5.0 DOSE MODELING

PURPOSE OF THIS SECTION

The purpose of this section is to describe dose modeling performed for Phase 1 of the decommissioning to establish cleanup criteria that will not limit options for Phase 2 of the decommissioning.

INFORMATION IN THIS SECTION

This section provides the following information:

- Section 5.1 contains introductory material to place information in the following sections into context.
- Section 5.2 describes the base-case and alternative conceptual models and the mathematical model (RESRAD) used to develop derived concentration guideline levels (DCGLs) for 18 radionuclides of interest in surface soil, subsurface soil, and streambed sediment. It identifies the results in terms of $DCGL_W$ values. It discusses the deterministic sensitivity analyses of model input parameters. It also describes the probabilistic uncertainty analysis and the multi-source model for subsurface soil DCGLs that was found to be limiting for many radionuclides of interest.
- Section 5.3 discusses considerations related to dose integration and describes analyses performed to ensure that cleanup criteria used in Phase 1 will not limit Phase 2 decommissioning options.
- Section 5.4 provides cleanup goals; describes the process for refining the DCGLs and these cleanup goals; addresses use of a surrogate radionuclide in field measurements; provides preliminary, order-of-magnitude dose assessments related to remediation of subsurface soil; and provides for final dose assessments after completion of the Phase 1 final status surveys.

RELATIONSHIP TO OTHER PLAN SECTIONS

To put into perspective the information in this section, one must consider:

- The information in Section 1 on the project background and those facilities and areas within the scope of this plan,
- The facility descriptions in Section 3,
- The information on site radioactivity in Section 4,
- The information in Section 6 on the as low as reasonably achievable (ALARA) analysis,
- The information in Section 9 on radiation surveys,
- The information in Appendix C that supplements the content of this section,
- The information in Appendix D on engineered barriers and groundwater flow fields, and
- The information in Appendix E on details of the probabilistic uncertainty analysis.

5.1 Introduction

To help place the dose modeling into context, it is useful to consider information about the applicable requirements and guidance, information on the environmental media of interest, and information relevant to consideration of doses from different parts of the project premises, along with information on matters that could impact dose modeling such as long-term erosion and potential changes in groundwater flow.

5.1.1 Applicable Requirements and Guidance

As explained in Section 1, certain areas of the project premises are being remediated in Phase 1 of the decommissioning to NRC's unrestricted release criteria in 10 CFR 20.1402. These criteria state that a site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent to an average member of the critical group that does not exceed 25 mrem per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are ALARA.

NRC provides guidance (NRC 2006) on two approaches that may be used to determine that these unrestricted release criteria have been achieved:

(1) The dose modeling approach, which involves characterizing the site – after remediation, if necessary – and performing a dose assessment; and

(2) The DCGL and final status survey approach, which involves developing or using DCGLs and performing a final status survey to demonstrate that the DCGLs have been met.

NRC observes that the second option is usually the more efficient or simpler method and that these two approaches are not mutually exclusive; they are just different approaches to show that the potential dose from a remediated site is acceptable (NRC 2006).

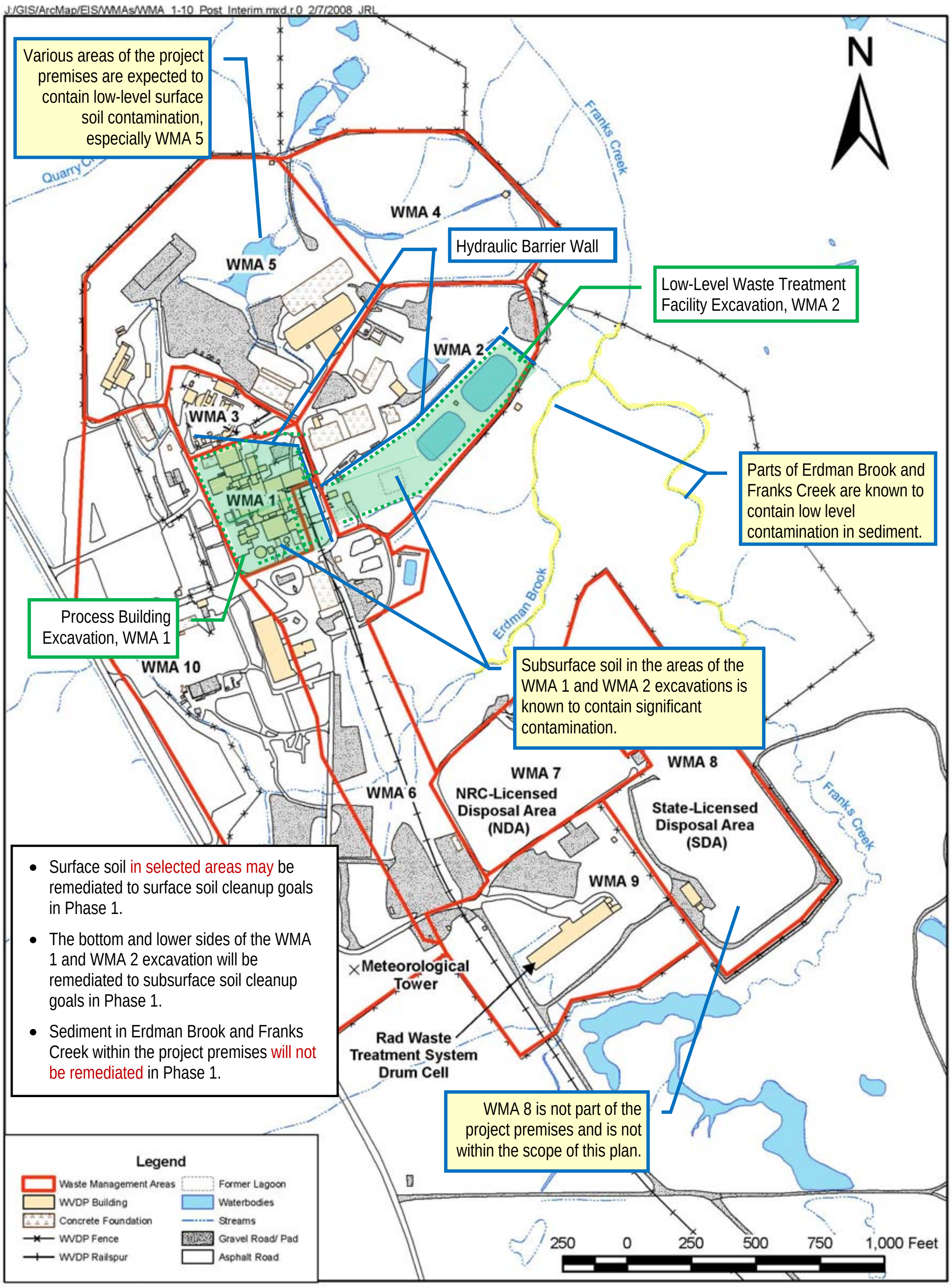
As explained below, DOE is using the DCGL approach in Phase 1 of the decommissioning and then, after remediation of subsurface soil in the two major areas of interest, will perform dose modeling using Phase 1 final status survey data to estimate potential future doses from these areas assuming the rest of the project premises were to also be cleaned up to the unrestricted release criteria in 10 CFR 20.1402.

DCGLs and Cleanup Goals

DCGLs are radionuclide-specific concentration limits used during decommissioning to achieve the regulatory dose standard that permit the release of the property and termination of the license. The DCGL applicable to the average concentration over a survey unit is called the $\mathrm{DCGL_W}$ and the DCGL applicable to limited areas of elevated concentrations within a survey unit is called the $\mathrm{DCGL_{EMC}}$ (NRC 2006). However, Phase 1 of the decommissioning will not result in the release of any property or in termination of the NRC license for the site. As explained below, cleanup goals below the DCGLs are used to ensure that Phase 1 criteria do not limit Phase 2 options.

5.1.2 Context for DCGL Development

Figure 5-1 shows the areas of interest for surface soil, subsurface soil, and streambed sediment for which separate DCGLs have been developed. Each area is discussed below.



Various areas of the project premises are expected to contain low-level surface soil contamination, especially WMA 5

Hydraulic Barrier Wall

Low-Level Waste Treatment Facility Excavation, WMA 2

Parts of Erdman Brook and Franks Creek are known to contain low level contamination in sediment.

Process Building Excavation, WMA 1

Subsurface soil in the areas of the WMA 1 and WMA 2 excavations is known to contain significant contamination.

- Surface soil in selected areas may be remediated to surface soil cleanup goals in Phase 1.
- The bottom and lower sides of the WMA 1 and WMA 2 excavation will be remediated to subsurface soil cleanup goals in Phase 1.
- Sediment in Erdman Brook and Franks Creek within the project premises will not be remediated in Phase 1.

WMA 8 is not part of the project premises and is not within the scope of this plan.

Figure 5-1. Areas of Interest – Surface Soil, Subsurface Soil, and Streambed Sediment Within the Project Premises

Surface Soil

As explained in Section 1 of this plan, surface soil and sediment in drainage ditches on the project premises will be characterized for radioactivity to better define the nature and extent of radioactive contamination. Section 4.2 summarizes available data on radioactivity in these environmental media. Available data indicate that radioactive contamination is present in some areas but the magnitude and areal extent of this contamination have not been fully defined. Figure 4-6 shows locations where soil and sediment are known to have radioactivity concentrations in excess of background.

Cs-137 concentrations in excess of background have been measured in surface soil samples from all waste management areas (WMAs) where samples have been collected, with the highest measured concentration being 280 pCi/g. Sr-90 concentrations above background have been measured in surface soil samples from several WMAs, with a maximum of 12 pCi/g. Data on other radionuclides in surface soil are very limited, but above-background concentrations of Pu-238, Pu-239/240, and Am-241 have been identified as indicated in Section 4.2.

DCGLs for surface soil based on the unrestricted release criteria in 10 CFR 20.1402 serve two purposes:

- They will support remediation of surface soil on selected portions of the project premises in Phase 1 of the decommissioning, and
- They will support decision-making for Phase 2 of the decommissioning.

The surface soil DCGLs and cleanup goals apply only to areas where there is no subsurface contamination, i.e., contamination below a depth of one meter.

Subsurface Soil

The subsurface soil DCGLs, which are also based on the unrestricted release criteria of 10 CFR 20.1402, apply only to the bottoms and lower sides of the two large excavations to be dug to remove facilities in WMA 1 and WMA 2.[1] Figure 5-2 shows a conceptual cross section view of the planned WMA 1 excavation with representative data on Sr-90 concentrations. Figure 5-3 shows a conceptual cross section view of the planned WMA 2 excavation with representative data. Both excavations will extend one foot or more into the Lavery till, as indicated in Section 7.

As explained in Section 1 and detailed in Section 7, the Process Building and the other facilities in WMA 1 will be completely removed during Phase 1 of the decommissioning, along with the source area of the north plateau groundwater plume. The excavation for this purpose will be approximately 2.8 acres in size and extend more than 40 feet below the ground into the unweathered Lavery till. Figure 5-1 shows the approximate location of this excavation.

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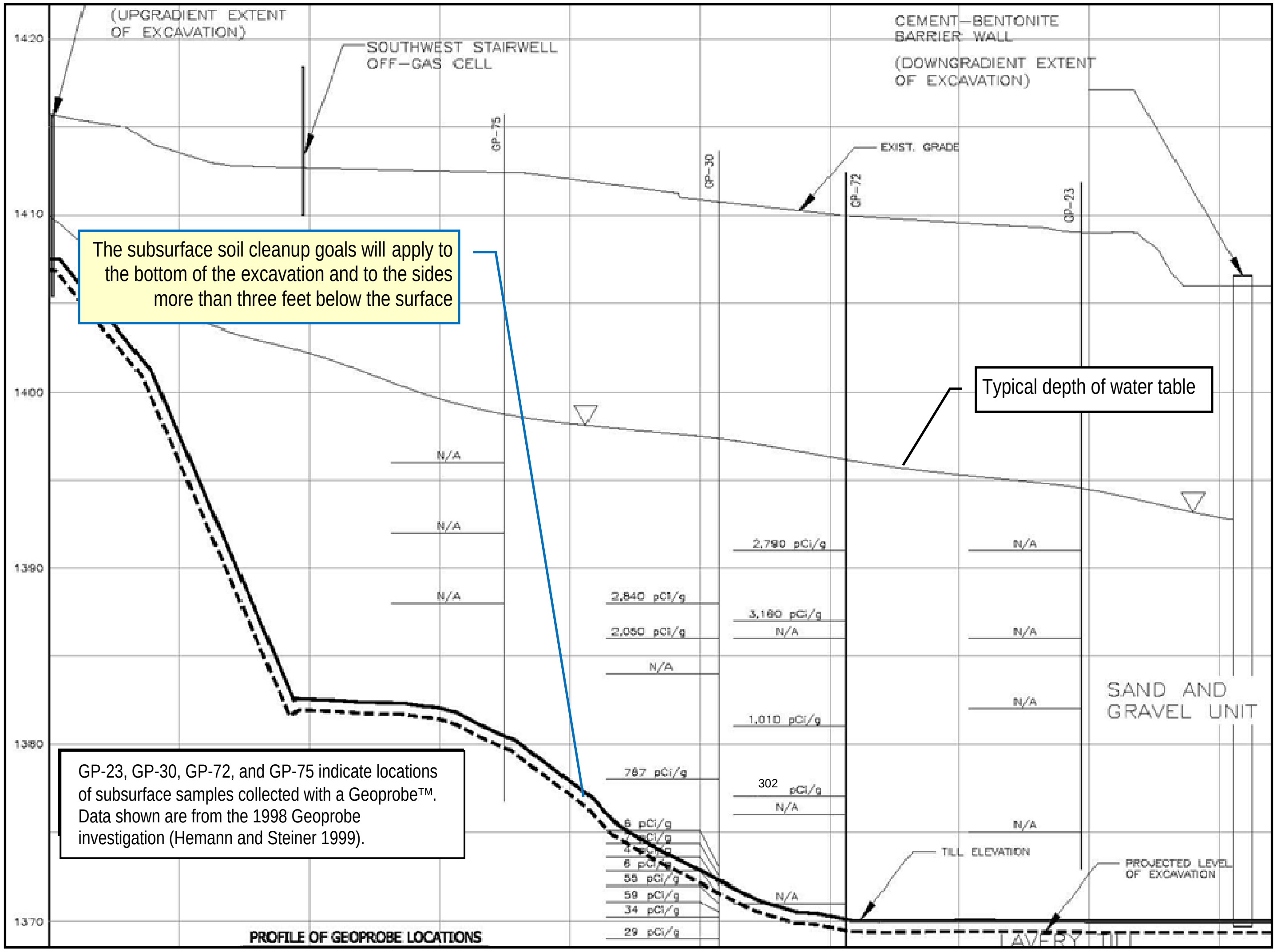
[1] The subsurface soil DCGLs will be applied to the sides of these excavations at depths greater than three feet below the surface; the surface soil DCGLs would be applied to the portions of the excavation sides closer to the ground surface. Note that the sides of the excavations that are upgradient or cross-gradient (i.e., not hydraulically downgradient) of the contamination source are not expected to be contaminated.

