	6.4E-02	38-40	1.2E+04	6.1E+03	1.3E-04	2.6E-04
Pu-240	6.4E-02	38-40	1.2E+04	6.4E+03	1.3E-04	2.5E-04
Pu-241	5.7E-01	38-40	2.4E+05	1.6E+05	5.9E-05	8.9E-05
Sr-90	5.9E+01	38.5-39	3.2E+03	1.0E+03	4.6E-01	1.4E+00
Tc-99	5.5E-01	37-39	1.1E+04	4.4E+03	1.2E-03	3.2E-03
U-232	4.1E-02	24-26	7.4E+01	5.4E+01	1.4E-02	1.9E-02
U-233	2.3E+00	38-40	1.9E+02	1.9E+02	3.0E-01	3.0E-01
U-234	2.3E+00	38-40	2.0E+02	2.0E+02	2.9E-01	2.9E-01
U-235	1.4E-01	24-26	2.1E+02	2.1E+02	1.7E-02	1.7E-02
U-238	1.4E+00	41-43	2.1E+02	2.1E+02	1.7E-01	1.7E-01
				Total Estimated Dose	1.9E+00	2.8E+00

NOTES: (1) Maximum detections from Table 5-1. Radionuclides with maximum detections below the detection limit were evaluated at the detection limit.

(2) Subsurface DCGLs are presented in Appendix E and account for 10 to 1 dilution of contaminated till with clean overlying soil during excavation. Subsurface DCGL are the lower of the deterministic values for the resident gardener and farmer or the probabilistic value for the farmer.

(3) Estimated dose (mrem/y) = 25 (mrem/y) x (maximum detection / $DCGL_W$)

Table Att-2. Estimated WMA 2 Doses from Observed Maximum Radionuclide Concentrations in the Lavery Till

Radionuclide	Maximum Detection (pCi/g)(1)	Depth (ft)	Peak-of-the-Mean Subsurface Soil $DCGL_w$ (pCi/g)(2)	95th Percentile Subsurface Soil $DCGL_w$ (pCi/g)	Peak-of-the-Mean Estimated Dose (mrem/y)(3)	95th Percentile Estimated Dose (mrem/y)(3)
Am-241	3.0E-02	12-14	6.8E+03	4.3E+03	1.1E-04	1.7E-04
C-14	None	None	3.7E+05	3.6E+05	NA	NA
Cm-243	None	None	1.1E+03	9.3E+02	NA	NA
Cm-244	None	None	2.2E+04	1.1E+04	NA	NA
Cs-137	4.5E-01	12-14	3.0E+02	2.7E+02	4.1E-02	4.1E-02
Np-237	None	None	4.3E+00	4.3E+00	NA	NA
I-129	None	None	5.2E+01	5.2E+01	NA	NA
Pu-238	1.0E-02	12-14	1.4E+04	6.8E+03	1.8E-05	3.7E-05
Pu-239	5.9E-03	12-14	1.2E+04	6.1E+03	1.2E-05	2.4E-05
PU-240	5.9E-03	12-14	1.2E+04	6.4E+03	1.2E-05	2.3E-05
Pu-241	1.3E+00	12-14	2.4E+05	1.6E+05	1.4E-04	2.0E-04
Sr-90	8.5E-01	12-14	3.2E+03	1.0E+03	6.7E-03	2.1E-02
Tc-99	None	None	1.1E+04	4.4E+03	NA	NA
U-232	1.2E-02	12-14	7.4E+01	5.4E+01	4.1E-03	5.5E-03
U-233	1.8E-01	12-14	1.9E+02	1.9E+02	2.3E-02	2.3E-02
U-234	1.8E-01	12-14	2.0E+02	2.0E+02	2.3E-02	2.3E-02
U-235	5.9E-03	12-14	2.1E+02	2.1E+02	7.1E-04	7.1E-04
U-238	1.1E-01	12-14	2.1E+02	2.1E+02	1.3E-02	1.3E-02
				Total Estimated Dose	**1.1E-01**	**1.3E-01**

NOTES: (1) Maximum detections from Table 5.1. Radionuclides with maximum detections below the detection limit were evaluated at the detection limit.

(2) Subsurface DCGLs are presented in Appendix E and account for 10 to 1 dilution of contaminated till with clean overlying soil during excavation. Subsurface DCGL are the lower of the deterministic values for the resident gardener and farmer or the probabilistic value for the farmer.

(3) Estimated dose (mrem/y) = 25 (mrem/y) x (maximum detection / $DCGL_W$)

LEGEND: NA = not available

RAI 5C21 (26)

Subject: I-129 sensitivity to hydraulic conductivity

RAI: The sensitivity analysis of the surface soil model indicated that decreasing the hydraulic conductivity increased the DCGL for I-129 due to increasing the travel time to the well. It is not clear why this result was obtained (see bullet on page 5-37). (Section 5.2.4, Page 5-37)

Basis: I-129 is very long-lived, and therefore the travel time to the well should have little impact on the estimated DCGL instead of resulting in a 1873% change.

