The conceptual model for streambed sediment was developed after consideration of how residual radioactivity enters and moves though the streams, plausible future land uses for the stream valleys, how humans might be exposed to residual contamination in the streams or on the banks, and plausible habits of a person who might spend time at the streams in the future. Such considerations led to selection of a conceptual model compatible with RESRAD. The RESRAD code was determined to be an appropriate mathematical model based on its extensive use in evaluating potential doses from radioactivity in surface soil and its use in the surface soil DCGL and subsurface soil DCGL models for this project.

As shown in Figure 5-10, the contamination zone was assumed to be on the stream bank rather than in the stream itself. This model is consistent with typical conditions observed along Frank's Creek downstream of the Lagoon 3 outfall as shown by the radiological control area in Figure 5-11 represented by the roped-off area. It is conservative compared to having the contamination zone in the stream itself where water would act as shielding to reduce the direct radiation dose.

The photograph in Figure 5-11 was taken from just inside the project premises security fence looking upstream toward the southwest. The confluence with Erdman Brook lies about 200 feet upstream from where the people are standing and the Lagoon 3 outfall is about 500 feet from where the people are standing.

Figure 5-11. Franks Creek Looking Upstream (2008 WVDP photo)

Key features of this conceptual model include the following:

- A person spending time in the area of the streams for recreation purposes was determined to be the appropriate member of the critical group; the area is not suitable for farming, livestock grazing, or residential use because of the steep stream banks, especially considering further erosion that is likely to occur as discussed previously.

- In this exposure scenario the primary radiation source is considered as the sediment deposited on the stream bank. The ability of sediment to adsorb and absorb radionuclides would be expected to concentrate otherwise dilute species of ions from the water (NRC 1977). The water in the stream provides some shielding and separation from radionuclides in sediments on the stream bottom, thus reducing direct exposure and incidental ingestion pathways from those sources.[11]
- The hypothetical recreationist is assumed to be located on the contaminated stream bank for 104 hours per year, which could involve spending two hours per day, two days per week for 26 weeks a year, reasonable assumptions considering the local climate.
- The contaminated zone of interest is located on the stream bank and is assumed to be three meters (10 feet) wide and 333 meters (1093 feet) long, with a total area of 1000 square meters (approximately ¼ acre).
- Having the contaminated zone on the stream bank takes into account a situation where the stream level might rise significantly then fall again to a lower level.
- The hypothetical recreationist is assumed to eat venison from deer whose flesh is contaminated with radioactivity from contaminated stream banks, such as from grazing on grass, and ingesting stream water.

Consideration was given to both receptor location and stream bank geometry.

Potential doses to a recreationist from impacted stream water will be less significant than potential doses from the stream bank for the following reasons:

- It would be plausible for the hypothetical recreationist to spend more time on the stream bank than immersed in stream water;
- The water would provide radiation shielding for radioactivity in the streambed sediment, which would decrease potential dose from direct radiation;
- While on the stream bank, the external dose from surface water would be negligible compared with the dose from the stream bank source; and
- Neglecting erosion of the stream bank source leads to greater doses than considering erosion of the source from the stream bank to the streambed, where significant shielding from surface water would reduce the dose.

The stream bank geometry was assumed to be represented by a plane source of contamination along the stream bank. Potential doses from alternative source configurations were not included in this evaluation for the following reasons:

[11] Note that modeling of transport, deposition, and concentrations of radionuclides in the stream itself would require assumptions on potential releases after Phase 1 of the decommissioning, and involve consideration of the Phase 2 end-state, factors which are appropriately not considered at this time.

- Any dose variation due to a sloped stream bank would likely result in doses similar to level sources due to movement of the receptor and exposure to an equivalent *uniform dose (e.g. receptor is assumed to spend time moving throughout the* source area and facing all directions for equal amounts of time);
- Although exposure to a source area wider than several meters is unlikely considering the steep terrain, the receptor is assumed to be externally exposed to a circular infinite plane source for conservatism; and
- Because the mass balance model was used for the sediment calculations, the source width parameter is not used in the calculations for water dependent pathways.

All of the input parameters for development of the streambed sediment DCGLs appear in Appendix C. Table 5-7 identifies selected key input parameters.

Table 5-7. Key Input Parameters for Streambed Sediment DCGL Development[1]

Parameter (Units)	Value	Basis
Area of contaminated zone (m^2)	1.0E+03	Area on stream bank.
Thickness of contaminated zone (m)	1.0E+00	Conservative assumption.
Fraction of year spent outdoors	1.2E-02	104 hours (out of a total of 8760 hours per year) in area.
Cover depth (m)	0	Contamination on surface.
Contaminated zone erosion rate (m/y)	0	Conservative assumption.[2]
Well pump intake depth (m below water table)	0	Only applicable to farming.
Well pumping rate (m^3/y)	0	Only applicable to farming.
Unsaturated zone thickness (m)	0	Contamination on stream bank surface.
Contaminated zone distribution coefficient for strontium (mL/g)	1.5E+01	See Table C-2.
Contaminated zone distribution coefficient for cesium (mL/g)	4.8E+02	See Table C-2.
Contaminated zone distribution coefficient for americium (mL/g)	4.0E+03	See Table C-2.

NOTES: (1) See Appendix C for other input parameters. Metric units are used here because they are normally used in RESRAD.

(2) This assumption is conservative because it results in no erosion of the source.

In development of the conceptual model, consideration was given to protection of environmental and ecological resources, as well as human health. It was determined that no changes to the model or the radioactivity cleanup criteria will be necessary for this purpose.[12]

5.2.4 Mathematical Model

As noted previously, RESRAD (Yu, et al. 2001) is used as the mathematical model for DCGL development. Version 6.4 was used to calculate the unit dose factors (in mrem/y per pCi/g) for each of the 18 radionuclides in each of the three exposure scenarios. Unit dose factors were then scaled in Microsoft Excel to calculate individual radionuclide DCGLs corresponding to 25 mrem per year.

RESRAD was selected as the mathematical model for DCGL development due to the extensive use by DOE and by NRC licensees in evaluating doses from residual radioactivity at decommissioned sites. The RESRAD model considers multiple exposure pathways for direct contact with radioactivity, indirect contact, and food uptake, which are the conditions being evaluated at the WVDP.

RESRAD was used with the post-Phase 1 conceptual models described previously to generate doses for unit radionuclide source concentrations (i.e., dose per pCi/g of source). The resulting doses were then scaled to the limiting acceptable dose (25 mrem in a year) to provide the radionuclide specific DCGLs (see Appendix C). For example, the maximum estimated annual dose from 1 pCi/g of Cs-137 in surface soil was determined to be 1.7 mrem, so the DCGL for 25 mrem per year is 25 divided by 1.7 or 14.8 pCi/g prior to accounting for decay (see Table C-5). The calculated DCGLs were then input into the model as the source concentration to verify that the dose limit of 25 mrem per year was not exceeded.

Among the general considerations for the application of RESRAD to the post-Phase 1 decommissioning conceptual models were:

- Use of the non-dispersion groundwater pathways model for surface soil due to the relatively large source area;
- Use of the mass balance model, instead of the less conservative non-dispersion model, for the subsurface and streambed sediment models due to the relatively small source areas; and

[12] DOE Order 450.1, *Environmental Protection Program*, requires that DOE Environmental Management facilities such as the WVDP have an environmental management system to ensure protection of the air, water, land, and other natural and cultural resources in compliance with applicable environmental; public health; and resource protection laws, regulations, and DOE requirements. Implementing guidance includes DOE Standard 1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. This guidance includes the use of biota concentration guides to evaluate potential adverse ecological effects from exposure to radionuclides.

The WVDP routinely evaluates potential annual doses to aquatic and riparian animals and plants in relation to the biota concentration guides using the RESRAD-BIOTA computer code (DOE 2004) and radionuclide concentrations measured in water and streambed sediment. These evaluations show compliance with the guides (WVES and URS 2009). The environmental monitoring and control program for Phase 1 of the decommissioning described in Section 1.8 would ensure compliance with DOE Order 450.1 during the decommissioning activities.

- The conservative assumption of no erosion for soil and sediment sources in the development of DCGLs, so there will be no source depletion from erosion.