These DCGLs may also be applicable to excavations made in Phase 2 of the decommissioning depending on the approach selected for Phase 2 and other factors if the conceptual models described in this section are representative of the Phase 2 conditions.



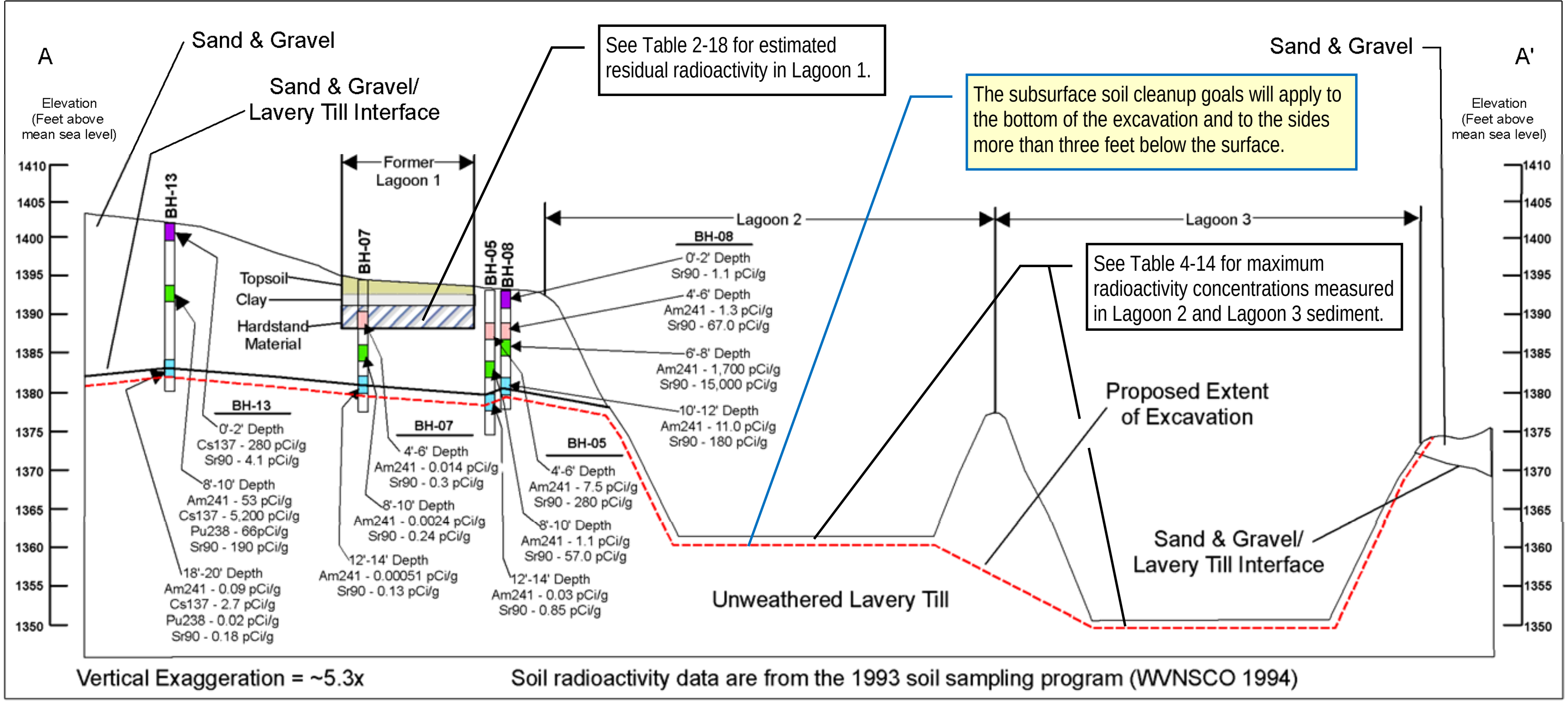
The subsurface soil cleanup goals will apply to the bottom of the excavation and to the sides more than three feet below the surface

Typical depth of water table

GP-23, GP-30, GP-72, and GP-75 indicate locations of subsurface samples collected with a Geoprobe™. Data shown are from the 1998 Geoprobe investigation (Hemann and Steiner 1999).

Figure 5-2. Conceptual Cross Section View of WMA 1 Excavation With Representative Soil Data on Sr-90 Concentrations (See Section 4.2 for more data and Section 7 for the excavation details.)

J:/GIS/ArcMap/EIS/Lagoon_Cross_Section_A_r1.mxd 2/04/2009 JRL/fjc



Vertical Exaggeration = ~5.3x

Soil radioactivity data are from the 1993 soil sampling program (WVNSCO 1994)

Figure 5-3. Conceptual Cross Section View of WMA 2 Excavation With Representative Data on Subsurface Soil Contamination (See Section 4.2 for more data and 7 for excavation details.

Available data on radioactive contamination in subsurface soil in WMA 1 described in Section 4.2 show Sr-90 to be the dominant radionuclide at depth. Figure 4-8 shows key data, which include three samples from several feet into the unweathered Lavery till that show Sr-90 concentrations of 13 pCi/g, 41 pCi/g, and 59 pCi/g at depths in the 35 to 40 feet range.

Other radionuclides with measured above-background concentrations in subsurface soil in WMA 1, with their maximum concentrations and the associated sample depth, include: Tc-99 (19 pCi/g at 19-23 feet), Cs-137 (31 pCi/g, at 27 to 29 feet), Pu-241 (15 pCi/g at 21 to 23 feet), and Am-241 (0.1 pCi/g, 19 to 23 feet). Table 5-1 shows the maximum measured radionuclide concentrations in the Lavery till in the areas of the large excavations in WMA 1 and WMA 2. Data in the Lavery till in these areas are limited – the complete set of data is provided in Table C-4 of Appendix C.

Table 5-1. Measured Maximum Lavery Till Radionuclide Concentrations(1)

Nuclide	WMA 1 Excavation Area		WMA 2 Excavation Area	
	Result (pCi/g)	Depth (ft)	Result (pCi/g)(3)	Depth (ft)
C-14	1.1E-01(2)	38-40	none	none
Sr-90	5.9E+01(4)	38.5-39	8.5E-01	12-14
Tc-99	<5.5E-01(2)	37-39	none	none
I-129	<2.9E-01(2)	38-40	none	none
Cs-137	3.9E+00(2)	38-40	4.5E-01	12-14
U-232	4.1E-02	24-26	1.2E-02	12-14
U-233/234	2.3E+00(2)	38-40	1.8E-01	12-14
U-235	1.4E-01(3)(5)	24-26	<5.9E-03	12-14
Np-237	<2.1E-02(2)	37-39	none	none
U-238	1.4E+00	41-43	1.1E-01	12-14
Pu-238	<2.3E-02(2)	38-40	1.0E-02	12-14
Pu-239/240	<6.4E-02(2)	38-40	<5.9E-03	12-14
Pu-241	<5.7E-01(2)	38-40	<1.3E+00	12-14
Am-241	<1.3E-01(2)	38-40	3.0E-02	12-14
Cm-243/244	<2.3E-02(2)	38-40	none	none

NOTES: (1) See Table C-4 for the complete data set, which includes samples at nine locations entirely within the unweathered Lavery till within the WMA 1 excavation area. Based on boring log data, only one sample (BH-05) taken within the WMA 2 excavation area contained only unweathered Lavery till soil; the others contained some soil from the sand and gravel layer.

(2) Data are from the 2008 north plateau groundwater plume Geoprobe® investigation described in Section 4, with the highest non-detection values recorded (with amended sample 7608 results).

(3) Data are from sample BH-05 collected during the 1993 RCRA facility investigation described in Section 4. .

(4) Data are from point GP3098 from the 1998 north plateau Geoprobe® sampling described in Section 4.

(5) U-235/U-236 result.

Additional Characterization Planned

The characterization program described in Section 9 will provide additional data on radioactivity in subsurface soil in WMA 1 and WMA 2 and lagoon sediment in WMA 2.

The actual depth of the WMA 1 excavation will extend at least one foot into the unweathered Lavery, and this is where the subsurface soil cleanup goals will apply, as explained in Section 7. The configuration of the residual source will therefore be similar to the bottom of the excavation shown in the representative cross section in Figure 5-2.

Figure 5-1 also shows the approximate location of the major excavation in WMA 2. As explained in Section 1 and detailed in Section 7, a single excavation will be made to remove Lagoons, 1, 2, and 3, the interceptors, the Neutralization Pit, and the Solvent Dike. The area of this excavation will be approximately 4.2 acres and its depth will vary from approximately 12 feet on the southwest end to approximately 26 feet on the northeast end.[2]

Figure 5-3 shows a conceptual cross section of the WMA 2 excavation. This figure also shows representative data on subsurface radioactivity. As indicated on the figure, Table 2-18 provides an estimate of residual radioactivity in Lagoon 1 and Table 4-14 shows maximum radionuclide concentrations measured in sediment in Lagoon 2 and Lagoon 3.

As indicated in order-of-magnitude estimates in Table 2-18, Cs-137 (at 510 curies) is expected to dominate the radioactivity in Lagoon 1. Other radionuclides expected to be present include Pu-241 (134 curies), Sr-90 (17 curies), and Pu-238 (6.4 curies). Table 4-14 shows significant concentrations of Sr-90, Cs-137, Pu-238, Pu-239/240, and Am-241 in Lagoon 2 sediment and lower concentrations of these radionuclides in Lagoon 3 sediment.

The actual depth of the WMA 2 excavation will extend at least one foot into the unweathered Lavery, and this is where the subsurface soil cleanup goals will apply, as explained in Section 7. In the cases of Lagoon 2 and Lagoon 3, the excavation will extend approximately two feet below the bottom the lagoons, which extend into the Lavery till. The configuration of the residual source will therefore be similar to the bottom of the excavation shown in the representative cross section in Figure 5-3.

While the subsurface soil cleanup goals serve as the remediation criteria for the two excavations as specified in Section 7, actual residual contamination levels in the Lavery till are expected to be well below these criteria. The concentrations of Sr-90 and Cs-137 are expected to be of the same order of magnitude as the lower surface soil cleanup goals. This conclusion is based on contamination data shown in Table 5-1 and the relative impermeability of the Lavery till to radionuclide migration compared to the sand and gravel layer above it.

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[2] The 26-foot estimate is based on using the ground surface adjacent to Lagoon 3 as a reference point. The excavation is expected to extend several feet below the bottoms of Lagoons 2 and 3 to remove sediment with radioactivity concentrations above the cleanup goals.

Streambed Sediment

Streambed sediment refers only to sediment in Erdman Brook and the portion of Franks Creek running through the project premises. Figure 5-12 in Section 5.2 below shows precisely where streambed sediment DCGLs apply.

Surface soil DCGLs will be applied to sediment in ditches, in tributaries to Erdman Brook and Franks Creek, and in other parts of the project premises, with the subsurface soil DCGLs being applied to the bottom of Lagoons 2 and 3. Unique DCGLs are appropriate for Erdman Brook and Franks Creek because the areas of these streams would not support farming or grazing of livestock as would other areas of the project premises, owing to the steep stream banks.

Section 4.2 summarizes the limited available data on radioactivity in the sediment of Erdman Brook and the portion of Franks Creek on the project premises. Figure 4-6 shows sample locations, with five in Erdman Brook and four in Franks Creek. Table 4-22 shows the highest measured concentrations of Cs-137 and other radionuclides. The highest measured Cs-137 concentration was 100 pCi/g and the highest Sr-90 concentration was 10 pCi/g. (However, Section 4.2 describes a hot spot found in Erdman Brook in 1990 with a gamma radiation level of 3000 µR/h; a sample collected at that location showed 10,000 pCi/g Cs-137.) The characterization program described in Section 9 will provide additional data on radioactivity in the sediment of the two streams.