Path Forward: Provide additional technical basis that the observed change in I-129 DCGL is a result of travel time to the well, or clarify the underlying reason for the change.

****

DOE Response:

NOTE

Changes from the previous version of this response submitted to NRC on 8/14/09 have been made for the following reasons:

(1) Information was added to describe the basis for the subsurface soil mass balance dilution calculation.

(2) Additional information was added on assumptions regarding infiltration rates used in the dilution calculations.

(3) The previous version of Table 5C21-1 presented calculation of subsurface dilution factors for the base case 100 m^2 contamination zone and a 1,000 m^2 test case. The revised table contains the dilution factor calculation for the range of contamination zone areas used to determine the limiting scenario.

Note that the updated response to RAI 5C9 provides information on the various subsurface soil conceptual models, including the multi-source conceptual model that proved to be more limiting than other models for most radionuclides of interest. The information provided here does not apply to multi-source model, which takes into account release of residual radioactivity by diffusion from the bottoms of the deep excavations.

The RESRAD non-dispersion model calculation of dilution factors is a primary basis for the parameter sensitivity. The model utilizes four different equations for the calculation of dilution factors, based on parameters such as well depth, contaminated area, area parallel to aquifer flow, infiltration rate, etc., which may lead to counterintuitive results for deterministic evaluations.

In the specific case of I-129, the dilution factor is reduced from 0.2 to 0.026 when reducing the hydraulic conductivity from 140 m/y to 1 m/y. For the high conductivity case, the dilution factor is calculated based on the depth of contamination in the aquifer relative to the depth of well intake. For the low conductivity case, the dilution factor is calculated as a ratio of infiltrating recharge to aquifer pumping rate.

After discussion with NRC, it was determined that utilizing a site-specific groundwater dilution factor (based on available site data and DEIS groundwater modeling results) would eliminate such anomalies in the results. In order to achieve a deterministic dilution factor in RESRAD several hydrogeologic parameters must be assigned deterministic values. The parameters for the surface soil model (utilizing the RESRAD non-dispersion groundwater model) and for the subsurface soil and sediment models (utilizing the RESRAD mass balance groundwater model) and the resulting dilution factors are discussed below.

The basis for establishing a site-specific dilution factor was the three-dimensional groundwater model used in the DEIS. Review of available three-dimensional modeling results indicated a groundwater dilution factor of approximately 0.14 in the vicinity of the Process Building and also suggested that the conditions discussed below were most representative of the site. (The detailed three-dimensional groundwater model was also used with the multi-source conceptual model that took into account the release of radioactivity from the bottom of the deep excavations as a continuing source to groundwater, as discussed in the updated response to RAI 5C9.)

The following discussion focuses on the DCGL development that did not consider the subsurface continuing source.

Assumptions Used with the Non-Dispersion and Mass Balance Models

For the surface soil model, the non-dispersion groundwater model was used with the following assumptions:

- The groundwater well has an effective pumping width that is less than the width of the contaminated zone (well is laterally capturing only contaminated water), and
- The groundwater well has a screened depth that exceeds the depth of contamination in the aquifer (some vertical dilution of groundwater in the well).

For the subsurface soil model, the mass balance groundwater model was used with the following assumptions:

- For the resident farmer scenario, the well pump rate is greater than the infiltration rate through the contaminated zone, and the well water is diluted leachate. All groundwater utilized is contaminated by the source area
- For the residential gardener scenario, the well pump rate is greater than the infiltration rate through the contaminated zone, and the well water is diluted leachate. All groundwater utilized is contaminated by the source area.

Surface Soil Model – Groundwater Dilution Factor

In the non-dispersion groundwater model used for surface soil calculations, several parameters were assigned fixed values to correspond with the detailed groundwater model as discussed below and presented in Table 5C21.

Precipitation rate – assigned a site-specific value based on historical records.

Runoff coefficient – based on site-specific area slope and land use to reflect clay/loam over a relatively flat area of cultivated land.

Evapotranspiration coefficient – assigned a value to achieve site-specific infiltration rate of 26 cm/y used in DEIS modeling. Assumed to be reflective of non-irrigation and irrigation conditions where the additional water input balances the evapotranspiration rate.

Irrigation rate – determined from site-specific climatological water demand and assumed irrigation efficiency (the value of 0.47m/y is consistent with the DEIS).