The RESRAD model has limitations in this application in that it was developed for soil exposures and therefore does not specifically address certain transport mechanisms associated with sediment, such as:

- Periodic saturation of the contaminated zone located along a stream bank flood zone;
- Erosion/scour of stream bank material and subsequent downstream deposition to the stream-bottom;
- Deposition of clean material onto the stream bank, transported downstream from unimpacted upstream locations;
- Variability in surface water concentrations due to fluctuation in flow rates during storm events;
- Partitioning of contaminants between the surface water and stream-bottom sediment; and
- Variability of airborne dust loads due to varying stream bank sediment moisture content.

To address the simplifications of the conceptual model, and still retain conservatism in the results, the following assumptions were made for the sediment model:

- The model will not allow the contaminated zone to be below the water table (as may periodically happen to the stream bank), therefore it was assumed that there was no unsaturated zone, and that the water table exists immediately below the source;
- The inhalation parameter values were conservatively selected to reflect soil on a farm, although stream bank sediment is likely to result in lower respirable dust loadings;
- Contaminated groundwater is assumed to discharge to the stream, where it is impounded and contributes to fish bioaccumulation;
- Fish ingested from the stream are large enough to provide a significant number of meals each year, but are assumed to only be exposed to contaminated water and never swim to uncontaminated sections of the stream; and
- In addition to assuming the fish are never in clean water, the recreationist is assumed to eat only fish that are contaminated when, in actuality, the stream will not support fish at all at the present time owning to the small amount of water typically present as shown in Figure 5-11.

The conceptual model just described represents plausible conditions on the stream banks and in the streambeds. It is considered to be a valid model for the long term in support of a Phase 2 strategy involving unrestricted release, that is, the site-wide removal alternative in the Decommissioning EIS. However, it would not necessarily serve as a valid model if the Phase 2 sources were to be closed in place, as with the site-wide close-in-place alternative.

This limitation results from the model not accounting for processes that could impact the streams in the future under the site-wide close-in-place alternative. For example, impacts on the streams could occur in the long term from unchecked erosion in the radioactive waste disposal areas, surface water runoff from eroded areas, and increased seepage of contaminated groundwater into the streams. Such impacts could include increases in radionuclide concentrations in water in the streams as well as increases in contamination in the sediment.

This limitation would be considered in any decision made by DOE to remediate sediment in the streams and on the stream banks. Such remediation during Phase 1 decommissioning activities would require a revision to this plan.

RESRAD input parameters were selected from the following sources, generally in the order given based on availability:

- Site-specific values where available, (e.g. groundwater and vadose zone parameters such as the distribution coefficients listed in Table 3-20);
- Semi site-specific literature values, (e.g. physical values based on soil type from NUREG/CR-6697 (Yu, et al. 2000) and behavioral factors based on regional data in the U.S. Environmental Protection Agency's *Exposure Factors Handbook* (EPA 1997);
- Scenario-specific values using conservative industry defaults, (e.g., from the *Exposure Factors Handbook*, the *RESRAD Data Collection Handbook* (Yu, et al. 1993), NUREG/CR-6697 (Yu, et al. 2000), and NUREG/CR-5512, Volume 3 (Beyeler, et al. 1999);
- The most likely values among default RESRAD parameters defined by a distribution, when available, otherwise mean values from NUREG/CR-6697 (Yu, et al. 2000).

5.2.5 Summary of Results

Table 5-8 provides the calculated individual radionuclide DCGLs for surface soil, subsurface soil, and streambed sediment which assure that the dose to the average member of the critical group will not exceed 25 mrem per year when considering the dose contribution from each radionuclide individually. Note that the surface soil DCGLs apply only to areas of the project premises where there is no subsurface soil contamination and that the subsurface soil DCGLs apply only to the bottoms and lower sides (extending from a depth of three feet and greater) of the large excavations in WMA 1 and WMA 2.

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

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

Nuclide	Surface Soil	Subsurface Soil(3)	Streambed Sediment
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
Sr-90(2)	6.3E+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 5.2.7 and 5.2.8 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 deterministic DCGL of the resident farmer and residential gardener conceptual models.

As noted previously, the sum-of-fractions rule will be applied if characterization data indicate that a mixture of radionuclides is present in an area.

Conclusions About Results

Detailed outputs of the RESRAD simulations are presented in Appendix C. For surface soil, the results show that:

- Am-241 doses are due primarily to ingestion of plants,
- Cs-137 doses are due primarily to external exposure, and
- Sr-90 doses are due primarily to ingestion of plants.

The modeling to develop the subsurface soil DCGLs indicated that:

- Am-241 doses are due primarily to external exposure and ingestion of impacted plants,
- Cs-137 doses are due primarily to external exposure,
- Sr-90 doses are due primarily to ingestion of impacted plants and water, and
- DCGLs for subsurface soil are greater than those for the surface soil.

The modeling to develop the streambed sediment DCGLs indicated that:

- Am-241 doses are due primarily to incidental ingestion of sediment and to external exposure,
- Cs-137 doses are due primarily to external exposure, as well as ingestion of venison,
- Sr-90 doses are due primarily to ingestion of venison, and
- DCGLs for the sediment source are orders of magnitude greater than those for surface soil.

Conservatism in Calculations

A number of factors make the DCGLs calculated using the initial base-case model conservative. For the surface soil DCGLs, these factors include, for example, the relatively short local growing season, which makes it likely that crop and forage yields will be less than those assumed for the site.

For the subsurface soil DCGLs, conservative factors include:

- As discussed previously, the diameter of the hypothetical well (cistern) used in the initial base-case model at two meters (about 6.6 feet) is much larger than the diameter of a typical water well (eight inches)[13].
- Use of the mass balance model within RESRAD is conservative in that all radionuclide inventory in leachate reaches the intake well.
- Because of the relatively short local growing season, it is likely that crop/forage yields will be less than those assumed for the site.

For the streambed sediment DCGLs, conservative factors include:

- Based on limited available data, the typical thickness of the contaminated zone is likely smaller than the one meter (about 3.3 feet) value used in the analysis.
- Based on available data, most contamination will be found in the stream beds, not on the banks.
- It is unlikely that the incidental ingestion rate (50 mg/d) for sediment will be exclusively from the contaminated area.
- It is assumed that all fish ingested by the recreationist are impacted by the streambed sediment source; however, it is more likely that a recreationist may ingest fish from other locations as well.
- Similarly, it is unlikely that the venison ingested will be impacted by streambed sediment sources exclusively. It is more likely that exposure will be from both impacted and non-impacted areas.

[13] With the larger diameter, much more contaminated soil and residual radioactivity would be brought to the surface where it could cause exposure through various pathways. The difference in volume would vary with the square of the radius; 100 times as much contaminated soil would be brought to the surface in the conceptual model with the two meter diameter well than with a model that assumed a 20 centimeter (eight inch) diameter well. The larger diameter well assumed ensures that the pumping needs of the residential farm would be met, since a smaller diameter well could not do this on some parts of the project premises.

- Assumptions regarding the availability of an adequate fish population to allow long term fish ingestion may also result in overestimation of doses related to the sediment source, as there are currently no fish in the streams of sufficient quality or quantity for sustained human consumption.

Applicability of Streambed Sediment DCGLs

The conceptual model used for developing DCGLs for stream bed sediment in Erdman Brook and the portion of Franks Creek on the project premises assumed that these streams have steep banks. This condition exists in most parts of the streams but not all parts. Consequently, it is necessary to define where the streambed sediment DCGLs and cleanup goals apply.

Figure 5-12 shows the points where the streambed sediment DCGLs and cleanup goals apply. As indicated on the figure, the surface soil DCGLs and cleanup goals apply upstream of these points and to the small tributaries to the streams.