DCGLs (cleanup goals) for streambed sediment based on the unrestricted use criteria in 10 CFR 20.1402 will support decision-making for Phase 2 of the decommissioning, and remediation of contaminated sediment in Erdman Brook and the portion of Franks Creek on the project premises is this were to be accomplished in Phase 2.

5.1.3 Context for the Integrated Dose Assessment

Three sets of DCGLs have been developed as described in Section 5.2 to be applied to the particular areas of interest, that is:

- Surface soil DCGLs for surface soil and for sediment in drainage ditches on the project premises and in tributaries to Erdman Brook and Franks Creek, and for the sides of the WMA 1 and WMA 2 excavations from the ground surface to three feet below the surface;
- Subsurface soil DCGLs for the bottoms of the WMA 1 and WMA 2 excavations and for the excavation sides more than three feet below the ground surface; and
- Streambed sediment DCGLs for sediment in Erdman Brook and the portion of Franks Creek on the project premises shown in Figure 5-12.

Each set of DCGLs was developed as if the area of interest remediated to the applicable DCGLs were to be the only area to which a hypothetical future resident or recreationist might be exposed. However, it is more likely that a variety of receptors will be exposed to multiple sources under a range of land use scenarios. Considering each source independently allows for flexibility in subsequent combined dose evaluations, as discussed further in Section 5.3.

Phase 1 and Phase 2 Sources

Inherent in the phased decision-making approach is the concept of Phase 1 and Phase 2 sources. Figure 5-4 identifies these different sources.

Phase 1 sources are those to be remediated during Phase 1 of the decommissioning: mainly the WMA 1 area and the large area in WMA 2 to be excavated. Surface soil in selected areas within the project premises may or may not be remediated in Phase 1[3]. Based on current characterization data, the main Phase 2 sources are the non-source area of the north plateau groundwater plume in WMA 2, WMA 4, and WMA 5; the Waste Tank Farm in WMA 3, and the NRC-Licensed Disposal Area (NDA) in WMA 7.

The table at the bottom of the Figure 5-4 shows the approximate amounts of total radioactivity in the different source areas based on estimates provided in Section 4. In this illustration, the remediated WMA 1 and WMA 2 excavated areas are the Phase 1 sources. The Waste Tank Farm, the non-source area of the north plateau groundwater plume, and the NDA are the Phase 2 sources, as is low-level contamination in streambed sediment. Low-level contamination in surface soil – which may or may not be remediated during Phase 1 – could be either be a Phase 1 (remediated) or Phase 2 (remediated or not) source, with the potential impact from this sources much smaller than for the others (with the exception of streambed sediment).

Figure 5-4 shows other features of the project premises at the conclusion of the Phase 1 decommissioning activities that could potentially influence future doses from residual radioactivity on the project premises:

- Groundwater flow, with the water table in the sand and gravel unit on the north plateau, with elevations expressed in feet above mean sea level, and the current pre-remediation general direction of groundwater illustrated on the figure;
- The full-scale Permeable Treatment Wall; and
- The hydraulic barrier walls to be installed during Phase 1 of the decommissioning as described in Section 7 and the French drain to be emplaced upgradient of the WMA 1 hydraulic barrier wall.

The effectiveness of these features impacts potential future doses to the receptor and overall contribution to the evaluation of combined dose from all sources.

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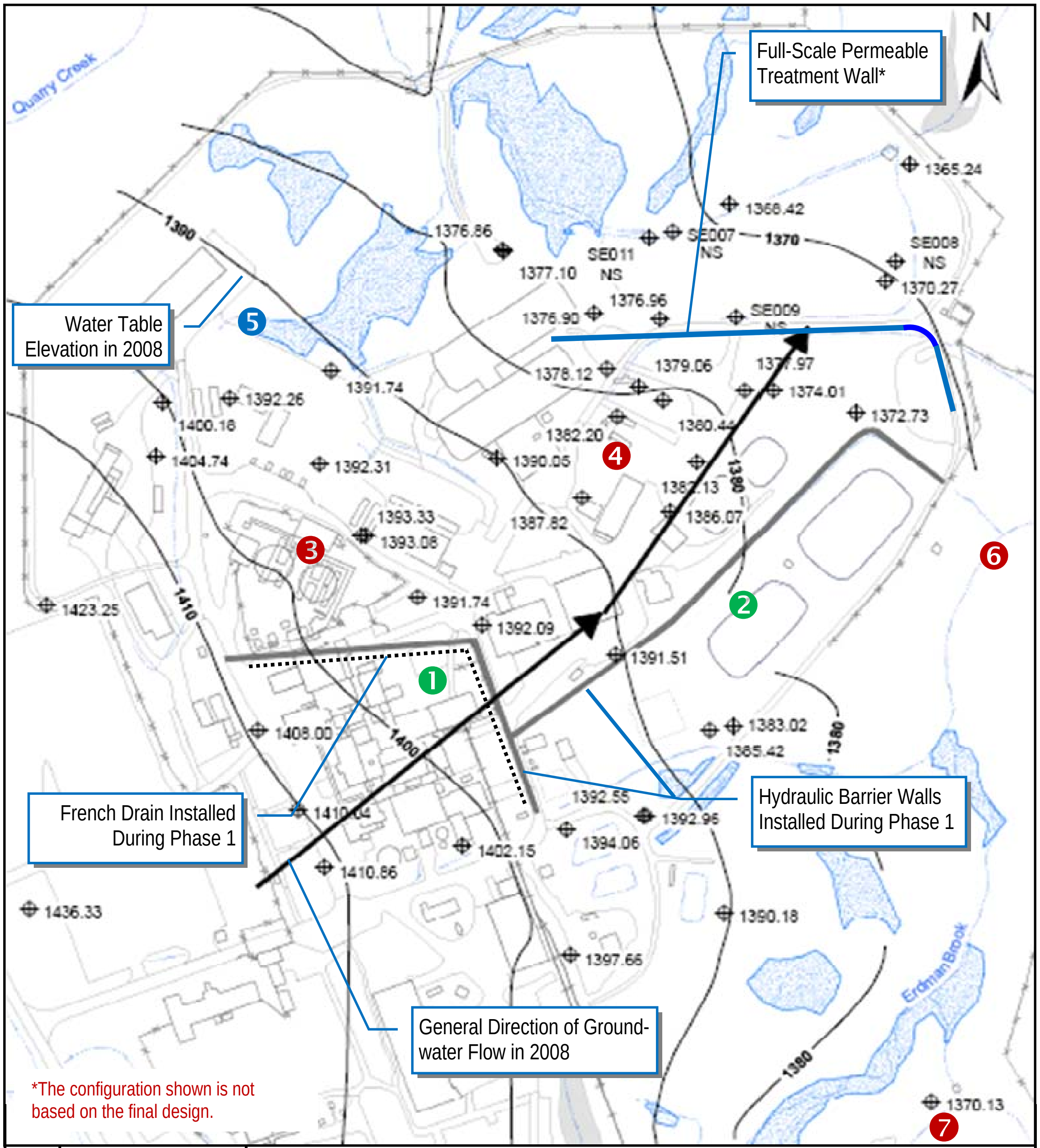
[3] As noted in Section 7.11, surface soil in selected areas of the project premises may be remediated during the Phase 1 decommissioning activities to ensure that surface soil cleanup goals are achieved in these areas.



*The configuration shown is not based on the final design.

1	WMA 1 excavation	Area 30-45 ft. below grade remediated below subsurface DCGLs for unrestricted release
2	WMA 2 excavation	Area 12-26 ft. below grade remediated below subsurface DCGLs for unrestricted release
3	Waste Tank Farm	Underground tanks with ~345,000 curies in 2011
4	North plateau plume	Contaminated subsurface soil and groundwater, ~40 curies Sr-90 in 2041
5	Surface soil	Low-level contamination in some areas, may be remediated below DCGLs
6	Streambeds	Low-level contamination, especially Cs-137, may be remediated below DCGLs
7	NDA	NRC-Licensed Disposal Area buried waste containing ~180,000 curies in 2011

Figure 5-4. Sources at the Conclusion of Phase 1 of the Decommissioning

Potential Conditions at the Conclusion of the WVDP Decommissioning

To determine whether criteria used in Phase 1 remediation activities could potentially limit the decommissioning options for Phase 2 of the decommissioning, consideration must be given to potential approaches to Phase 2. The Decommissioning EIS evaluates a range of closure alternatives. Two of these alternatives provide bounding conditions for assessment of whether the criteria used for Phase 1 remediation activities could limit Phase 2 options:

- The site-wide close-in place-alternative, where the major facilities would be closed in place, with residual radioactivity in the Waste Tank Farm and the NDA being isolated by engineered barriers and the non-source areas of the north plateau groundwater plume being allowed to decay in place; and
- The site-wide removal alternative, where the Phase 2 sources would be removed and the entire site remediated to the unrestricted release criteria of 10 CFR 20.1402.

Compatibility of Phase 1 Remediation With the Site-Wide Close-In-Place Alternative

With the site-wide close-in place-alternative, the Phase 2 source areas would likely remain under NRC license. With Phase 1 of the decommissioning being accomplished, the contamination remaining in the WMA 1 and WMA 2 excavations will be residual radioactivity at concentrations below the subsurface soil cleanup goals located far below the surface and covered with uncontaminated earth.

Under a site-wide close-in-place approach, the remediated Phase 1 areas would be expected to fall within the controlled licensed area because of their close proximity to the Phase 2 source areas. In view of this situation, the remediation of the Phase 1 areas to unrestricted release standards would clearly be compatible with the Phase 2 source areas remaining under license. That is, remediation of the Phase 1 source areas as planned will have no impact on the site-wide close-in place-alternative and will not limit its implementation in any way.

Compatibility of Phase 1 Remediation With the Site-Wide Removal Alternative

Under the site-wide removal alternative, the Phase 2 source areas would be remediated to unrestricted release standards like the Phase 1 source areas. All of the associated radioactive waste will be disposed of offsite. However, while the remediation standards will be the same, the critical group for potential future exposures will not be the same for all parts of the site. Because remediation to unrestricted release standards under Phase 1 of the decommissioning does not preclude achievement of unrestricted release standards under Phase 2, all remedial options may be considered.

However, this situation requires consideration of potential exposures to members of the different critical groups, a matter which is addressed below.

Critical Group

Critical Group means the group of individuals reasonably expected to receive the greatest exposure to residual radioactivity for any applicable set of circumstances (10 CFR 20.1003).

Section 5.2 describes the critical groups for development of the different DCGLs. The average member of the critical group for development of the surface soil and subsurface soil DCGLs is a resident farmer. (Alternative scenario analyses described in Section 5.2 also evaluate exposure to a residential gardener.) The average member of the critical group for development of the streambed sediment DCGLs is a recreationist, that is, a person who would spend time in the Erdman Brook and Franks Creek areas engaged in activities such as fishing and hiking.

One reasonably foreseeable set of circumstances would involve a person 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. Because this scenario is not considered in development of the DCGLs for the different areas of interest, it would be appropriate to consider whether it could result in such a hypothetical individual exceeding the unrestricted dose limit, that is, 25 mrem in one year, and whether the residual radioactivity has actually been reduced to levels that are ALARA in accordance with 10 CFR 20.1402.

Considering the foregoing discussion, Section 5.3 evaluates the potential impacts of this set of circumstance (combined sources of dose to a single receptor) on the DCGLs and the associated cleanup goals to be used to guide remediation during Phase 1 of the decommissioning.

Two other factors that could potentially affect potential future doses from the remediated Phase 1 areas would be long-term erosion and potential changes in groundwater flow.

5.1.4 Potential Impact of Long-Term Erosion

The potential impact of long-term erosion is a consideration in development of DCGLs for Phase 1 of the decommissioning and for estimating potential future doses from different parts of the project premises assuming that the entire site would be remediated for unrestricted use.

Section 3.5.3 of this plan describes the site geomorphology, including erosion processes such as channel incision, slope movement, and gully formation. Table 3-13 provides information on site erosion rates from various sources.

Detailed erosion studies performed in support of the Decommissioning EIS are described in Appendix F to that document. This appendix describes past studies and recent analyses that made use of the CHILD landscape evolution model, which was calibrated for the site using a probabilistic process.

The CHILD model was used for 26 forward-in-time simulations to predict erosion rates at the WVDP over a 10,000-year time period. The models generally predicted minimal erosion on the central portion of the north plateau, gully development along the north plateau rim, and active erosion along the steep valley sides of Erdman Brook and Franks Creek. In the more erosive north plateau scenarios, gullies were predicted to advance within 328 to 656 feet of the Process Building area within the 10,000 year simulation period.

Limited field data showing actual sheet and rill erosion rates are available as indicated in Table 3-13. The maximum measured erosion among 19 measurements over an 11-year period ending in 2001 was 0.04 feet (approximately 0.5 inch) on the slope of a gully. One spot south of Lagoon 2 showed buildup of 0.04 feet (about 0.5 inch) during that period.

Conclusions that can be drawn from the available field data and the erosion studies detailed in Appendix F of the Decommissioning EIS include:

- The central portion of the north plateau is expected to be generally stable over the next 1000 years;
- The WMA 2 area, which is near the Erdman Brook stream valley, is more susceptible to erosion than the WMA 1 area;
- Existing gullies will propagate, becoming deeper and longer, and new gullies will form, mainly on the edges of the north plateau, if erosion proceeds unchecked;
- Rim widening and channel downcutting could occur in Erdman Brook and Franks Creek;
- With unmitigated erosion, gullies could eventually extend into the areas of Lagoons 1, 2, and 3 during the 1000-year evaluation period; and
- With unmitigated erosion, rim widening and downcutting of Erdman Brook could possibly impact the eastern edge of the areas of these lagoons, especially Lagoon 3.