Infiltration rate – calculated by RESRAD based on the above parameters. The calibrated near-field flow model used in the DEIS was based on an infiltration rate of 0.26 m/y and is duplicated in RESRAD utilizing the above parameters. Due to limitations in the RESRAD model, a single irrigation rate is applied across the contaminated zone assuming a constant application of irrigation water.

Contamination zone (CZ) length parallel to aquifer flow – assigned a value to achieve site-specific groundwater dilution factor observed in DEIS modeling.

Saturated zone (SZ) saturated hydraulic conductivity – average value for sand and gravel thick bedded unit from Table 3-19 of the DP.

Hydraulic gradient – site-specific value selected in consideration of the presence of the hydraulic barrier walls as described in Appendix D of the DP (see Figure D-2).

Well pumping rate – site specific value based on required irrigation rate, assumed crop area and number of livestock, and household water use.

Depth of well intake below water table – site specific value adjusted to achieve site-specific groundwater dilution factor observed in DEIS modeling.

As indicated above, the hydraulic gradient was assigned a site-specific value of 0.03 when defining other parameters to achieve the groundwater dilution factor of 0.14. In order to provide conservative results, the dilution factor was adjusted to a value of 0.2 by adjusting the length of the contamination zone parallel to aquifer flow. The selected hydraulic gradient considered the presence of the hydraulic barriers as follows;

- Potential flattening of the hydraulic gradient downgradient of the barriers does not impact DCGLs as there will be no remediation of this portion of WMA 2.
- Changes to the hydraulic gradient within the remediated portion of WMA 2, downgradient of the barriers are insignificant based on current three dimensional modeling (see DEIS).
- Changes to the hydraulic gradient within WMA 1, upgradient of the barriers are insignificant as installation of the French drain in conjunction to the barrier walls will minimize changes to the flow field.

Subsurface Soil – Groundwater Dilution Factor

In the mass balance model, used in subsurface soil calculations (those not considering the bottoms of the deep excavations as a continuing source to groundwater), the following parameters were used to establish the site-specific dilution factor, as discussed below and presented in Table 5C21-1.

Precipitation rate – assigned a site-specific value based on historical records.

Runoff coefficient – based on site-specific area slope and land use to reflect clay/loam over a relatively flat area of cultivated land.

Evapotranspiration coefficient – assigned a value to achieve site-specific infiltration rate of 26 cm/y used in DEIS modeling assumed to be reflective of non-irrigation and irrigation conditions where the additional water input balances the evapotranspiration rate.

Irrigation rate – determined from site-specific climatological water demand and assumed irrigation efficiency (the value of 0.47m/y is consistent with the DEIS).

Infiltration rate – calculated by RESRAD based on the above parameters. The calibrated near-field flow model used in the DEIS was based on an infiltration rate of 0.26 m/y and is duplicated in RESRAD utilizing the above parameters. Due to limitations in the RESRAD model, a single irrigation rate is applied across the contaminated zone assuming a constant application of irrigation water.

Well pumping rate – site-specific value based on required irrigation rate, assumed crop area/number of livestock, and household water use.

The parameter values for the subsurface soil model were consistent with those used for surface soil where applicable. As with the surface soil model, the subsurface soil model used a hydraulic gradient that considers the presence of the hydraulic barriers.

Changes to the plan: Changes to the plan are being made in the following areas:

- Revising deterministic surface soil and subsurface soil DCGLs based on the parameters and dilution factors in Table 5C21-1;
- For the surface soil model (non-dispersion groundwater model) probabilistic uncertainty analysis, varying values of parameters from Table 5C21-1, to provide a range of dilution factors for the site-specific conditions described above (undiluted lateral flow to well, diluted vertical flow within well);
- For the subsurface soil model (mass balance groundwater model), varying applicable parameters from Table 5C21-1, similar to surface soil model;
- Additional modeling to incorporate the subsurface till as a continuing source to groundwater, and
- Including a deterministic residential groundwater ingestion scenario based on parameters presented in Table 5C21-1.

The response to RAI 5C12 provides a revised version of Appendix C which incorporates the parameters and dilution factors in Table 5C21-1.

Table 5-8 will be revised to include the revised deterministic DCGLs as follows. (Note that the $DCGL_{EMC}$ values are being omitted from this table because this set of DCGLs was not used in establishing cleanup goals with the single exception of Pu-241 for subsurface soil.)