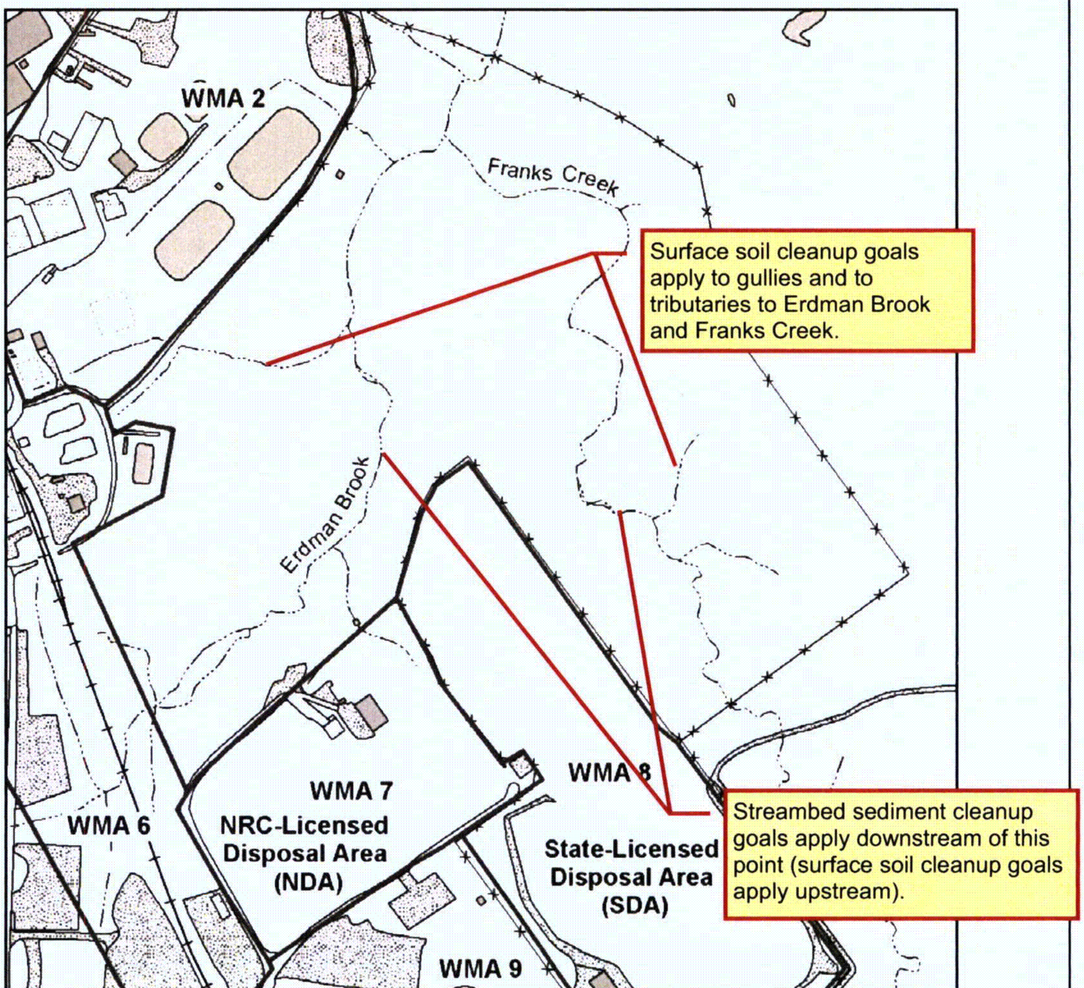

Figure 5-12. Areas Where Streambed Sediment DCGLs and Cleanup Goals Apply

5.2.6 Discussion of Sensitivity Analyses

Table 5-9 summarizes the sensitivity analyses performed for the surface soil DCGL base-case model, which are detailed in Appendix C.

Table 5-9 Summary of Parameter Sensitivity Analyses – Surface Soil DCGLs(1)

Parameter	Run	Change in Sensitivity Parameter	Minimum DCGL Change		Maximum DCGL Change	
			Change	Nuclide(s)	Change	Nuclide(s)
Indoor/Outdoor Fraction	1	-32%	-22%	U-232	0%	I-129
	2	21%	0%	I-129 U-234	28%	U-232
Contamination Zone Thickness	3	-50%	9%	U-232	81%	Sr-90
	4	200%	-28%	U-235	0%	Cs-137
Unsaturated Zone Thickness	5	-50%	-3%	U-235	0%	Cs-137 Sr-90 U-232
	6	150%	0%	Cs-137 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 (K_d)	9	lower	-71%	U-234	0%	Cs-137
	10	higher	-3%	U-232	867%	U-234
Hydraulic Conductivity	11	-55%	-36%	I-129	0%	Cs-137 Sr-90 U-232
	12	57%	0%	Cs-137 Sr-90 U-232	40%	I-129
Runoff/ Evaporation Coefficient	13	-23%	-29%	U-234	2%	U-232
	14	15%	-2%	U-232	79%	I-129
Depth of Well Intake	15	-40%	-40%	I-129	0.0%	Cs-137 Sr-90 U-232
	16	100%	0%	Cs-137 Sr-90 U-232	99%	I-129
Length Parallel to Aquifer Flow	17	-30%	0%	Cs-137 Sr-90 U-232	30%	I-129
	18	21%	-12%	I-129	0.0%	Cs-137 Sr-90 U-232
Hydraulic Gradient	19	-33%	-23%	I-129	0.0%	Cs-137 Sr-90 U-232
	20	33%	0%	Cs-137 Sr-90 U-232	23.3%	I-129
Gamma Shielding Factor	21	-38%	0%	Cs-137 I-129 Sr-90 U-232 U-233 U-234 U-235 U-238	0.0%	Cs-137 I-129 Sr-90 U-232 U-233 U-234 U-235 U-238

Table 5-9 Summary of Parameter Sensitivity Analyses – Surface Soil DCGLs[(1)]

Parameter	Run	Change in Sensitivity Parameter	Minimum DCGL Change		Maximum DCGL Change	
			Change	Nuclide(s)	Change	Nuclide(s)
	22	87%	-24%	U-232	0.0%	I-129
Indoor Dust Filtration Factor	23	-60%	0%	Cs-137 I-129 Sr-90 U-234	0.2%	U-232
	24	-25%	0%	Cs-137 I-129 Sr-90 U-233 U-234	0.1%	U-232
Dust Loading Factor	25	-70%	0%	Cs-137 I-129 Sr-90 U-234	0.3%	U-232
	26	67%	0%	U-232	0.0%	Cs-137 I-129 Sr-90 U-235 U-238
Root Depth	27	-67%	0%	Cs-137 I-129 Sr-90 U-232 U-233 U-234 U-235 U-238	0.0%	Cs-137 I-129 Sr-90 U-232 U-233 U-234 U-235 U-238
	28	233%	0%	I-129	193.7%	Sr-90
Food Transfer Factors	29	lower	-38%	U-235	875%	Sr-90
	30	higher	-97%	Sr-90	-42%	U-238
Mass Balance Model	31	NA	-67%	U-234	0.0%	Cs-137 Sr-90 U-232

NOTES: (1) Results presented here are for radionuclides considered likely to contribute significantly to the overall surface soil dose based on available characterization data.

Discussion of Surface Soil Results

The sensitivity analysis results for the surface soil source model been evaluated considering those radionuclides that are the primary dose drivers, i.e., those that are likely to contribute significantly to predicted dose based on available characterization data. The radionuclides are Sr-90 (due to water independent plant uptake), I-129 (due to water dependent pathways), Cs-137 (external radiation dose), and most uranium radionuclides (water dependent pathways).

The sensitivity analysis of the surface soil model, for these radionuclides, indicates the following:

- A lower indoor exposure fraction results in the largest DCGL decrease for U-232. Similarly, a higher indoor exposure fraction results in the largest increase for U-232 and no change for I-129 and U-234. However, it is unlikely that the indoor fraction is too low based on the local climate. The U-232 doses are mainly due to external exposure, which accounts for the relative sensitivity to this parameter.
- Decreasing the source thickness increased the DCGL for all radionuclides and increasing the source thickness resulted in the most significant DCGL decrease for U-235. The sensitivity to this parameter is due to increased/decreased dose from the water ingestion and plant pathways (both water dependent and independent).

- Decreasing the unsaturated zone thickness resulted in a decreased DCGL for U-235 and produced no change for Cs-137, I-129, and U-232. Similarly, increasing the unsaturated zone thickness increased the U-235 DCGL and produced no change for Cs-137, I-129, and U-232. Sensitivity to this parameter is mainly due to increased/decreased travel time of contaminants to the saturated zone, resulting in water dependent doses occurring earlier/later with respect to doses from water independent pathways.
- Reducing the irrigation/well pump rate increased the DCGL for I-129 most significantly. Similarly, increasing the pump rate decreased the DCGL for I-129. This is because reducing the pumping rate results in a lower dilution factor, and increasing the pumping rate results in more radionuclide inventory available for exposure.
- The most significant effects of varying the K_d values were observed for U-234, which ranged from a decrease of 71 percent when lowering the K_d, to an increase of 867 percent when increasing the K_d.
- Decreasing the hydraulic conductivity significantly reduced the DCGL for I-129 due to reduced dilution and larger groundwater dose relative to other pathways at the time of peak dose. Similarly, increasing the hydraulic conductivity significantly increased the DCGL for I-129.
- Variations in the runoff/evapotranspiration coefficients had the greatest effect on U-234 and I-129, and the least impact on U-232. Radionuclides that are most sensitive to this parameter have doses mainly due to water dependent pathways.
- Decreasing the well intake depth most significantly decreased the DCGL for I-129, while increasing this parameter results in significantly increased the DCGL for I-129, due to increased/decreased dilution in the well water.
- Changes to the parameter for length of contamination parallel to the aquifer flow had the most significant effect on the I-129 DCGL, due to increased/decreased dilution in the aquifer.
- Changes to the hydraulic gradient most significantly impacted I-129, due to the large water dependent pathway contributions.
- Decreasing the gamma shielding factor had no impact; however, increasing the shielding factor decreased the U-232 DCGL.
- Changes to the indoor dust filtration factor had minimal impact on DCGLs, due to relatively larger contribution to dose from other pathways.
- Similarly, changes to the dust loading factor had minimal impact on DCGLs, due to relatively larger contribution to dose from other pathways.
- Decreases in root depth did not significantly impact the DCGLs; however, increased root depths impacted Sr-90 most significantly due to relatively large plant pathway doses.