These projections formed the basis for the alternate conceptual models involving erosion that are described in Section 5.2.

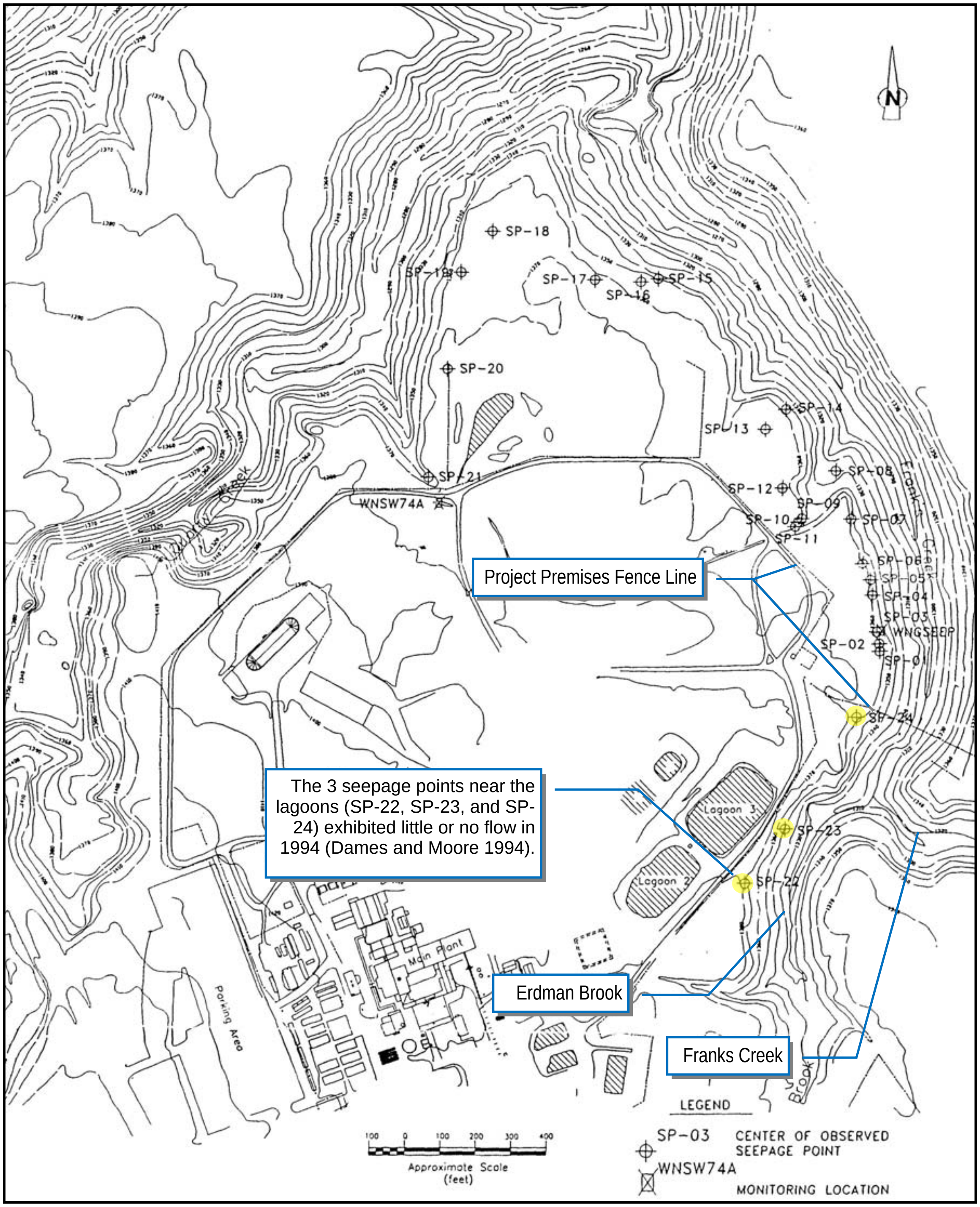
5.1.5 Potential Changes in Groundwater Flow Fields

Changes in the groundwater flow pattern that might result from installation of the hydraulic barriers shown in Figure 5-1 could increase the potential for recontamination of the areas remediated in Phase 1. Groundwater in the sand and gravel unit on the north plateau currently flows northeast as indicated on Figure 5-4. With this flow pattern, and with the WMA 1 and WMA 2 hydraulic barriers remaining in place, the potential for transport of contaminants by groundwater into the WMA 1 and WMA 2 areas remediated during Phase 1 of the decommissioning from Phase 2 source areas is low.

Appendix D describes the results of an analysis performed to evaluate groundwater flow conditions near these engineered barriers. This analysis suggests that the potential for recontamination of the remediated WMA 1 and WMA 2 areas will not be significantly increased with the engineered barriers in place.

5.1.6 Seepage of Groundwater

Figure 5-5 shows the locations of groundwater seeps on the north plateau. As can be seen in the figure, any groundwater from the seeps located on the project premises runs into Erdman Brook or Franks Creek (Dames and Moore 1994).



Project Premises Fence Line

The 3 seepage points near the lagoons (SP-22, SP-23, and SP-24) exhibited little or no flow in 1994 (Dames and Moore 1994).

Erdman Brook

Franks Creek

Figure 5-5. Locations of Perimeter Seeps on the North Plateau (From Dames and Moore 1994)

One other factor that could possibly affect conditions following Phase 1 of the decommissioning is seepage of radioactively contaminated groundwater into Erdman Brook and Franks Creek.

As noted previously, streambed sediment will not be remediated during Phase 1 of the decommissioning. The presence of groundwater seeps in the Erdman Brook area was one factor taken into account in the decision not to proceed with this remediation during Phase 1, since these seeps could possibly result in recontaminating the sediment in Erdman Brook.[4]

However, the potential for significant radioactivity in seeps in this area following Phase 1 of the decommissioning will be low due to the following factors:

- Any residual radioactivity that might remain in the Lavery till at the bottom of the remediated WMA 2 excavation will be at very low concentrations; and
- Groundwater flow changes with the Phase 1 vertical hydraulic barriers in place, as described in Appendix D, will be expected to substantially reduce the potential for contamination from the non-source area of the north plateau groundwater plume seeping into Erdman Brook.

Another factor that was taken into account in the decision to not proceed with remediation of sediment in Erdman Brook and in the portion of Franks Creek on the project premises during Phase 1 of the decommissioning was surface water runoff, especially runoff from the two radioactive waste disposal areas on the south plateau. Surface water runoff from both waste disposal sites is potentially contaminated due to surface soil contamination in these areas, although the potential impact on the streams is limited so long as the geomembrane covers for the waste disposal sites remain intact.

Note that Table D-4 in Appendix D provides flow balance estimates for post-Phase 1 conditions. These estimates do not show an increase in downward groundwater flow to the Kent Recessional Sequence following Phase 1 of the decommissioning.

5.1.7 Potential Impacts on the Kent Recessional Sequence

The potential for impacts on groundwater in the Kent Recessional Sequence from any residual radioactivity that might remain in the bottom of the WMA 1 and WMA 2 excavated areas has been evaluated and found to be very low.

Groundwater in the sand and gravel unit generally flows to the northeast across the north plateau towards Franks Creek as shown in Figure 5-4. Water balance estimates (Yager 1987 and WVNSCO 1993a) suggest that approximately 60 percent of the groundwater from the sand and gravel unit discharges to Quarry Creek, Franks Creek, and Erdman Brook through surface water drainage discharge points and the groundwater seeps located along the margins of the north plateau that are shown in Figure 5-5.

Approximately two percent of the total discharge from the sand and gravel unit travels vertically downward to the underlying unweathered Lavery till, where groundwater flows vertically downward toward the underlying Kent Recessional Sequence at an average vertical groundwater velocity of 0.20 feet per year (WVNSCO 1993a). The unweathered Lavery till is approximately 30 to 45 feet thick below the planned WMA 1 excavation and 40 to 110 feet thick below the planned WMA 2 excavation (WVNSCO 1993b).

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[4] Seeps could also release contamination into Quarry Creek. Quarry Creek lies outside of the project premises and is not within the scope of Phase 1 decommissioning activities.

It will take approximately 200 years for groundwater to migrate through the unweathered Lavery till at WMA 1 and WMA 2 assuming a Lavery till thickness of 40 feet and an average groundwater velocity of 0.20 feet per year. Mobilization and migration of the residual radionuclide inventory at the bottom of the WMA 1 and WMA 2 excavations through the Lavery till groundwater pathway will take even longer considering the sorptive properties of the Lavery till (Table 3-20).

Short-lived radionuclides (Sr-90, Cs-137, and Pu-241) will have decayed away during these time frames. The long-lived radionuclide inventory is not an issue as the residual concentrations within the Lavery till are expected to be comparable to background concentrations for surface soil. The residual radionuclide concentrations in the Lavery till in the bottom of the WMA 1 and WMA 2 excavations are expected to be lower than those reported in Table 5-1 and will therefore not significantly impact the Kent Recessional Sequence. Groundwater reaching the Kent Recessional Sequence flows laterally to the northeast at an average velocity of 0.40 feet per year and eventually discharges to Buttermilk Creek.

The potential for impacts on groundwater in Lavery till sand has also been considered.

The Lavery till sand is located 30 to 40 feet below grade within the Lavery till and is recharged by downward groundwater flow from the Lavery till. The Lavery till sand is located south of the WMA 1 excavation (Figure 3-64) and will not be impacted by the Phase 1 excavation of WMA 1.

However, the Lavery till sand underlies approximately 15,000 square feet of the southwestern most portion of WMA 2 near the Solvent Dike (Figure 3-64). The Solvent Dike was originally excavated in 1986 and will be excavated down into the Lavery till during the excavation of WMA 2. Because any residual radionuclide concentrations are expected to be less than those reported in Table 5-1, groundwater flow from the Lavery till will not significantly impact the Lavery till sand.

Note that Section 9 provides for characterization surveys around selected Process Building foundation pilings to determine whether there might be evidence of contaminant migration along some of the pilings downward towards the Kent Recessional Sequence.

5.1.8 General Dose Modeling Process

The general process for the dose modeling described in Section 5.2 and 5.3 is illustrated in Figure 5-6.

As indicated in the figure, the process involves the following major steps:

- Calculating the DCGLs using RESRAD in the deterministic mode to produce the initial base cases;
- Performing parameter sensitivity analyses and refining the conceptual models and the DCGLs as appropriate based on the results;
- Performing a probabilistic uncertainty analysis to evaluate the degree of conservatism in model input parameters, producing probabilistic peak-of-the-mean and 95th percentile DCGLs;

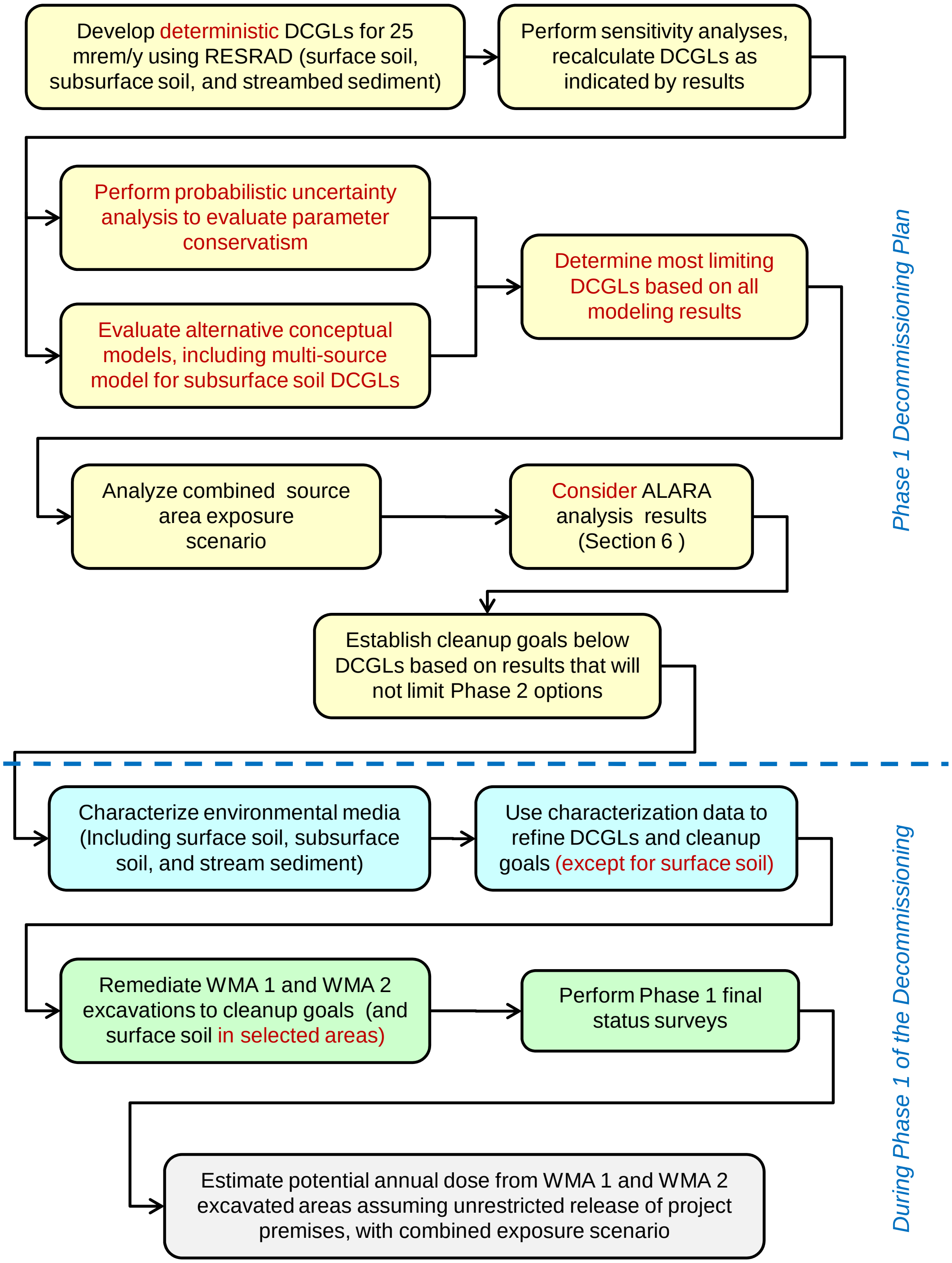

Figure 5-6. General Dose Modeling Process

- Evaluating alternate conceptual models, including a residential gardener and a multi-source conceptual model for subsurface soil DCGLs, for comparison with the initial base-case models;