Table 5-8. DCGLs For 25 mrem Per Year ($DCGL_W$ Values in pCi/g)(1)

Nuclide	Surface Soil	Subsurface Soil(3)	Streambed Sediment
Am-241	4.3E+01	7.1E+03	1.6E+04
C-14	2.0E+01	3.7E+05	3.4E+03
Cm-243	4.1E+01	1.2E+03	3.6E+03
Cm-244	8.2E+01	2.3E+04	4.8E+04
Cs-137(2)	2.4E+01	4.4E+02	1.3E+03
I-129	3.5E-01	5.2E+01	3.7E+03
Np-237	9.4E-02	4.3E+00	5.2E+02
Pu-238	5.0E+01	1.5E+04	2.0E+04
Pu-239	4.5E+01	1.3E+04	1.8E+04
Pu-240	4.5E+01	1.3E+04	1.8E+04
Pu-241	1.4E+03	2.4E+05	5.1E+05

Table 5-8. DCGLs For 25 mrem Per Year ($DCGL_W$ Values in pCi/g)[1]

Nuclide	Surface Soil	Subsurface Soil[3]	Streambed Sediment
Sr-90[2]	6.2E+00	3.2E+03	9.5E+03
Tc-99	2.4E+01	1.1E+04	2.2E+06
U-232	5.8E+00	1.0E+02	2.6E+02
U-233	1.9E+01	1.9E+02	5.7E+04
U-234	2.0E+01	2.0E+02	6.0E+04
U-235	1.9E+01	2.1E+02	2.9E+03
U-238	2.1E+01	2.1E+02	1.2E+04

NOTES: (1) Refer to Sections 5.2.5 and 5.2.6 for discussions about how this set of DCGLs was considered in establishing cleanup goals.

(2) Sr-90 and Cs-137 DCGLs reflect 30 years of decay and apply to the year 2041 and later.

(3) The lower DCGL of the resident farmer and residential gardener, and multi-source DCGLs (developed to include the subsurface till as a continuing source to groundwater).

The updated response to RAI 5C15 provides the results of the probabilistic uncertainty analysis and the details of this analysis. The response to RAI 5C18 provides the results of the residential gardener analysis and the associated details.

Table 5C21-1. West Valley – Summary of RESRAD Parameters for Dilution Calculations

Parameter	Units	Surface Soil - Resident Farmer (Non-dispersion Model)	Surface Soil - Residential Gardener (Non-dispersion Model)	Subsurface - Resident Farmer - 50 m² CZ (Mass Balance Model)	Subsurface - Resident Farmer - 100 m² CZ (Mass Balance Model)	Subsurface - Resident Farmer – 300 m² CZ (Mass Balance Model)	Subsurface - Residential Gardener - 50 m² CZ (Mass Balance Model)	Subsurface - Residential Gardener - 100 m² CZ (Mass Balance Model)	Subsurface - Residential Gardener - 300m² CZ (Mass Balance Model)
					Input				
Precipitation rate	m/y	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16
Irrigation rate	m/y	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Runoff coefficient	unitless	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Evapotranspiration coefficient	unitless	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Infiltration rate (1)	m/y	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
CZ Length parallel to aquifer (2)	m/y	165	165	na	na	na	na	na	na
SZ Saturated Conductivity (3)	m/y	1400	1400	na	na	na	na	na	na
Hydraulic Gradient (4)	m/m	0.03	0.03	na	na	na	na	na	na
Well pumping rate (5)	m3/y	5720	1140	5720	5720	5720	1140	1140	1140
Depth of well intake below water table	m	5	5	na	na	na	na	na	na
Irrigated Area	m²	10000	2000	10000	10000	10000	2000	2000	2000
CZ area	m²	10000	10000	50	100	300	50	100	300
					Calculated Values				
Darcy velocity	m/y	42	42	na	na	na	na	na	na
Contaminant depth in aquifer	m	1.01	1.01	na	na	na	na	na	na
Effective pump width	m	27.24	5.43	na	na	na	na	na	na
CZ width	m	61	61	na	na	na	na	na	na
Groundwater Dilution Factor	**unitless**	**0.202**	**0.202**	**0.002**	**0.004**	**0.013**	**0.011**	**0.023**	**0.068**

LEGEND: CZ = contamination zone, na = not applicable to mass balance calculation. (Mass balance dilution factor based on total infiltration volume/total pumped volume.)
SZ = saturated zone

NOTES: (1) Infiltration rate of 26 cm/y for irrigation scenario is based on DEIS groundwater model.

(2) Contaminated Zone (CZ) length parallel to aquifer is adjusted for ND surface model to achieve site-specific dilution factor of 0.14 for a gradient of 0.03. Final dilution factor adjusted to a conservative value of 0.2.

(3) Saturated conductivity from Table 3-19 of DP for average value in the thick bedded unit (4.4E-3 cm/s).

(4) Hydraulic gradient of 0.03 from DEIS used to assign other values and achieve a 0.14 dilution factor for non-dispersion surface model.

(5) Well pumping rate assumed for resident farmer with five cattle, five milk cows, irrigating at 0.47 m/y, or residential gardener at 0.47 m/y and 200 m^3/y household.