- Decreasing/increasing the plant transfer factors significantly increased/decreased the DCGL for Sr-90, as dose is mainly due to ingestion via plant uptake from soil.
- Use of the mass balance groundwater model significantly decreases the DCGL for U-234 but had no effect on Sr-90, Cs-137, or U-232. Radionuclides most sensitive to this parameter have doses mainly due to water dependent pathways.

Table 5-10 summarizes the sensitivity analyses performed for the subsurface soil initial base-case model DCGLs, which are detailed in Appendix C.

Table 5-10 Summary of Sensitivity Analyses – Subsurface Soil DCGLs

Parameter	Run	Change in Sensitivity Parameter	Minimum DCGL Change		Maximum DCGL Change	
			Change	Nuclide(s)	Change	Nuclide(s)
Indoor/Outdoor Fraction	1	-32%	-25%	Cs-137	0.3%	U-238
	2	21%	0%	I-129	35%	U-232
Contamination Zone Thickness	3	-67%	-65%	U-238	170%	Sr-90
	4	233%	-4%	U-232	98%	U-234
Unsaturated Zone Thickness	5	-50%	-1%	I-129	58%	U-238
	6	150%	0%	Cs-137 Sr-90 U-232 U-235	2218%	U-234
Irrigation/Pump Rate	7	-57%	-39%	I-129	57%	U-238
	8	70%	0%	Cs-137	20%	I-129
Soil/Water Distribution Coefficients (K_d)	9	lower	-86%	U-238	116%	U-232
	10	higher	-20%	U-232	2168%	U-234
Hydraulic Conductivity	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	0%	U-235
	18	-25%	0%	Cs-137 I-129 Sr-90 U-233 U-234 U-238	0%	U-235
Inhalation Dust Loading	19	-70%	0%	U-238	1%	U-233
	20	67%	0%	U-235	0%	Cs-137 I-129 Sr-90
Root Depth	21	-67%	-65%	Sr-90	1%	U-233
	22	233%	0%	U-238	181%	Sr-90
Food Transfer Factors	23	lower	-0.1%	U-238	522%	Sr-90
	24	higher	-93%	Sr-90	0%	U-234

Discussion of Subsurface Soil Results

The sensitivity analysis results for the subsurface soil source initial base-case model were evaluated considering those radionuclides that are the primary dose drivers, i.e., those that are likely to contribute significantly to predicted dose based on available characterization data (see Table 5-1). The radionuclides are Sr-90 (due to water independent plant uptake), I-129 (due to water dependent pathways), Cs-137 (external radiation dose), and uranium radionuclides (water dependent pathways).

The sensitivity analysis of the subsurface soil model for these radionuclides indicates the following:

- A lower indoor exposure fraction results in a DCGL decrease for Cs-137 and no significant change for U-238. A higher indoor exposure results in a significant increased DCGL for U-232. However, it is unlikely that the indoor fraction is too low based on the local climate. Doses for these isotopes are mainly due to external exposure, which accounts for the relative sensitivity to this parameter.
- The source thickness parameter sensitivity was most significant for Sr-90, U-234, and U-238. The sensitivity to this parameter is due to increased/decreased dose from the water ingestion and plant pathways (both water dependent and independent).
- Decreasing or increasing the unsaturated zone thickness resulted in significant changes for U-234 and U-238.
- The I-129 and U-238 DCGLs were sensitive to changes in the irrigation/well pump rate but the Cs-137 DCGL was not. This effect is because reducing the pumping rate results in a lower dilution factor, and increasing the pumping rate results in more dilution for water dependent pathways.
- The most significant effects of varying the K_d values were observed for U-232, U-234, and U-238.
- The hydraulic conductivity changes had no impact on DCGLs because the mass balance groundwater model was used.
- The U-232 and U-234 DCGLs are sensitive to changes in the runoff/ evapotranspiration coefficient. Radionuclides that are most sensitive to this parameter have doses mainly due to water dependent pathways.
- Changes to the gamma shielding factor most significantly impacted Cs-137 and U-232, based on a relatively large external exposure dose.
- The indoor dust filtration factor variations had no impact on DCGLs, due to relatively large dose contributions from other pathways.
- Changes to the dust loading factor had a minimal impact on DCGLs, due to relatively large dose contributions from other pathways.
- Varying the root zone depth impacted the Sr-90 DCGL most significantly.

- The plant transfer factor is most sensitive for Sr-90, as the dose is mainly due to ingestion via plant uptake.

Table 5-11 Summary of Sediment DCGL Sensitivity Analysis

Parameter	Run	Change in Sensitivity Parameter	Minimum DCGL Change		Maximum DCGL Change	
			Change	Nuclide(s)	Change	Nuclide(s)
Outdoor Fraction	1	-50%	2%	I-129	97%	U-232
	2	100%	-50%	U-232	-3%	I-129
Source Thickness	3	-50%	0%	U-235	29%	Sr-90
	4	200%	-23%	U-233	0%	Cs-137
Soil/Water Distribution Coefficients (K_d)	5	lower	-76.5%	U-234	26%	U-232
	6	higher	-64.5%	U-233	52%	U-234
Runoff/Evaporation Coefficient	7	-23%	0%	Cs-137	4%	U-232
	8	15%	-3%	I-129	0%	Cs-137
Mass Loading for Inhalation	9	-70%	0%	Cs-137 I-129 Sr-90 U-232	1%	U-233
	10	67%	-3%	U-234	0%	Cs-137 I-129 Sr-90
Root Depth	11	-67%	0%	no change	0%	no change
	12	233%	0%	U-232 U-235	50%	Sr-90
Food Transfer Factors	13	lower	1%	U-232	852%	Sr-90
	14	higher	-98%	Sr-90	-13%	U-232

Discussion of Streambed Sediment Results

The streambed sediment model sensitivity simulations have been evaluated considering those radionuclides that are likely to significantly contribute to the overall doses in this media, which are Sr-90 (venison ingestion) and Cs-137 (external radiation dose).

The sensitivity analysis for the sediment model, for these radionuclides, indicates:

- The DCGLs for Sr-90 and Cs-137 are inversely related to changes in outdoor fraction, with Cs-137 being the most sensitive. Radionuclides with primary doses from external exposure pathways are more sensitive to changes in this parameter.
- Decreasing the source thickness results in higher DCGLs for Sr-90 and Cs-137. While increasing the source thickness has little effect on these radionuclides, Sr-90 is most sensitive to this parameter.
- Varying the K_d values had a minimal effect on the Cs-137 DCGL, but decreasing the K_d decreased the Sr-90 DCGL due to doses from water dependent pathways.

- Varying the runoff/evapotranspiration coefficient had little effect on Cs-137 or Sr-90 DCGLs. Radionuclides most sensitive to this parameter have doses mainly due to water dependent pathways.
- Changes to the mass loading factor had minimal impact on DCGLs.
- Decreasing the root zone depth did not impact DCGLs; however, increasing the depth increased the Sr-90 DCGL significantly.
- Decreasing both plant and fish transfer factors resulted in increased DCGLs for Sr-90, and increasing these parameters resulted in decreased DCGLs for both Cs-137 and Sr-90.

Changes to Base-Case Models Based on Sensitivity Analysis Results

Development of the conceptual model for surface soil DCGLs was an iterative process that used conservative assumptions for model parameters and took into account the results of early model runs and the related input parameter sensitivity analyses.

The initial model runs produced inordinately low DCGLs for uranium radionuclides in surface soil. The calculated $DCGL_W$ for U-238, for example, was 1.0 pCi/g, slightly above measured background concentrations in surface soil shown in Table 4-11 of this plan.