- Evaluating the DCGLs produced by all of the modeling and determining the most limiting DCGLs for each radionuclide of interest; Analyzing combined source area exposure scenarios;
- Considering the results of the ALARA analysis described in Section 6;
- Establishing cleanup goals (target levels below the DCGLs) to ensure that the degree of remediation in Phase 1 of the decommissioning will not limit Phase 2 options;
- Characterizing surface soil, subsurface soil, and streambed sediment as specified in Section 9;
- Refining the DCGLs and cleanup goals based on the resulting data[5];
- Completing remediation of the WMA 1 and WMA 2 excavations and selected surface soil areas to the cleanup goals;
- Performing Phase 1 final status surveys in the remediated Phase 1 areas, and
- Making estimates of the potential future doses for the remediated WMA 1 and WMA 2 deep excavation areas using these data.

Note that use of a surrogate radionuclide such as Cs-137 to represent all radionuclides in a mixture of radionuclides is not practical at this time because available data are not sufficient to establish radionuclide distributions in environmental media. This matter is discussed further in Section 5.4.3.

5.2 DCGL Development

This section provides the following information:

- Subsection 5.2.1 describes the conceptual models used for developing DCGLs for surface soil.
- Subsection 5.2.2 describes the conceptual models used for developing DCGLs for subsurface soil.
- Subsection 5.2.3 describes the conceptual model used for developing DCGLs for streambed sediment.
- Subsection 5.2.4 describes the mathematical model (RESRAD) used to calculate deterministic DCGLs for the various conceptual models.

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[5] The characterization to be performed as described in Section 9 will provide data on the depth and lateral extent of contamination that may be useful in better defining source geometry in the conceptual model. For example, if the actual streambed and stream bank source geometry were found to be substantially different from that assumed in the conceptual model, then the conceptual model would be revised accordingly and the DCGLs recalculated. The same approach would be used for the subsurface soil DCGLs. However, there are no plans to recalculate surface soil DCGLs for this reason because the assumed one meter source thickness is generally conservative and it is important to avoid changes to surface soil DCGLs that would impact the design of the Phase 1 final status surveys. While DCGLs are developed for 18 radionuclides, characterization data may indicate that some radionuclides may be dropped from further consideration. This could be the case, for example, if one or more of the 18 radionuclides do not show up above the minimum detectable concentration in any of the soil or sediment samples.

- Subsection 5.2.5 provides the modeling results – the deterministic DCGLs – along with a discussion of these results.
- Subsection 5.2.6 describes sensitivity analyses performed.
- Subsection 5.2.7 describes the probabilistic uncertainty analysis.
- Subsection 5.2.8 describes the multi-source analysis for subsurface soil DCGLs that takes into account releases of radioactivity from the bottoms of the deep excavations by diffusion.

The DCGL development analyses simulate the behavior of residual radioactivity over 1000 years, a period during which peak annual doses from the radionuclides of primary interest would be expected to occur. DCGLs have been developed for residual radioactivity that will result in 25 mrem per year dose to the average member of the critical group for each of the following 18 radionuclides of interest:

Am-241
C-14
Cm-243
Cm-244
Cs-137
I-129
Np-237
Pu-238
Pu-239
Pu-240
Pu-241
Sr-90
Tc-99
U-232
U-233
U-234
U-235
U-238

Early studies related to the long-term performance assessment for residual radioactivity at the site included consideration of the initial inventory of radionuclides received on site and their progeny. This list was screened to eliminate short-lived radionuclides and those radionuclides present in insignificant quantities. Thirty radionuclides of interest remained after this screening process. These radionuclides were important to worker dose and/or long-term dose from residual radioactivity.

In characterization of radionuclides in the area of the Process Building, the north plateau groundwater plume, and the lagoons, it was determined that 18 of the 30 radionuclides were important for the development of Phase 1 DCGLs. These radionuclides were selected based on screening of simplified groundwater release and intrusion scenarios for north and south plateau facilities. The screening indicated that other radionuclides will in combination contribute less than one per cent of potential dose impacts at the individual facility.

The list of radionuclides for which DCGLs are initially developed will be expanded if necessary following completion of soil and sediment characterization described in Section 9. If other radionuclides show up in concentrations significantly above the minimum detectable concentrations, additional DCGLs will be developed for these radionuclides and their progeny, as appropriate. Conversely, if any of the 18 radionuclides of interest fail to show up in concentrations above the minimum detectable concentrations, then they may be omitted from the final DCGLs for the Phase 1 actions.

As explained in Section 1, the DCGLs for Sr-90 and Cs-137 were developed to incorporate a 30-year decay period from 2011. That is, achieving residual radioactivity levels less than the DCGLs will ensure that dose criteria of 10 CFR 20.1402 will be met in

2041.[6] Although a 30-year decay period could have been applied to all radionuclides, Sr-90 and Cs-137 were selected based on their prevalence in soil and sediment contamination, their expected peak doses at the onset of exposure, and the short half lives of these particular radionuclides.

5.2.1 Conceptual Models for Surface Soil DCGL Development

The initial base-case conceptual model for development of surface soil DCGLs is described first.

Surface Soil Conceptual Model (Base-Case)

Figure 5-7 illustrates the conceptual model for surface soil DCGL development. As is evident from this figure, which was adapted from the RESRAD Manual (Yu, et al. 2001), the basic RESRAD model is used.

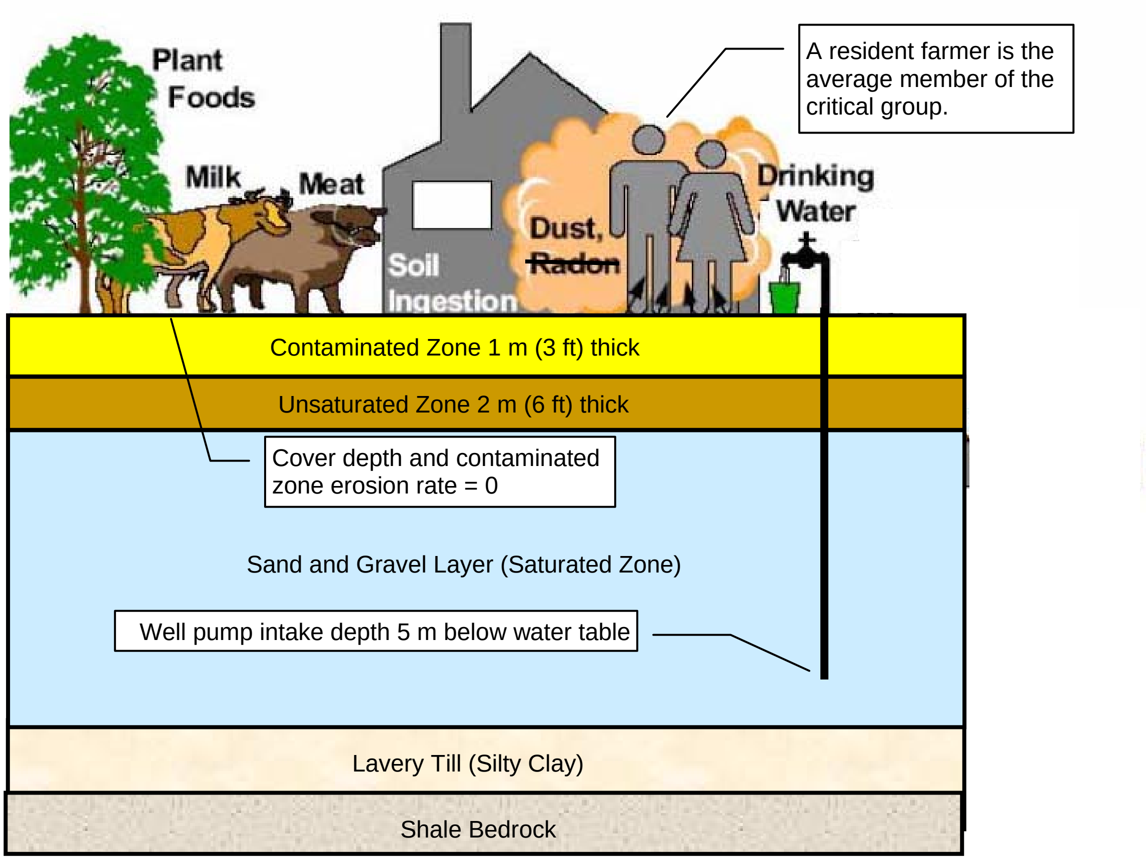

Figure 5-7. Conceptual Model for Surface Soil DCGL Development

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[6] This approach will support any license termination actions that may take place in Phase 2 of the decommissioning. As noted previously, the decision on the Phase 2 decommissioning approach could be made within 10 years of the Record of Decision and Findings Statement documenting the Phase 1 decisions. If this approach were to involve unrestricted release of the site, achieving this condition would be expected to take at least another 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.

RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials (Yu, et al. 2001). DOE Order 5400.5 designates RESRAD for the evaluation of radioactively contaminated sites, and NRC has approved the use of RESRAD for dose evaluation by licensees involved in decommissioning. RESRAD capabilities are discussed further in Section 5.2.2.

A resident farmer is the average member of the critical group for development of surface soil DCGLs. The hypothetical residence and farm are assumed to be located on a part of the project premises impacted solely by radioactivity in surface soil.

Other possible critical groups were considered. However, a resident farmer was assumed to be most limiting because such an individual would be engaged in a wider range of activities that could result in greater exposure to residual radioactivity in surface soil than other critical groups considered. (This assumption was confirmed by evaluation of alternate conceptual models involving erosion and a residential gardener as discussed below.)

The resident farmer would be impacted by a number of exposure pathways with long exposure durations. This hypothetical individual would utilize significant amounts of groundwater that involves consideration of secondary exposure pathways such as household water use, irrigation, and watering livestock. The resident farmer scenario also is consistent with current and projected future land uses for Cattaraugus County as discussed in Section 3.

Note that the geological units shown in Figure 5-7 are representative models of the north plateau as shown in Figure 3-6. Figure 3-7 shows that the geological units on the south plateau are different in that the sand and gravel unit does not extend to that area. However, DCGLs developed using the conceptual model illustrated in Figure 5-7 are appropriate for surface soil on the south plateau because the input parameters used in the modeling for the north plateau will generally be conservative for the south plateau. For example, site-specific distribution coefficients for the sand and gravel unit (where available) are typically lower than those for the Lavery till, and use of the lower values results in less resistance to radionuclide movement though soil, allowing less time for radioactive decay to take place.[7]

Table 5-2 shows the exposure pathways evaluated for development of the surface soil DCGLs.

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[7] Table C-2 of Appendix C shows that site-specific K_d values for neptunium, plutonium, and strontium in the sand and gravel unit are used in the surface soil model. Table 3-20 of shows the basis for these values. The use of lower K_d values than those in south plateaus soil is conservative for water pathways, but may not be conservative for plant uptake and direct exposure pathways. However, the model would be conservative for south plateau conditions for most radionuclides.

Table 5-2. Exposure Pathways for Surface Soil DCGL Development

Exposure Pathways	Active
External gamma radiation from contaminated soil	Yes
Inhalation (airborne radioactivity from re-suspended contaminated soil)	Yes
Plant ingestion (produce impacted by contaminated soil and groundwater sources)	Yes
Meat ingestion (beef impacted by contaminated soil and groundwater sources)	Yes
Milk ingestion (impacted by contaminated soil and groundwater sources)	Yes
Aquatic food ingestion	No(1)
Ingestion of drinking water (groundwater impacted by contaminated soil)	Yes
Ingestion of drinking water (from surface water)(2)	No
Soil ingestion (while farming and residing on contaminated soil)	Yes
Radon inhalation	No(3)

NOTES: (1) Fish ingestion is considered in development of the streambed sediment DCGLs and in the combined scenario discussed in Section 5.3.

(2) Groundwater was assumed to be the source of all drinking water because the low flow volumes in Erdman Brook and Franks Creek could not support the resident farmer. Also, use of surface water would not be as conservative as groundwater since surface water is diluted by runoff from the entire watershed area. Incidental ingestion of water from the streams is evaluated in development of the streambed sediment DCGLs as shown in Table 5-6.