The next iteration involved changes to radionuclide distribution coefficients. Evaluation of the basis for the original distribution coefficients and sensitivity analysis results led to the conclusion that some distribution coefficients used were inappropriate. These distribution coefficients were changed. The resulting distribution coefficients are based either on site-specific data for the sand and gravel layer or, where site-specific data are not available, values for sand from Sheppard and Thibault 1990, as shown in Table C-2.

These model changes produced higher $DCGL_W$ values for uranium radionuclides, e.g., 4.8 pCi/g for U-238. However, these values were still low compared to uranium DCGLs for unrestricted release developed at other sites. Further evaluation showed that the main reason for the low uranium DCGLs was the conservative use of the RESRAD mass balance model. After considering the results of the sensitivity analysis that evaluated use of the non-dispersion model, and RESRAD Manual guidance[14], it was determined to be more appropriate to use the non-dispersion model in the surface soil analysis and this was done.

The probabilistic uncertainty analysis discussed in the next subsection provided insight into the degree of conservatism in model input parameters, producing DCGLs that were generally lower than those from the deterministic analyses.

5.2.7 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

[14] The RESRAD Manual (Yu, et al. 2001) notes in Appendix E that:"The user has the option of selecting which [groundwater] model to use. Usually, the MB [mass balance] model is used for smaller contaminated areas (e.g., 1,000 m^2 or less) and the ND [non-dispersion] model is used for larger areas."

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[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	**9.4E-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]	6.3E+00	**4.1E+00**	**3.2E+03**	3.4E+03	9.5E+03	**4.7E+03**
Tc-99	2.4E+01	**2.1E+01**	**1.1E+04**	1.4E+04	2.2E+06	**6.6E+05**
U-232	5.8E+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**

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)
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 based 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 5.2.8, 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.
(6) These values take into account 30 years decay.

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 5.2.8 results in even lower DCGLs for 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 5.2.8.

5.2.8 Subsurface Soil DCGL Multi-Source Analysis

As noted in Section 5.2.1, the original base-case conceptual model used in developing the subsurface soil DCGLs recognizes one source of contamination – the Lavery till from the bottom of one of the deep excavations that is brought to the surface during construction of the hypothetical cistern. This model does not consider potential impacts to groundwater in the backfilled excavation from continuing release of remaining residual radioactivity at the bottom of the deep excavations.

To address this limitation, analyses were performed that take into account the impacts of releases of this other residual radioactivity on both a hypothetical residential gardener and a resident farmer with a modified model that accounts for a surface and a subsurface source of radiation. Figure 5-13 illustrates the modified conceptual model used in these analyses.

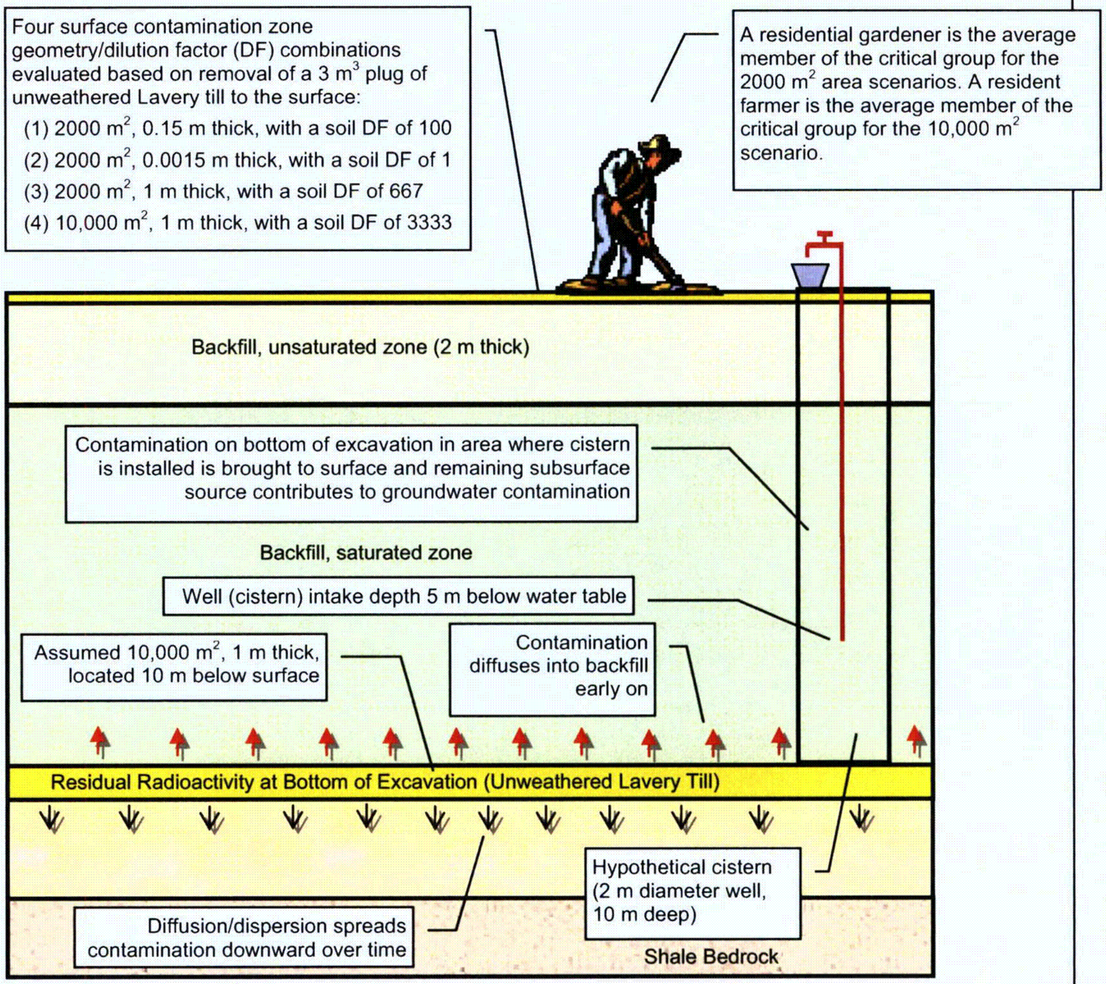

Figure 5-13. Modified Conceptual Model for Subsurface Soil DCGL Development

With this model, the subsurface soil DCGLs are based on exposure to residual radioactivity associated with the bottom of the deep excavation in the unweathered Lavery till, with (1) soil from this area assumed to be relocated to the surface during installation of a cistern and (2) with the remaining contaminated Lavery till in the excavation bottom serving as a continuing source of contaminants to groundwater. These sources and the exposure pathways considered are described below.

Excavation Bottom Treated as Two Sources of Contamination

The excavation bottom is treated as two distinct sources: (1) a plug of contaminated soil from the excavation bottom that is brought to the surface during installation of the cistern and spread over the entire surface of the hypothetical garden, and (2) the remaining contaminated Lavery till at the excavation bottom from which residual radioactivity moves upward by diffusion and enters groundwater being drawn into the well. Both the residential gardener scenario and the resident farmer scenario were considered as indicated in Figure 5-13.

The surface source that results from the contribution of contamination in soil being removed from the bottom of the excavation and brought to the surface and the contribution of contamination in irrigation water has the following characteristics:

- It is assumed that the contaminated material is evenly spread across the entire hypothetical garden and mixed uniformly in the soil to varying depths (the surface contamination zone),
- Exposure occurs from direct exposure and soil pathways associated with contaminated soil brought to the ground surface, and
- Exposure occurs from groundwater pathways as contaminated water is drawn into the well and used as irrigation water resulting in plant contamination and animal contamination where these plants are used as feed. As a result, the resident is exposed to radioactivity from the plants being consumed and, in the case of the resident farmer scenario, from meat and milk produced from cattle that have been raised on the contaminated feedstock.

The subsurface source remaining at the bottom of the excavation is assumed to have the following characteristics:

- The diffusive movement of contamination from the excavation bottom (the subsurface contamination zone) begins immediately after the excavation is backfilled and results in contaminating the aquifer,
- Contaminated groundwater entering the well is a source to soil in the surface contamination zone because well water is used to irrigate the garden, and
- Drinking water exposure occurs from contaminated well water being used as a source of drinking water.

Table 5-11b shows the exposure pathways evaluated.