(3) For the standard resident farmer scenario, the radon pathway is not considered (Appendix J, NRC 2006).

RESRAD requires a variety of input parameter values to completely describe the conceptual model. All of the input parameters for development of the surface soil DCGLs appear in Appendix C. Table 5-3 identifies selected key input parameters.

Table 5-3. Key Input Parameters for Surface Soil DCGL Development(1)

Parameter (Units)	Value	Basis
Area of contaminated zone (m^2)	1.0E+04	Necessary for subsistence farming.
Thickness of contaminated zone (m)	1.0E+00	Conservative assumption.(2)
Cover depth (m)	0	Contamination on surface.
Contaminated zone erosion rate (m/y)	0	Conservative assumption.(3)
Well pump intake depth below water table (m)	5.0E+00	Consistent with water table.
Well pumping rate (m^3/y)	5.72E+03	See Table C-2.
Unsaturated zone thickness (m)	2.0E+00	Typical for north plateau.
Distribution coefficient for strontium (mL/g)	5.0E+00	See Table C-2.
Distribution coefficient for cesium (mL/g)	2.8E+02	See Table C-2.
Distribution coefficient for americium (mL/g)	1.9E+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) Available data discussed in Sections 2.3.2 and 4.2 suggest that most contamination will be found within a few inches of the surface except where the north plateau groundwater plume has impacted subsurface soil. The one meter thickness is an appropriate compromise for the set of radionuclides of interest whose primary dose pathways range from direct exposure, to groundwater ingestion, to plant uptake.

(3) This assumption is conservative because it results in no depletion of the source through erosion.[8]

Key features of this conceptual model and key assumptions include:

- The areal extent of surface soil contamination, which has not been well defined, can be represented by a distributed source spread over a relatively large area (10,000 square meters or approximately 2.5 acres);
- The average depth of contamination (contamination zone thickness) is approximately 3.3 feet (one meter), a conservative assumption for the site;
- Because the model considers only surface contamination, the resulting DCGLs and cleanup goals are applicable only to portions of the project premises where there is no subsurface contamination (i.e., contamination does not extend beyond a depth of 1 meter);
- All water use (e.g., household, crop irrigation, and livestock watering) is from contaminated groundwater;
- Adequate productivity from a well pumping from the aquifer will be available in the future to support a subsistence farm;
- Soil erosion (i.e., source depletion) does not occur over the 1,000-year modeling period;
- The non-dispersion groundwater model is used because of the large contaminated area consistent with applicable guidance (Yu, et al. 2001, Appendix E);
- The groundwater flow regime under the post-remedial conditions is unchanged from the current configuration (e.g. flow direction, aquifer productivity); and
- DCGLs that reflect 30 years of decay (i.e., apply to the year 2041) are appropriate for Sr-90 and Cs-137. Although a 30-year decay period could have been applied to all radionuclides, Sr-90 and Cs-137 were selected based on their prevalence in surface soil, their expected peak doses at the onset of exposure, and the short half lives of these particular radionuclides, as noted previously.

Alternate Conceptual Model for Surface Soil DCGLs (Erosion, Offsite Receptor)

Other conceptual models were considered, even though the resident farmer model with its many exposure pathways is generally considered to be the most conservative model. To

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[8] The conservative nature of the assumption can be demonstrated by assuming that erosion takes place and evaluating potential doses to a receptor located in a gully where radioactivity has been displaced by erosion. As explained in the discussion of alternate conceptual models below, the receptor in the area of the gully would receive less dose on an annual basis than would the resident farmer due to factors such as source dilution, spending less time in the contaminated area, and receiving exposure through fewer pathways. Consideration of potential doses to an offsite receptor from radioactivity displaced to the stream through erosion indicates that there is a reasonable expectation that offsite doses would not be significant either.

confirm that the assumption of no erosion in the contamination zone (one of the key parameters in Table 5-3) is conservative, an analysis was performed to estimate the potential doses to an offsite receptor from radioactivity that could be released from the hypothetical garden used in the base-case model through erosion.

In this analysis, eroded soil was assumed to be transported in surface water to a receptor located on Cattaraugus Creek near the confluence with Buttermilk Creek who ingested both the water and fish harvested from the water and used the water to irrigate a garden. The results showed that doses to this receptor would be insignificant.

Alternate Conceptual Model for Surface Soil DCGLs (Residential Gardener)

Another alternative exposure scenario was evaluated to confirm that the base-case resident farmer scenario is bounding for development of surface soil DCGLs. This alternative scenario involved a residential gardener scenario.

The receptor in the residential gardener scenario is a hypothetical person who resides in the area and grows a vegetable garden. This scenario differs from the resident farmer scenario in that the person of interest does not consume meat or milk produced on the property and spends less time outdoors in the hypothetical garden. The well pumping rate used in this scenario was lower than that used in the resident farmer model (1140 cubic meters per year compared to 5720 meters per year) to reflect the smaller garden being used and the lower well water usage.

This alternative exposure scenario produced DCGLs that were slightly higher than those produced by the base-case resident farmer model for all 18 radionuclides. Consequently, the base-case model is bounding for surface soil DCGL development when compared to the residential gardener scenario. (See Section 5.2.7 for the results of the probabilistic uncertainty analysis.)

5.2.2 Subsurface Soil Conceptual Models

Evaluation of Various Subsurface Soil Conceptual Models

The analyses described in Revision 0 and Revision 1 to this plan made use of the base-case conceptual model for subsurface soil DCGL development described below and illustrated in Figure 5-8. Minor changes were made to this conceptual model in Revision 2 that produced DCGLs that were slightly higher for most radionuclides.

Additional analyses were also performed to determine whether this conceptual model, which makes use of the resident farmer scenario, represented the bounding case for potential future doses from the remediated deep excavations. These additional analyses, which are described below, involved:

- Evaluating the potential acute dose to the hypothetical individual drilling the well (the two meter diameter cistern) used in the original base case model,
- Evaluating potential acute dose to a hypothetical individual who might drill a natural gas well in the area of one of the deep excavations,
- Evaluating potential doses to a recreational hiker in the area of the lagoons in WMA 2 assuming that unchecked erosion would eventually produce deep gullies in this area,
- Evaluating potential doses to an offsite receptor from residual radioactivity at the bottom of the deep excavation in WMA 2 that might be released to Erdman Brook if deep gullies were to eventually cut into this area, and
- Evaluating a residential gardener scenario.

Of these five alternate conceptual models, one, the residential gardener model, was found to be more limiting for some radionuclides than the original base-case resident farmer scenario.

To help determine whether the input parameters used in the original base-case model were sufficiently conservative, a comprehensive probabilistic uncertainty analysis was performed (similar analyses were also performed for surface soil and streambed sediment DCGL development). Section 5.2.7 describes this analysis. The resulting peak-of-the-mean DCGLs were somewhat lower for most radionuclides than the DCGLs produced by the deterministic resident farmer and residential gardener scenarios.

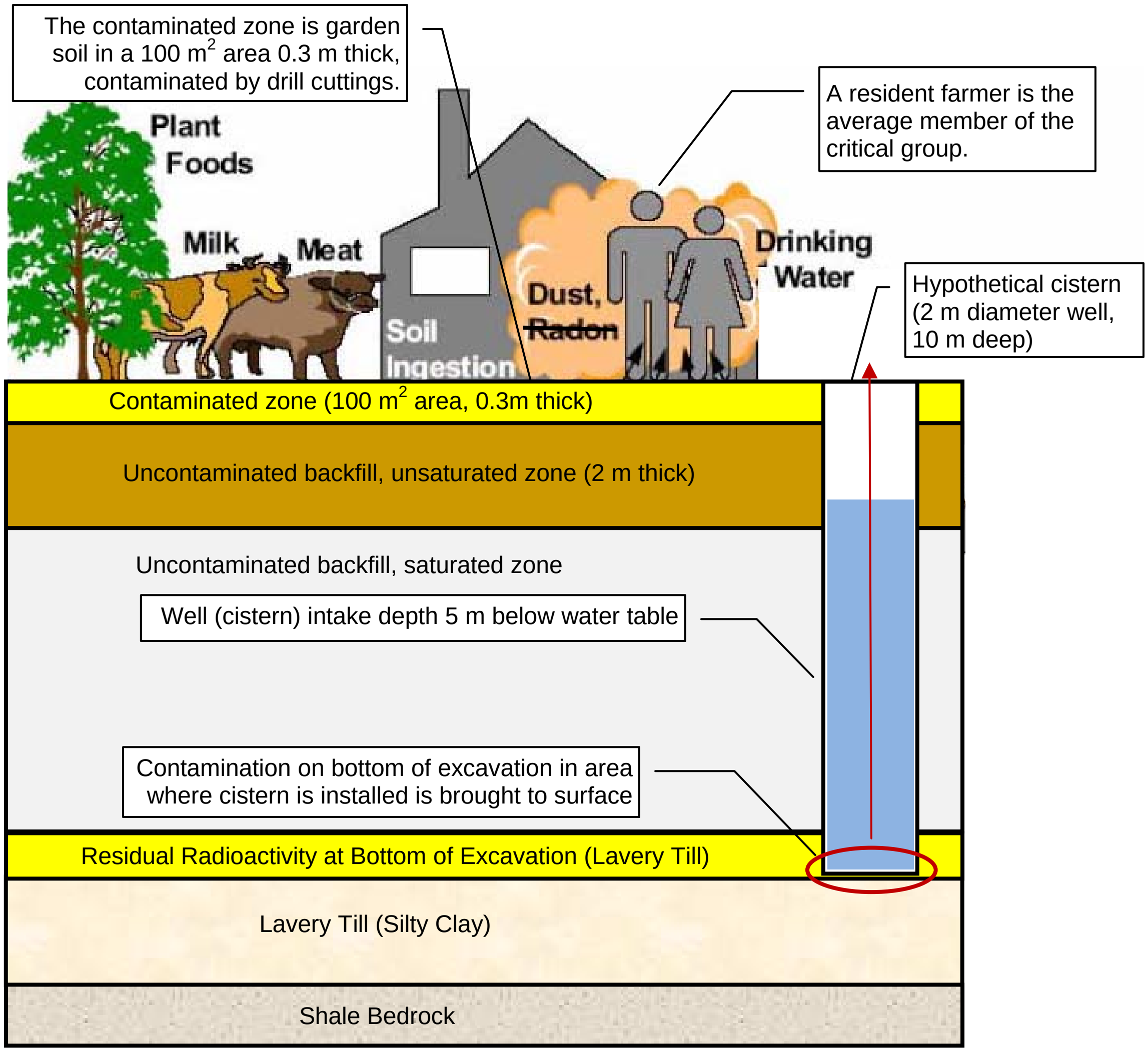
Another analysis was performed to evaluate whether continuing release of residual radioactivity from the bottom of the deep excavations would influence potential future doses from the remediated deep excavations. Section 5.2.8 describes this analysis. The original base-case conceptual model was modified to add a secondary source of radioactivity from residual contamination at the bottom of the deep excavation that moves upward by diffusion and is drawn into the hypothetical well, resulting in additional dose to the resident primarily from the drinking water pathway.

This multi-source model was analyzed using the resident farmer scenario and also the residential gardener scenario, the latter with three different upper contamination zone geometries to evaluate the sensitivity of the model to the contamination zone area and thickness. The results showed that this model was more limiting for nine of the 18 radionuclides of interest than the other subsurface soil DCGL conceptual models that were evaluated.

Consideration of the results of all of this subsurface soil dose modeling led to the decision to use the lowest DCGLs among all of the modeling results as the basis for the subsurface soil cleanup goals in the interest of conservatism.

Initial Base-Case Conceptual Model

Figure 5-8 illustrates the initial base-case conceptual model for subsurface soil DCGL development. The basic RESRAD model is used as with development of surface soil DCGLs, with a resident farmer being the average member of the critical group. The hypothetical residence and farm are assumed to be located in the remediated WMA 1 area. Exposure to the subsurface radioactivity occurs following intrusion and surface dispersal when installing a water collection cistern.



The contaminated zone is garden soil in a 100 m^2 area 0.3 m thick, contaminated by drill cuttings.

A resident farmer is the average member of the critical group.

Hypothetical cistern (2 m diameter well, 10 m deep)

Well (cistern) intake depth 5 m below water table

Contamination on bottom of excavation in area where cistern is installed is brought to surface

Figure 5-8. Conceptual Model for Subsurface Soil DCGL Development

Other possible critical groups were considered as with the conceptual model for surface soil DCGLs. However, a resident farmer was initially assumed to be most limiting because such an individual would be engaged in a wider range of activities that could result in greater exposure to residual radioactivity in subsurface soil than other critical groups considered.

Consideration was given to a home construction scenario with the basement in the hypothetical home extending 10 feet below the surface. However, this scenario was not considered to be plausible because any contaminated subsurface soil will be more than 10 feet below the surface in the remediated WMA 1 and WMA 2 areas (the bottoms of the excavations will be more than 10 feet below the surface and uncontaminated soil will be used to backfill the excavations).

Note that Section 7 specifies that the uncontaminated backfill as shown in the figure will be soil obtained from outside of the Center from an area that has not been impacted by site radioactivity. No soil removed during the excavation work will be used in filling the excavation, even if that soil were determined to be uncontaminated.