Table 5-11b. Exposure Pathways for Modified Subsurface Soil DCGL Model

Exposure Pathways	Residential Gardener	Resident Farmer
External gamma radiation from contaminated soil	Yes	Yes
Inhalation of airborne radioactivity from re-suspended	Yes	Yes

Table 5-11b. Exposure Pathways for Modified Subsurface Soil DCGL Model

Exposure Pathways	Residential Gardener	Resident Farmer
contaminated soil		
Plant ingestion (produce impacted by contaminated soil and groundwater contaminated by primary and secondary sources)	Yes	Yes
Meat ingestion (beef impacted by contaminated soil and groundwater contaminated by primary and secondary sources)	No	Yes
Milk ingestion (impacted by contaminated soil and groundwater contaminated by primary and secondary sources)	No	Yes
Aquatic food ingestion	No	No
Ingestion of drinking water (from groundwater contaminated by primary and secondary sources)	Yes	Yes
Soil ingestion	Yes	Yes
Radon inhalation	No	No

Details of the modeling including values of input parameters such as distribution coefficients appear in the calculation package (Price 2009).

Mathematical Models

Calculation of the combined dose utilized information from the three-dimensional near field STOMP finite difference model of the north plateau for groundwater transport, a model that estimated the drinking water dose associated with contamination from the subsurface source diffusing into the aquifer, and RESRAD dose to source ratios associated with unit soil concentrations to determine the total dose from all pathways. The calculations were implemented with a FORTRAN language computer program that estimates time dependent human health impacts.[15]

The model performs mass balance calculations and develops concentrations over time for three distinct areas (1) the remaining subsurface source, (2) the backfilled saturated zone, and (3) the surface which has been contaminated with material excavated from the subsurface source and radionuclides in irrigation water.

In order to identify controlling scenarios, the area of the contaminated zone at the surface and the degree of mixing into the soil of the garden were varied.

The STOMP model was executed with parameter values for the contaminated area and well pumping rates that corresponded with assumptions used in the RESRAD model for the exposure scenarios under consideration. A contaminated area of 10,000 m^2 and pumping rate of 5720 m^3/y were used to evaluate the resident farmer, and a contaminated area of 2,000 m^2 and well pumping rate of 1140 m^3/y were used to evaluate the residential gardener scenario. The residential gardener scenario assumed several source

[15] These analyses were deterministic analyses. Consideration was given to performing probabilistic analyses instead. However, the complexity of the multi-source model made a probabilistic analysis impractical.

configurations within the contaminated area for the three m^3 of contaminated Lavery till assumed to be excavated to the surface:

- Contamination is spread over the surface in a thin layer (1.5 mm thick) of undiluted till,
- Contamination is spread over the surface and then tilled into the soil to a depth of 15 cm, and
- Contamination is spread over the surface and then tilled into the soil to a depth of 1 m.

The source configuration determined to be most limiting for each radionuclide was used as the basis for the development of the subsurface DCGLs.

Results

Table 5-11c shows the results of the analyses compared to DGCLs developed using other conceptual models.

Table 5-11c. Subsurface Soil DCGL Comparison (pCi/g)(1)

Nuclide	Multi-Source	Cistern Well Driller	Recreat. Hiker	Lagoon 3 Erosion	Natural Gas Well Driller	Basic Deterministic Models(2)	Probabilistic Peak of the-Mean
Am-241	**6.3E+03**	1.7E+04	2.7E+05	2.9E+05	1.4E+05	7.1E+03	6.8E+03
C-14	**9.9E+02**	2.3E+09	3.3E+08	6.4E+06	4.9E+09	3.7E+05	7.2E+05
Cm-243	3.6E+03	1.1E+04	5.0E+04	1.8E+05	1.2E+05	1.2E+03	**1.1E+03**
Cm-244	3.4E+04	3.3E+04	1.0E+09	3.9E+05	2.6E+05	2.3E+04	**2.2E+04**
Cs-137(3)	2.8E+03	6.7E+03	9.8E+05	7.4E+05	9.2E+04	4.4E+02	**3.0E+02**
I-129	**7.5E+00**	8.0E+05	1.9E+06	3.5E+05	9.2E+06	5.2E+01	6.7E+02
Np-237	**1.0E+00**	6.6E+03	2.7E+04	5.9E+05	6.6E+04	4.3E+00	9.3E+01
Pu-238	**1.3E+04**	2.0E+04	1.5E+06	2.7E+05	1.6E+05	1.5E+04	1.4E+04
Pu-239	**3.1E+03**	1.9E+04	2.8E+05	2.4E+05	1.5E+05	1.3E+04	1.2E+04
Pu-240	**3.4E+03**	1.9E+04	2.8E+05	2.4E+05	1.5E+05	1.3E+04	1.2E+04
Pu-241	5.5E+05	5.5E+05	1.7E+07	1.2E+07	4.5E+06	**2.4E+05**	2.5E+05
Sr-90(3)	**2.8E+02**	8.7E+05	1.6E+08	9.2E+06	1.1E+07	3.2E+03	3.4E+03
Tc-99	**5.9E+02**	7.9E+07	2.2E+08	4.7E+07	9.4E+08	1.1E+04	1.4E+04
U-232	8.8E+01	1.6E+03	2.8E+04	4.5E+05	1.6E+04	1.0E+02	**7.4E+01**
U-233	2.7E+02	6.2E+04	1.3E+06	2.9E+06	4.9E+05	**1.9E+02**	9.9E+03
U-234	2.8E+02	6.4E+04	1.4E+06	3.1E+06	5.0E+05	**2.0E+02**	1.3E+04
U-235	2.9E+02	1.2E+04	4.2E+04	3.2E+06	1.4E+05	**2.1E+02**	9.3E+02
U-238	3.0E+02	3.7E+04	1.9E+05	3.3E+06	3.6E+05	**2.1E+02**	4.6E+03

NOTES: (1) The lowest DCGLs are shown in boldface.
(2) The lower value of the deterministic resident farmer and residential gardener DCGLs.
(3) These values take into account 30 years decay.

In nine cases, the DCGLs developed using other conceptual models are lower than the DCGLs developed by the multi-source model that accounts for continuing releases from the bottom of the deep excavations:

- The peak-of-the-mean probabilistic DCGLs, which did not take into account continuing releases from the bottom of the deep excavations, are lower for Cm-243, Cm-244, Cs-137, and U-232; and
- The limiting deterministic DCGL from the deterministic resident farmer and residential gardener conceptual models, which did not take into account continuing releases from the bottom of the excavations, was lower for Pu-241, U-233, U-234, U-235, and U-238.

This situation can be attributed to conceptual model differences such as different contamination zone geometry.

5.2.9 Overall Conclusions

Development of DCGLs proved to be an iterative process.

For surface soil DCGLs, the initial-base case conceptual model was determined to be more conservative than an alternate conceptual model involving erosion and the resulting potential doses to an offsite receptor. However, the probabilistic peak-of-the-mean DCGLs were lower than the base-case deterministic DCGLs for all radionuclides except Np-237. The peak-of-the-mean DCGLs were therefore selected as the basis for the surface soil cleanup goals to be conservative.

For subsurface soil DCGLs, analysis of the residential gardener and the multisource alternate conceptual models showed that the initial base-case resident farmer model was not conservative. The probabilistic uncertainty analysis provided additional insight into potential future doses from residual radioactivity at the bottom of the deep excavations. In the interest of conservatism, the lowest DCGLs produced by the various models were selected as the basis for the subsurface soil cleanup goals.

For streambed sediment DCGLs, the refined base-case model produced essentially the same DCGLs as the initial base-case model. However, the probabilistic peak-of-the-mean DCGLs were lower and were therefore selected as the basis for the cleanup goals.

5.3 Limited Site-Wide Dose Assessment

This section describes the limited integrated dose assessment performed to ensure that criteria used in Phase 1 remediation activities will not limit options for Phase 2 of the decommissioning.

5.3.1 Basis for this Assessment

Section 5.1.3 explains why such a dose assessment is appropriate, considering the Phase 1 and Phase 2 sources illustrated in Figure 5-4. Section 5.1.3 also explains that the appropriate dose assessment involves a hypothetical individual engaged in farming at some time in the future on one part of the remediated project premises who also spends time fishing and hiking at Erdman Brook and Franks Creek.

This scenario would involve an individual being exposed to two different remediated source areas and being a member of the two different critical groups. As described in Section 5.2, the exposure group for the resident farmer scenario used for development of DCGLs for surface and subsurface soil is significantly different from the exposure group for the development of the streambed sediment DCGLs, which involves a hypothetical individual spending a relatively small fraction of his or her time hiking, fishing, and hunting in the areas of Erdman Brook and Franks Creek.