Consideration of NRC Guidance Related to Buried Radioactivity

Also considered in development of this conceptual model was NRC guidance related to assessment of buried radioactivity in Appendix J to NUREG-1757, Volume 2 (NRC 2006). This guidance applies to cases where radioactive material is buried deep enough that an external dose is not possible in its existing configuration; any radioactivity remaining at the bottom of the WMA 1 and WMA 2 excavations would meet this condition, and the WVDP situation is consistent with the intent of the guidance.

The NRC notes that a conservative analysis could be performed that assumes all of the material is spread on the surface. It describes two alternative exposure scenarios: (1) leaching of the radionuclides to groundwater, which is then used by a residential farmer, and (2) inadvertent intrusion into the buried radioactive material, with part of the radioactivity being spread across the surface where this fraction causes exposure to a resident farmer through various pathways. NRC further notes that

> “The second alternative exposure scenario encompasses all the exposure pathways and, although not all of the source term is in the original position, leaching will occur both from the remaining buried residual radioactivity (if there is any) and the surface soil. Unless differences in the thickness of the unsaturated zone will make a tremendous difference in travel time to the aquifer, the groundwater concentrations should be similar and, therefore, will generally result in higher doses than the first alternate scenario.”

The surface soil DCGLs discussed previously represent the case where all of the radioactive material of interest is located on the surface; as explained in Section 6, possible application of these DCGLs to the subsurface soil of interest would be addressed in the ALARA analysis. DOE has selected the second alternative exposure scenario – inadvertent intrusion into the buried material, that is, into any residual radioactivity at the bottom of the WMA 1 and WMA 2 excavations – as the basis for development of the subsurface soil DCGLs. NRC discusses in Appendix J to NUREG-1757 (NRC 2006) the use of RESRAD in analysis of the inadvertent intrusion scenario, which DOE has implemented here.

Note that a combination of inadvertent intrusion and continuing releases from the bottoms of the remediated deep excavations was also evaluated in the multi-source conceptual model as described in Section 5.2.8, This conceptual model has the following features, some of which are indicated on Figure 5-8:

- The initial modeled source of contamination brought to the surface consists of residual radioactivity in an area two meters (about six feet) in diameter and one meter (about three feet) thick, the top surface of which lies nine meters (about 30 feet) below the ground surface. The contamination assumed to be in this volume of subsurface soil represents the residual radioactivity of interest at the bottom of the WMA 1 or WMA 2 excavation. The exposure occurs when the subsurface radioactivity is deposited on the ground surface where it can result in exposure to members of the critical group through various pathways.
- For conservatism the hypothetical well is assumed to have a large diameter representative of a cistern, rather than the smaller diameter of a typical water supply well (eight inches). The larger diameter provides for a greater volume of contamination being brought to the surface, and is therefore conservative compared to the typical well diameter.
- The nine meters (about 30 feet) of uncontaminated backfill above the initial source of contamination comingles with the contaminated soil, and the mixture is assumed to uniformly cover a cultivated garden area of 100 square meters (about 1000 square feet), i.e., a small portion of the 10,000 square meter garden, to a depth of 0.3 meter (one foot).[9]
- The remainder of the contamination in the bottom of the excavation was not modeled as a continuing source to groundwater because this source is located below the assumed well pump intake depth and was not expected to leach upward into the source of water available to the resident farmer. (However, additional analysis showed that doses from continuing releases from the contamination at the bottom of the excavation would be significant for some radionuclides as described in Section 5.2.8.)

Table 5-4 shows the exposure pathways for development of the subsurface soil DCGLs, which are the same as for the surface soil DCGLs.

Table 5-4. Exposure Pathways for Subsurface Soil DCGL Development

Exposure Pathways	Active
External gamma radiation from contaminated soil	Yes
Inhalation of airborne radioactivity from re-suspended contaminated soil	Yes
Plant ingestion (produce impacted by contaminated soil and groundwater contaminated by impacted soil)	Yes
Meat ingestion (beef impacted by contaminated soil and groundwater contaminated by impacted soil)	Yes
Milk ingestion (impacted by contaminated soil and groundwater contaminated by impacted soil)	Yes
Aquatic food ingestion	No(1)

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[9] Note that larger contamination zone areas were evaluated in the multi-source conceptual model described in Section 5.2.8

Table 5-4. Exposure Pathways for Subsurface Soil DCGL Development

Exposure Pathways	Active
Ingestion of drinking water (from groundwater contaminated by impacted soil)	Yes
Ingestion of drinking water (from surface water)(2)	No
Soil ingestion	Yes
Radon inhalation	No(3)

NOTES: (1) Fish ingestion is considered in development of the streambed sediment DCGLs and in the combined scenario discussed in Section 5.3.

(2) Groundwater was assumed to be the source of all drinking water because the low flow volumes in Erdman Brook and Franks Creek could not support the resident farmer. Use of surface water would also not be as conservative as groundwater since surface water is diluted by runoff from the entire watershed area. Incidental ingestion of water from the streams is evaluated in development of the streambed sediment DCGLs as shown in Table 5-6.

(3) In using the standard resident farmer scenario in modeling of buried radioactivity, the radon pathway is not considered (Appendix J, NRC 2006).

All of the input parameters for development of the subsurface soil DCGLs appear in Appendix C. Table 5-5 identifies selected key input parameters.

Table 5-5. Key Input Parameters for Subsurface Soil DCGL Development(1)

Parameter (Units)	Value	Basis
Initial source - cistern diameter (m)	2.0E+00	Conservative values used to estimate radioactivity brought to the surface to be mixed in garden soil.
Initial source – depth below surface (m)	9.0E+00	
Initial source – thickness (m)	1.0E+00	
Area of contaminated zone (m^2)	1.0E+02	Area drill cuttings from cistern installation spread on surface.
Thickness of contaminated zone (m)	3.0E-01	Contaminated soil depth in garden.
Cover depth (m)	0	Contamination on surface.
Contaminated zone erosion rate (m/y)	0	Conservative assumption.(2)
Well pumping rate (m^3/y)	5.72E+03	See Table C-2.
Unsaturated zone thickness (m)	2.0E+00	Reasonable for WMA 1 and WMA 2.
Distribution coefficient for strontium (mL/g)	1.5E+01	See Table C-2.
Distribution coefficient for cesium (mL/g)	4.8E+02	See Table C-2.
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 depletion of the source.[10]

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[10] The conservative nature of the assumption can be demonstrated by assuming that erosion takes place and evaluating potential doses to a receptor located in a gully where radioactivity has been exposed by erosion. As explained in the discussion of alternate conceptual models below, the receptor in the area of the gully would receive less dose on an annual basis than would the resident farmer due to factors such as spending less time in the contaminated area and receiving exposure through fewer pathways. Consideration of potential doses to an offsite receptor from radioactivity displaced to the stream through erosion indicates that there is a reasonable expectation that offsite doses would not be significant either, as discussed below.

Key assumptions associated with this conceptual model include:

- Contamination in the bottom one meter of the 10 meter deep excavation of the two meter diameter cistern would be brought to the surface, along with the overlying uncontaminated backfill, and blended into the soil over a 100 square meter area used by the resident farmer.
- All water used by the resident farmer (e.g., household, crop irrigation, and livestock watering) is groundwater which has been impacted by leaching of contaminants from surface soil (distributed excavated material) via infiltration of precipitation and irrigation water;
- Surface soil erosion (i.e., source depletion) does not occur over the 1,000 year-modeling period;
- The groundwater flow regime under the post-remedial conditions is unchanged from the current configuration (e.g. flow direction, aquifer productivity); and
- DCGLs that reflect 30 years of decay (i.e., apply to the year 2041) are appropriate for Sr-90 and Cs-137. Although a 30-year decay period could have been applied to all radionuclides, Sr-90 ad Cs-137 were selected based on expected peak doses at the onset of exposure and the short half lives of these particular radionuclides, as noted previously.

Alternate Conceptual Model for Subsurface Soil DCGLs (Cistern Well Driller)

A drilling worker scenario evaluates dose to a hypothetical individual installing the cistern, such as from contamination brought to the surface in the form of drill cuttings that could be set aside near the cistern. A well driller scenario was evaluated using RESRAD with conservative assumptions. Key elements in the model included:

- The drilling worker being exposed to excavated Lavery till material from the bottom of the excavation that was deposited on top of uncontaminated soil in the vicinity of the cistern for a 40 hour period, even though the actual exposure period would likely be much shorter;
- The contamination zone being nine square meters in area and 0.333 meters thick, based on an excavated volume of three cubic meters of contaminated Lavery till material; and
- An assumption of no water shielding, even though water in a cuttings pond would typically provide shielding from direct radiation.

The exposure pathways considered included inadvertent ingestion of contaminated soil, inhalation of contaminated dust, and direct exposure to contaminated soil brought to the surface during the drilling. The resulting DCGLs, which are shown in Table 5-11c in Section 5.2.8, were greater than the subsurface soil DCGLs for all radionuclides developed for the resident farmer scenario, indicating the well driller scenario is less limiting that the resident farmer scenario used in developing the subsurface soil DCGLs.

Alternate Conceptual Model for Subsurface Soil DCGLs (Erosion, Onsite Receptor)

An alternate conceptual model was evaluated involving the potential impact of unchecked erosion in WMA 2 to an onsite receptor. The model assumed that gully erosion would produce narrow, deep steep-sided gullies, conditions where building a home and growing crops would not be practical. A plausible scenario for these conditions would involve a recreationist spending time hiking in the area, which is assumed to be rent by deep gullies that extend to the bottom of the WMA 2 excavation. Figure 5-9 illustrates the basic conceptual model. This scenario was analyzed using RESRAD in the deterministic mode.

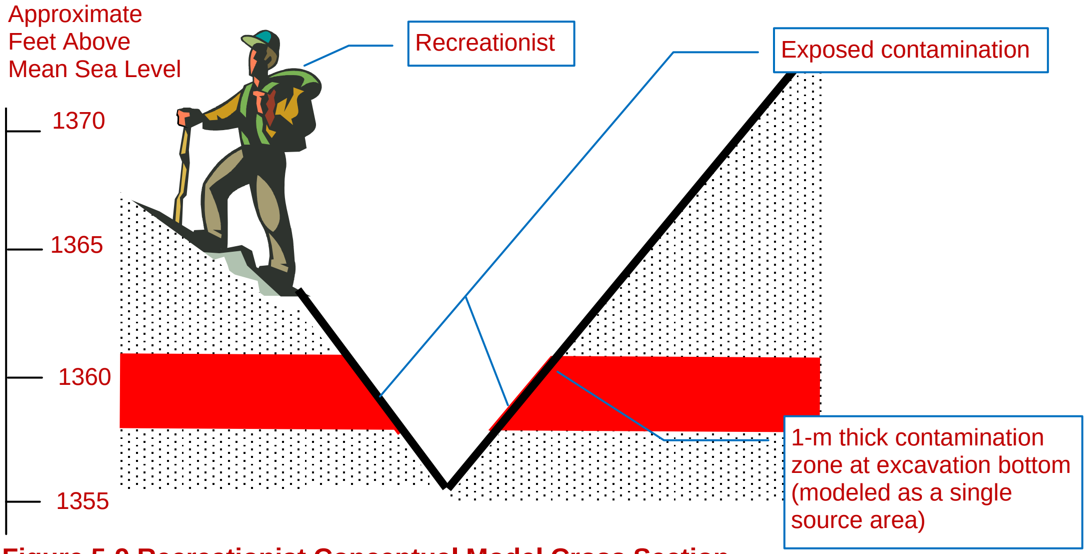

Figure 5-9 Recreationist Conceptual Model Cross Section

The modeling of this recreationist scenario produced DCGLs for 25 mrem per year that were more than one order of magnitude greater than the DCGLs produced with the initial base-case resident farmer/cistern scenario for all 18 radionuclides of interest as shown in Table 5-11c in Section 5.2.8. These results demonstrate that the resident farmer/cistern scenario is more limiting for an onsite receptor.

Alternate Conceptual Model for Subsurface Soil DCGLs (Erosion, Offsite Receptor)

Another alternative scenario was evaluated to determine the potential impact of long-term erosion in WMA 2 to an offsite receptor. This analysis estimated the potential doses to an offsite receptor from radioactivity that could be released from the bottom of the remediated WMA 2 excavation due to formation of a gully that eventually cut through the bottom of the backfilled excavation.

In this analysis, radioactivity in eroded soil from the bottom of the WMA 2 backfilled excavation was assumed to be transported in surface water to a receptor located on Cattaraugus Creek near the confluence with Buttermilk Creek who ingested both the water and fish harvested from the water and used the water to irrigate a garden. Both the area of Lagoon 1 and the area of Lagoon 3 were considered using conservative erosion rates. The results showed that doses to this receptor would be insignificant compared to the onsite receptor doses estimated in the base-case resident farmer model. Table 5-11c below shows the DCGLs calculated for the Lagoon 3 area.

Alternate Conceptual Model for Subsurface Soil DCGLs (Natural Gas Well Driller)

Installation of a natural gas well was also evaluated. Installation of this type of well would take longer than installation of a cistern because the well would be much deeper, would require well/formation development by hydrofracturing, and would require the installation of conveyance piping and valving. The analysis focused on exposure to the drilling worker. Key elements in the model included:

- The natural gas well being 0.5 meter (20 inches) in diameter and 100 meters (330 feet) deep (a conservative estimate given typical depths in excess of 1,000 meters); and
- The drilling worker being exposed to excavated Lavery till material from the bottom of the excavation that was deposited in a cuttings pit near the worker's location for 500 hours.