In both of these cases, it was assumed that the hypothetical individual (the average member of the critical group) would be exposed only to the residual radioactivity of interest. That is, the resident farmer would not be exposed to residual radioactivity in the areas of the streams and the recreationist would not be exposed to residual radioactivity in surface soil or subsurface soil.

5.3.2 Assessment Approach

The approach used involves partitioning doses between two critical groups and two areas of interest: (1) the resident farmer who lives in an area of the project premises where surface soil or subsurface soil has been remediated to the respective DCGLs and (2) the person who spends time in the areas of the streams hiking, fishing, and hunting (the recreationist). This approach is analogous to addressing multiple radionuclides in contaminated media of interest using the sum-of-fractions approach or unity rule (NRC 2006).

Consideration of potential risks related to the different areas led assigning 90 percent of the total dose limit of 25 mrem per year to the resident farmer activities and 10 percent to the recreational activities. This arrangement involves assigning an acceptable dose of 22.5 mrem per year to resident farmer activities and 2.5 mrem per year to recreation in the area of the streams, values which total 25 mrem per year.[16] The assessment was then performed using the base case analysis results for the resident farmer and the recreationist at Erdman Brook and Franks Creek.

Two separate assessments were performed with the resident farmer located in: (1) the area of the remediated WMA 1 subsurface soil excavation, and (2) the resident farmer located in an area where surface soil was assumed to have been remediated. Details appear in Appendix C.

5.3.3 Results of the Assessments

Table 5-12 provides the assessment results for the WMA 1 subsurface soil case and Table 5-13 provides the results for the surface soil case. The streambed sediment $DCGL_W$ values are the same in both cases because the apportioned dose limit of 2.5 mrem per year is the same.

[16] This 0.90/0.10 split is based on judgment related to relative risk. Consideration was given to using a split based on the relative time the hypothetical farmer would spend in the area of the farm compared to the area of the streams. However, because the assumed time in the area of the streams is relatively small at 104 hours per year, such as spilt could result in an allowable annual dose of 24.7 mrem for resident farmer activities and 0.3 mrem for recreation at the streams. This split would have a minimal impact on the soil DCGLs while driving the streambed sediment DCGLs to unrealistically low levels.

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 for subsurface soil are the lowest values from Table 5-11c and the base-case values for streambed sediment are the lowest values from Table 5-11a.

(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.

As can be seen from Table 5-13, the dose partitioning approach reduced the $DCGL_W$ values for surface soil by 10 percent and reduced the $DCGL_W$ values for streambed sediment by an order of magnitude.

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
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

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)
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 are the lowest values from Table 5-11a.

(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.

5.4 Cleanup Goals and Additional Analyses

This section (1) identifies the cleanup goals to be used in remediation of surface soil, subsurface soil, and streambed sediment and the basis for these cleanup goals; (2) describes how the DCGLs and the cleanup goals will be later refined; (3) discusses use of surrogate radionuclides; and (4) identifies plans for the dose assessment of the remediated WMA 1 and WMA 2 areas.

5.4.1 Cleanup Goals

As explained in Section 5.1.6, the dose modeling process includes establishing cleanup goals below the DCGLs developed to meet the 25 mrem per year unrestricted dose limit that are to be used to guide remediation efforts, considering the results of the analysis of the combined source area exposure scenario described in Section 5.3 and the ALARA analysis described in Section 6.

Combined Source Area Analysis

As indicated in Section 5.3, analysis of the limiting scenario for dose integration – a resident farmer living on the remediated project premises who spends time in the vicinity of Erdman Brook and Franks Creek hiking, fishing, and hunting – produced lower $DCGL_W$ values for both critical groups, with the reduction for the recreationist in the area of the streams being a much greater percentage.

ALARA Analysis

Section 6 describes the process used to evaluate whether remediation of surface soil, subsurface soil, and streambed sediment below DCGLs based on 25 mrem/y would be cost-effective, following the standard NRC methodology for ALARA analyses. Section 6 provides the results of a preliminary analysis and provides for a final ALARA analysis to be performed during the Phase 1 decommissioning work.

The preliminary ALARA analysis suggests that the costs of removing slightly contaminated soil or sediment at concentrations below the DCGLs for 25 mrem per year will outweigh the benefits. That is, areas where surface soil, subsurface soil, and stream sediment are remediated to radioactivity concentrations at the DCGLs satisfy the ALARA criteria. The evaluation process balances the cost of offsite disposal of additional radioactively contaminated soil (cost of $6.76 per cubic foot) and the benefits of reduced dose (benefit of $2000 per person-rem as set forth in NRC guidance).

The final ALARA analysis that will be performed during the Phase 1 decommissioning activities will make use of updated information, such as actual rather than predicted waste disposal costs. However, the results will likely be similar to the preliminary analysis.

Section 6 explains that the methods to be used in remediation of contaminated soil and sediment, which involve excavation of the material in bulk quantities, will generally remove more material than necessary to meet the DCGLs. As noted in Section 6, NRC recognizes that soil excavation is a coarse removal process that is likely to remove large fractions of the remaining radioactivity (NRC 1997). The contaminated soil and sediment removal method is therefore expected to produce residual radioactivity concentrations well below the DCGLs.

Cleanup Goals

Demonstration that the decommissioning activities have achieved the desired dose-based criteria is through the process described in the *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000). This process is outlined in Section 9, which describes the general content of the Phase 1 Final Status Survey Plan. The Phase 1 Final Status Survey Plan provides the details.

For surface soils and sediments in the WVDP Phase 1 areas, the field cleanup goal need not be too far below the DCGL, if at all. As discussed previously, bulk excavation will generally remove more material than necessary to meet the DCGL, so it is likely that the post-remediation average concentration will be below whatever in-process goal is chosen. And the costs for additional remediation of a surface soil or sediment site, while extra, are not unusually high.

However, for subsurface soils a field cleanup goal should be well below the DCGL because of the large costs to be incurred if additional remediation were necessary to an area that failed the statistical testing. Re-excavating to depth with shoring, engineering controls, and management or disposal of extensive overburden would be expensive compared to excavating some additional material in the original remediation.

Consideration of such factors led to DOE establishing in this plan the cleanup goals shown in Table 5-14. Note that the surface soil cleanup goals apply only to areas of the project premises where there is no subsurface soil contamination and that the subsurface soil cleanup goals apply only to the bottoms and lower sides (extending from a depth of three feet and greater) of the large excavations in WMA 1 and WMA 2.

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	2.1E+04
C-14	1.5E+01	1.6E+06	4.5E+02	8.0E+04	1.8E+02	5.9E+05
Cm-243	3.1E+01	7.5E+02	5.0E+02	4.0E+03	3.1E+02	2.8E+03
Cm-244	5.8E+01	1.2E+04	9.9E+03	4.5E+04	3.8E+03	3.6E+05
Cs-137(4)	1.4E+01	3.0E+02	1.4E+02	1.7E+03	1.0E+02	9.4E+02
I-129	2.9E-01	6.0E+02	3.4E+00	3.4E+02	7.9E+01	2.0E+04
Np-237	2.3E-01	7.5E+01	4.5E-01	4.3E+01	3.2E+01	1.1E+03
Pu-238	3.6E+01	7.6E+03	5.9E+03	2.8E+04	1.2E+03	1.7E+05
Pu-239	2.3E+01	6.9E+03	1.4E+03	2.6E+04	1.2E+03	1.7E+05
Pu-240	2.4E+01	6.9E+03	1.5E+03	2.6E+04	1.2E+03	1.7E+05
Pu-241	1.0E+03	1.3E+05	1.1E+05	6.8E+05	3.4E+04	7.5E+05
Sr-90(4)	3.7E+00	7.9E+03	1.3E+02	7.3E+03	4.7E+02	7.1E+04
Tc-99	1.9E+01	2.6E+04	2.7E+02	1.5E+04	6.6E+04	4.2E+06
U-232	1.4E+00	5.9E+01	3.3E+01	4.2E+02	2.2E+01	2.1E+02
U-233	7.5E+00	8.0E+03	8.6E+01	9.4E+03	2.2E+03	4.4E+04
U-234	7.6E+00	1.6E+04	9.0E+01	9.4E+03	2.2E+03	2.1E+05
U-235	3.1E+00	6.1E+02	9.5E+01	3.3E+03	2.3E+02	2.0E+03
U-238	8.9E+00	2.9E+03	9.5E+01	9.9E+03	8.2E+02	8.2E+03

NOTE: (1) These cleanup goals (CGs) are to be used as the criteria for the remediation activities described in Section 7 of this plan. Note that the streambed sediment cleanup goals will support unrestricted release of the project premises but will not necessarily support restricted release alternatives due to the continued presence of Phase 2 sources as discussed in Section 5.2.2.

(2) The CG_W values for surface soil and streambed sediment are the same as the limited dose assessment DCGL values in the third and fifth columns of Table 5-13, respectively. The CG_{EMC} values are based on the limiting case among the probabilistic analysis resident farmer analysis, the deterministic resident farmer analysis, and the deterministic residential gardener analysis.

(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 $DCGL_{EMC}$ values are the limiting values from the multi-source analysis or the deterministic resident farmer/residential gardener deterministic analyses using the 1 m^2 area factor from Table 9-2. The subsurface soil cleanup goals apply only to the bottoms of the WMA 1 and WMA 2 deep excavations and to the sides of these excavations more than three feet below the ground surface.

(4) The cleanup goals for Sr-90 and Cs-137 apply to the year 2041 and later, that is, they incorporate a 30-year decay period from 2011. The 30-year decay period was selected for these key radionuclides because of their short half-life. As noted previously, the Phase 2 decision could be made within 10 years of issue of the Record of Decision and Findings Statement documenting the Phase 1 decision. If this approach were to involve unrestricted release of the site, achieving this condition would be expected to take more than 20 years due to the large scope of effort to exhume the underground waste tanks and the NDA. It is therefore highly unlikely that conditions for unrestricted release of the project premises could be established before 2041. If Phase 2 were to involve closing radioactive facilities in place, then institutional controls would remain in place after 2041. DOE will be responsible for maintaining institutional control of the project premises and providing for monitoring and maintenance of the project premises until completion of Phase 2 of the decommissioning.

The basis for these cleanup goals is as follows. Compliance with the cleanup goals used for remediation when mixtures of radionuclides are present will be determined by use of the sum-of-fractions approach.

Basis for Cleanup Goals for Surface Soil

The surface soil CG_W values are the values in the Surface Soil $DCGL_W$ Assessment column of Table 5-13. DOE considers these goals to be conservative and appropriate to provide assurance that any remediation of surface soil and sediment in drainage ditches on the project premises that may be accomplished during Phase 1 of the decommissioning will support releasing the remediated areas under the criteria of 10 CFR 20.1402, should the licensee eventually determine that approach to be appropriate for Phase 2 of the decommissioning.[17]

Basis for Cleanup Goals for Subsurface Soil

DOE has established the subsurface soil cleanup goals at 50 percent of subsurface soil DCGLs calculated in the limited site-wide dose assessments for 22.5 mrem per year (Table 5-12). The cleanup goals for subsurface soil will therefore equate to 11.25 mrem per year. DOE is taking this approach to provide additional assurance that remediation of the WMA 1 and WMA 2 excavated areas will support all potential options for Phase 2 of the decommissioning. As indicated previously, these cleanup goals apply only to the bottom of the large WMA 1 and WMA 2 excavations and to the sides of these excavations three feet or more below the surface.

Basis for Cleanup Goals for Streambed Sediment

DOE has used the $DCGL_W$ values from the limited site-wide dose assessment (the last column in Table 5-12 and Table 5-13) as the cleanup goals for streambed sediment. These values are substantially less than those developed for the base-case recreationist scenario and are considered to be supportive of any approach that may be selected for Phase 2 of the decommissioning.

As noted in the discussion on the ALARA analysis results, DOE expects that the actual levels of residual radioactivity will turn out to be less than the DCGLs used for remediation, i.e., these cleanup goals, owing to the characteristics of the remediation method to be used.

5.4.2 Refining DCGLs and Cleanup Goals

The calculated DCGLs for 25 mrem per year and the associated cleanup goals will be refined as appropriate after the data from the soil and sediment characterization program to be completed early in Phase 1 of the decommissioning becomes available. These data are expected to provide additional insight into the radionuclides of interest in environmental media and the depth and areal distribution of the contamination. Such information could, for example, lead to deleting one or more radionuclides from further consideration in the Phase 1 cleanup or lead to more realistic source geometry for development of DCGLs for surface soil contamination. Analytical data from the subsurface soil characterization measurements being taken in 2008 could also provide information to help refine the subsurface soil DCGLs.

[17] As noted previously, surface soil may or may not be remediated in Phase 1 of the decommissioning. However, it is possible that characterization performed early in Phase 1 could identify surface soil contamination that would warrant remediation to reduce radiation doses during the period between Phase 1 and Phase 2 of the decommissioning. In the unlikely event that this situation developed, the areas of concern would be remediated in Phase 1.

If evaluation of the new data leads to refinement of the DCGLs and cleanup goals, then this plan will be revised accordingly to reflect the new values. Since such a change could affect the project end conditions, the plan revision would be provided to NRC for review and input prior to issue following the change process described in Section 1.

5.4.3 Use of a Surrogate Radionuclide DCGL

A *surrogate radionuclide* is a radionuclide in a mixture of radionuclides whose concentration is easily measured and can be used to infer the concentrations of the other radionuclides in the mixture. If actual radioactive contamination levels of the surrogate radionuclide are below the specified concentration, then the sum of doses from all radionuclides in the mixture will fall below the dose limit.[18]

The tables in this section do not provide $DCGL_W$ values for a surrogate radionuclide because available data on radionuclide distributions in soil and sediment are not sufficient to support this. However, surrogate radionuclide $DCGL_W$ values for the cleanup goals will be developed and incorporated into this section if evaluation of additional characterization data shows that Cs-137 or another easy to measure radionuclide can be used effectively as a surrogate for all radionuclides in source soil, subsurface soil, and/or streambed sediment in an area.

5.4.4 Preliminary Dose Assessment

Preliminary dose assessments have been performed for the remediated WMA 1 and WMA 2 excavations. These assessments made use of the maximum measured radioactivity concentration in the Lavery till for each radionuclide as summarized in Table 5-1, and the results of modeling to develop DCGLs for 25 mrem per year and the multi-source analysis results as shown in Table 5-11c. The results were as follow:

WMA 1, a maximum of approximately 8 mrem a year

WMA 2, a maximum of approximately 0.2 mrem a year

Given the limited data available, these results must be viewed as order-of-magnitude estimates. However, they do suggest that actual potential doses from the two remediated areas are likely to be substantially below 25 mrem per year. Note that the primary dose driver for these estimates is Sr-90, which accounts for approximately 66 percent of the estimated dose for the WMA 1 excavation and approximately 61 percent of the estimate for the WMA 2 excavation.

NOTE

The use of maximum rather than average values in these dose estimates adds conservatism, as does including values that are simply the highest minimum detectable concentrations, especially in the case of Np-237. (There was a wide range of several orders of magnitude among the minimum detectable concentrations reported for the 2008 sample data.) As with the DCGLs, decay of Sr-90 and Cs-137 over 30 years is accounted for in the estimate.

[18] Guidance on the use of surrogate measurements provided in Section 4.3.2 of NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* (NRC 2000) would be followed.

As noted previously, DOE will perform a dose assessment for the residual radioactivity in the WMA 1 and WMA 2 excavated areas using Phase 1 final status survey data. This assessment will use the same methodology used in development of the subsurface soil DCGLs to estimate the potential radiation dose using the actual measured residual radioactivity concentrations. The results of the dose assessment will be made available to NRC and other stakeholders. Note that a more-comprehensive dose assessment that also takes into account the Phase 2 sources may be performed in connection with Phase 2 of the decommissioning, depending on the approach selected for that phase.

5.5 Monitoring, Maintenance, and Institutional Controls

Inherent in the use of the 30-year decay period used in development of DCGLs and cleanup goals for Sr-90 and Cs-137 is the assumption that all or part of the project premises will not be released for unrestricted use before 2041. DOE will be responsible for monitoring and maintenance of the project premises and for maintaining institutional controls until completion of Phase 2 of the WVDP decommissioning, which is assumed to occur after 2041 if Phase 2 were to be designed to meet unrestricted release criteria. If a close-in-place approach was selected for Phase 2, then institutional controls are assumed to be required beyond 2041.

5.6 References

Code of Federal Regulations

10 CFR 20, Subpart E, *Radiological Criteria For License Termination (LTR)*.

10 CFR 20.1003, *Definitions.*

DOE Orders

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DOE Technical Standards

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