The exposure pathways considered included inadvertent ingestion of contaminated soil, inhalation of contaminated dust, and direct exposure to contaminated soil brought to the surface during the drilling. RESRAD version 6.4 in the deterministic mode was used to perform the calculations. The resulting DCGLs shown in Table 5-11c below were one or more orders of magnitude greater than the deterministic base-case resident farmer subsurface soil DCGLs for all radionuclides, demonstrating that the base-case resident farmer-cistern installation scenario is more limiting.

Alternate Conceptual Model for Subsurface Soil DCGLs (Residential Gardener)

Another alternative exposure scenario was evaluated to determine whether the base-case resident farmer-cistern installation scenario was bounding for development of subsurface soil DCGLs. This alternative scenario involved a residential gardener scenario.

The receptor in the residential gardener scenario is a hypothetical person who resides in the area and grows a vegetable garden. This scenario differs from the resident farmer scenario in that the person of interest does not consume meat or milk produced on the property and spends less time outdoors in the hypothetical garden. The well pumping rate used in this scenario was lower than the rate used in the resident farmer model (1140 cubic meters per year compared to 5720 meters per year) to reflect the smaller area being used and the lower well water usage.

This analysis was performed using three models which differed with respect to the area of the contamination zone and its thickness:

- Model 1 used a 100 square meter area and 0.3 meter depth, the base-case values in the base-case resident farmer deterministic analysis;
- Model 2 used a 300 square meter area and 0.1 meter depth; and
- Model 3 used a 50 square meter area and 0.6 meter depth;

This alternative exposure scenario produced DCGLs for some radionuclides that were lower than those produced by the base-case resident farmer model. In most cases, Model 2 with the largest contamination zone area produced the lowest DCGLs due to higher groundwater concentrations from reduced dilution and larger contaminated fractions from ingestion pathways. The results appear in Section 5.2.8 and were taken into account in establishing revised cleanup goals.

5.2.3 Streambed Sediment Conceptual Model

Figure 5-10 illustrates the conceptual model for development of streambed sediment DCGLs. Table 5-6 identifies the exposure pathways considered.

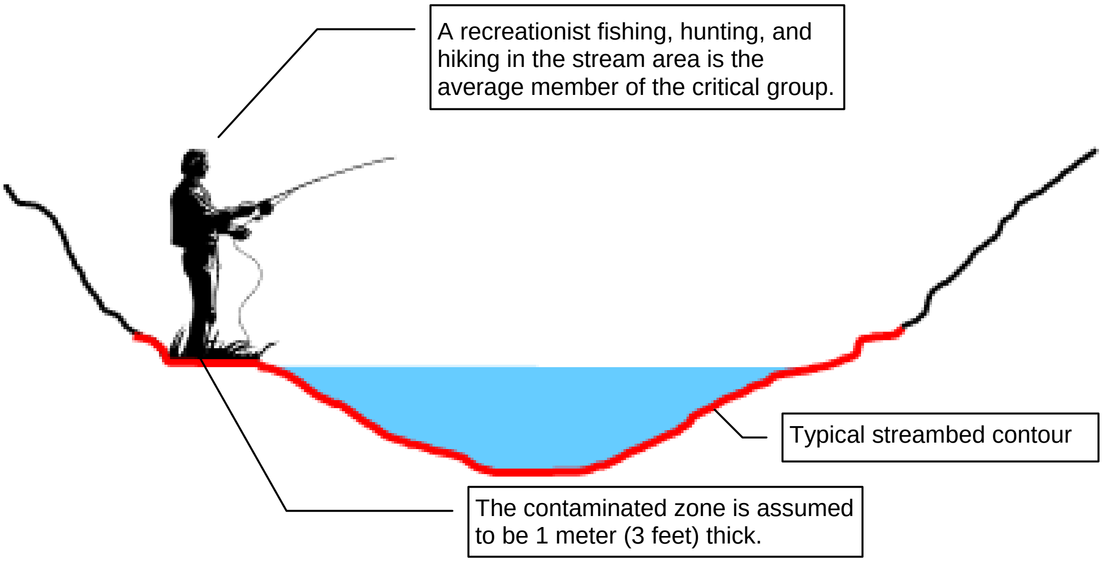

Figure 5-10. Conceptual Model for Streambed DCGLs Development

Table 5-6. Exposure Pathways for Streambed Sediment DCGL Development

Exposure Pathways	Active
External gamma radiation from contaminated sediment	Yes
Inhalation of airborne radioactivity from resuspended contaminated sediment	No(1)
Plant ingestion (produce impacted by soil and water sources)	No
Meat ingestion (venison impacted by soil and water sources)	Yes
Milk ingestion (impacted by soil and water sources)	No
Aquatic food ingestion (fish)	Yes
Ingestion of drinking water (from groundwater well)	No
Ingestion of drinking water (incidental from surface water)	Yes
Sediment ingestion (incidental during recreation)	Yes
Radon inhalation	No(2)

NOTES: (1) Sediments adjacent to streambed have significant moisture content that inhibits their resuspension potential, which would minimize inhalation exposure. Additionally, vegetation along the streambed will likely preclude significant wind scour and subsequent inhalation. To confirm these conclusions, the model was revised to include the inhalation pathway as well as to make other minor refinements; these changes did not produce a significant difference in the results.

(2) The radon pathway is not considered because radon is primarily naturally occurring and neither radon nor its progeny are among the radionuclides of significant interest in dose modeling.

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:

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[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

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[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.

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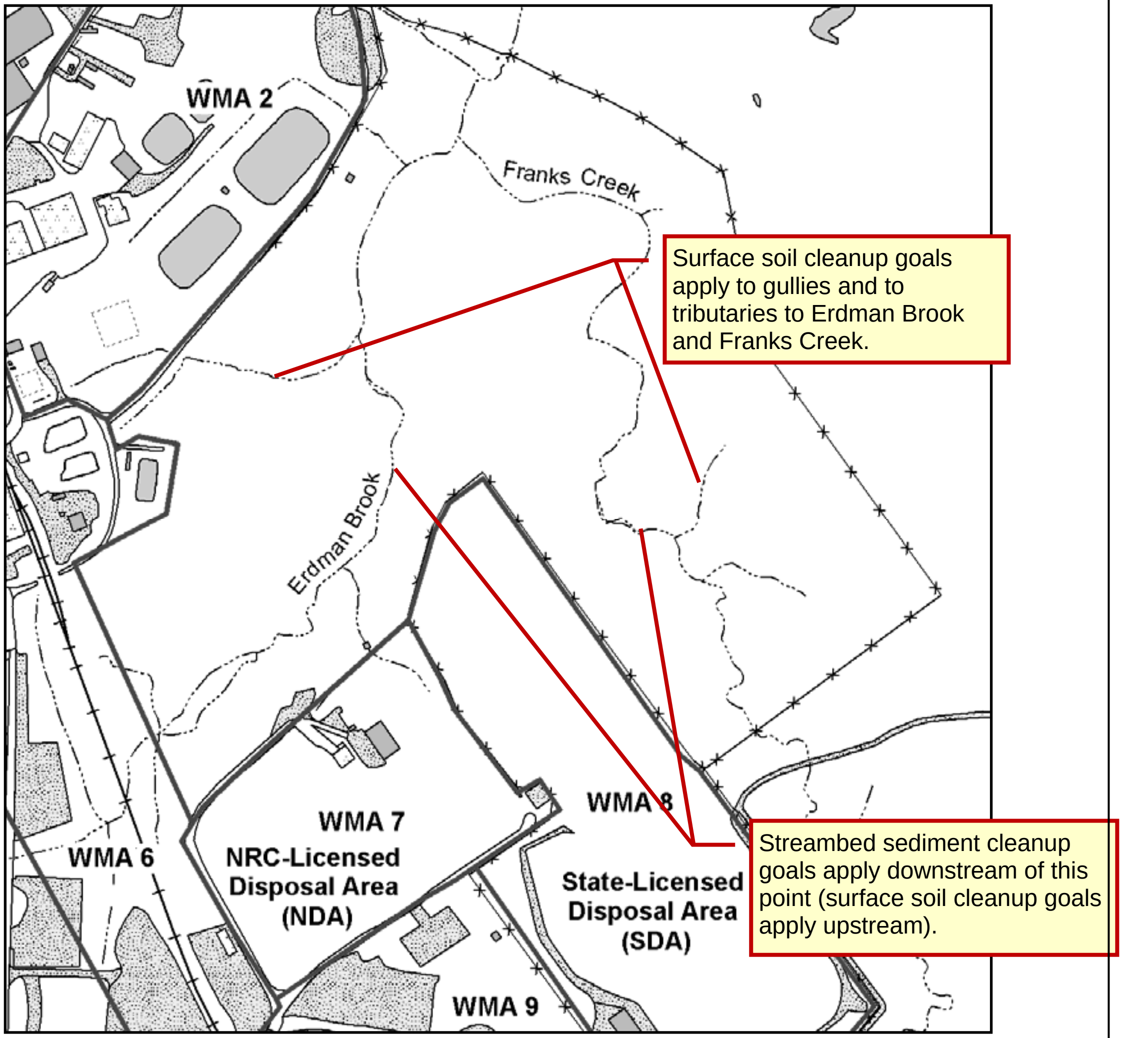
[13] With the larger diameter, much more contaminated soil and residual radioactivity would be brought to the surface where it could cause exposure through various pathways. The difference in volume would vary with the square of the radius; 100 times as much contaminated soil would be brought to the 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.



Surface soil cleanup goals apply to gullies and to tributaries to Erdman Brook and Franks Creek.

Streambed sediment cleanup goals apply downstream of this point (surface soil cleanup goals apply upstream).

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

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[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.

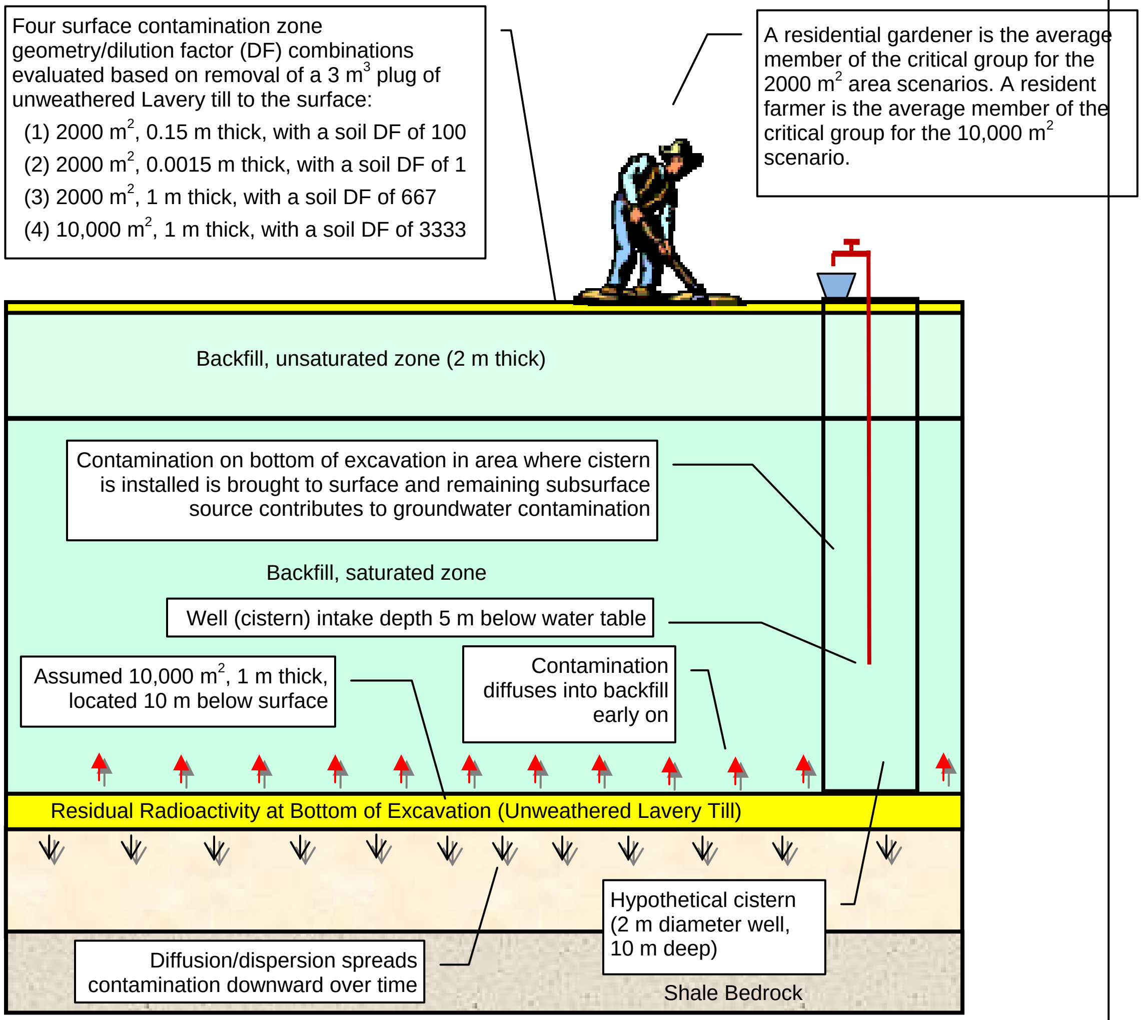

Figure 5-13. Modified Conceptual Model for Subsurface Soil DCGL Development

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

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[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.

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[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.

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[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.

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[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

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