LIFE-CYCLE RISK ANALYSIS FOR DEPARTMENT OF ENERGY (DOE) BURIED WASTES

Volume II

By

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APPENDIX A

IDAHO SITE SUBSURFACE DISPOSAL AREA (SDA) REMEDIAL ALTERNATIVES RISK AND UNCERTAINTY EVALUATION

The overall risk assessment framework and methodology for the disposition of Department of Energy (DOE) buried waste sites are described in detail in Chapter III. The results of applying the qualitative elements of the framework and methodology to the Idaho Site Subsurface Disposal Area (SDA) are described in Chapter IV. Additional information including the detailed hazard and gap analyses from applying the qualitative elements of the risk analysis framework and methodology are provided in this appendix.

Acceptable remedial alternatives are initially defined for the buried waste site as described in Chapter IV[197]. In this research, possible remedial alternatives for buried waste sites have been conceptually grouped in terms of whether the wastes will be managed in-place or will be retrieved for treatment and disposal elsewhere. For the SDA, the process steps for implementing remedial alternatives can be described as shown in Table 12 in Chapter IV.

As described in Chapter III, remedial alternative risks are initially evaluated by completing the following steps for each acceptable remedial alternative:

- A *task list* is developed in conjunction with a *management flow diagram* that describes the primary subtasks required to implement the alternative. The task list for the SDA is provided in Exhibit 5 in Chapter IV and the management flow diagrams are illustrated in Figure 19 and Figure 20 in Chapter IV.
- A *risk flow diagram* is developed that indicates the sequence of activities that have the potential to pose significant health risks to workers or the general public.

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[197] For example, one common way of defining acceptable remedial alternatives is to apply three of the nine CERCLA evaluation criteria (i.e., effectiveness, implementability, and cost) (CFR 1994).

The risk flow diagrams for the SDA are provided in Figure 22 and Figure 23 in Chapter IV.

- A set of uniform terminologies and categories are developed to characterize both hazards and knowledge gaps in a meaningful fashion. The definitions used in this research were originally developed by Brown et al. (2005) and are reproduced in Exhibit 1 through Exhibit 4 in Chapter III for clarification.

- *A detailed hazard analysis is developed. For each primary subtask, the following is determined: the task frequency, what can potentially go wrong, how likely is the adverse event to occur, the severity of the consequences, the impacted population, the basis for characterizing the risk, and the contribution of the subtask to overall risk of the remedial alternative.*

- *A detailed gap analysis describing key knowledge barriers, missing information, and uncertainties involved in implementing the remedial alternative. For each primary subtask, knowledge gaps were identified and then characterized by: what information is missing, how important the missing information is, and how large the knowledge gap is according to the aforementioned uniform terminology.*

- An integrated hazard and gap analysis is performed and the results provided in the form of a summary table of the most important potential risks and information gaps for the remedial alternative. The summary table for the SDA remedial alternatives is provided in Table 15 in Chapter IV.

The italicized items in the above list are described in this appendix. The complementary items are described in Chapter III and Chapter IV as indicated above. Additional information is provided in the initial SDA remedial action risk and uncertainty evaluation in Brown et al. (2005).

Hazard Analysis Tables for the SDA Manage-in-Place Remedial Alternative

The hazard analyses in Table 55 through Table 57 are for Alternative 1, which involves managing the SDA buried wastes in-place. That is, no wastes are retrieved from the buried waste site in this alternative. The hazard tables provide the following information for each task associated with a remedial alternative:

- Task Frequency

- How likely is it? (Event Probability)
- What is the severity of the consequences?
- Overall contribution to risk

The definitions in Exhibit 1 (Chapter III) are used for the tables that follow.

Alternative 1: Manage in Place
1A. No Action Option

Table 55. Hazard Evaluation for Manage-in-Place Alternative, No Action Option (1A)

1. BURIAL SITE CHARACTERIZATION							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
1.1 Determine contaminant waste forms, inventories, distributions, and fluxes from the burial site[a]	Occasional[b]	• Construction-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Possible • Unlikely • Possible • Possible • Possible	• Critical • Critical • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and similar activity	• Significant • Low • Significant • Low • Significant
1.2 Complete analysis of remedial activities[c]	Occasional[b]	• Office hazards not considered[d]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
1.3 Complete conceptual model(s) for the burial site	Occasional[b]	• Office hazards not considered[d]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
TASKS 2 THROUGH 8 ARE NOT APPLICABLE							

a. There is an on-going integrated probing project in the SDA to identify the extent of contamination. This is will include site preparation, surveys and mapping, probehole installation and testing, and sampling and data collection (Miller 2003)

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

c. There are hazards associated with the Pit 4 Accelerated Retrieval (USDOE-ID 2004c) and Beryllium Block Grouting (Lopez 2004; Lopez and Schultz 2004) Projects. However, the tasks associated with these projects have been omitted because they are common to all alternatives and will be completed before and regardless of what remedial alternative is selected.

d. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

Table 55, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
9.1 Determine needed long-term monitoring, maintenance, and institutional controls (ICs)	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
9.2 Implement long-term monitoring and ICs	Occasional[a]	• Construction-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia • Failure of Long-term Stewardship	• Possible • Unlikely • Possible • Probable • Possible • Probable	• Critical • Critical • Critical • Marginal • Critical • Severe	• Worker • Worker • Worker • Worker • Worker • Public	Judgment and unlined landfill experience	• Significant • Low • Significant • Low • Significant • High
9.3 Routine maintenance, repair, and replacement	Anticipated	• Maintenance-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Unlikely • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Low • Low • Low • Low • Significant
9.4 Non-routine maintenance, repair, and replacement	Occasional[a]	• Maintenance -related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Possible • Possible • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Significant • Significant • Low • Low • Significant
TASK 10 IS NOT APPLICABLE							

a. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 56. Hazard Evaluation for Manage-in-Place Alternative, Surface Barrier Option (1B)

Task	Task Frequency	What can go wrong? (Failure mode event)	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis?	Overall Contribution to Risk
1. BURIAL SITE CHARACTERIZATION							
No change from Alternative 1A: Please refer to Table 55 for details							
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION							
2.1 Determine performance criteria	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
2.2 Method development and treatability testing[c]	Occasional[a]	• Usual and customary laboratory hazards • Direct contact and resulting exposure to simulated waste materials • Heat stress or hypothermia during field treatability testing • High noise levels and hearing damage	• Unlikely • Possible • Possible • Probable	• Marginal • Marginal • Critical • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, HASP, and PDSA[d]	• Low • Low • Significant • Low
2.3 Install ISG equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Drill penetrates pressurized cylinder or one containing H_2 resulting in explosion • Leak in drill shroud or filter releasing hazardous material • High noise levels and hearing damage	• Unlikely • Possible • Possible • Probable	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and PDSA[d]	• Low • Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. *In Situ* Grouting treatability testing includes both laboratory and field testing (Abbott and Santee 2004; Miller 2001).

d. The HASP is the *Health and Safety Plan* for the *In Situ* Grouting Treatability Study (Miller 2001) and PDSA is the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004).

Table 56, Continued

2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
2.4 Grout designated areas for subsurface stabilization	Anticipated	• Failure of high-pressure grout system resulting in projectiles or grout release • Inadvertent criticality from disturbance of fissile material • Dose from external radiation • Contaminated grout returns to surface • Failure of containment system results in exposure to hazardous contaminants	• Probable • Unlikely • Probable • Unlikely • Possible	• Severe • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience, and PDSA[b]	• High • Low • Low • Low • Low
2.5 Dismantle and decontaminate ISG equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Construction-related traumatic injury • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Possible	• Marginal • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker	Previous, similar experience, and PDSA[b]	• Low • Significant • Low • Significant
2.6 Dispose of ISG equipment (under surface barrier)	Occasional[a]	• Construction-related traumatic injury[c]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant
TASKS 3 THROUGH 7 ARE NOT APPLICABLE							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. The HASP is the *Health and Safety Plan* for the *In Situ* Grouting Treatability Study (Miller 2001) and PDSA is the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004).

c. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, this table.

Table 56, Continued

Task	Task Frequency	What can go wrong? (Failure mode event)	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis?	Overall Contribution to Risk
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
8.1 Determine performance criteria	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
8.2 Prepare work plans and safety analyses and obtain permits	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
8.3 Determine type of surface barrier required	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
8.4 Prepare burial site for surface barrier installation	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Uncovering high radiation source during grading and resulting exposure • Construction-related injuries • High noise levels and hearing damage • Heat stress or hypothermia	• Probable • Unlikely • Possible • Possible • Possible	• Marginal • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Low
8.5 Install surface barrier over burial site[c]	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Construction-related injuries including those for borrow soil transport • High noise levels and hearing damage	• Probable • Probable • Possible	• Marginal • Marginal • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
No change from Alternative 1A: Please refer to Table 55 for details							
TASK 10 IS NOT APPLICABLE							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. For example, the SDA surface barrier may be installed in two stages because of on-going low-level waste disposal operations.

Table 57. Hazard Evaluation for Manage-in-Place Alternative, *In Situ* Grouting Option (1C)

Task	Task Frequency	What can go wrong? (Failure mode event)	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis?	Overall Contribution to Risk
1. BURIAL SITE CHARACTERIZATION							
No change from Alternative 1A: Please refer to Table 55 for details							
TASK 2 IS NOT APPLICABLE							
3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION							
3.1 Determine performance criteria	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
3.2 Method development and treatability testing[c]	Occasional[a]	• Usual and customary laboratory hazards • Direct contact and resulting exposure to simulated waste materials • Heat stress or hypothermia during field treatability testing • High noise levels and hearing damage	• Unlikely • Possible • Possible • Probable	• Marginal • Marginal • Critical • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, PDSA[d]	• Low • Low • Significant • Low
3.3 Install ISG equipment and enclosure	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Drill penetrates pressurized cylinder or one containing H_2 resulting in explosion • Construction-related injuries • Leak in drill shroud or filter releasing hazardous material • High noise levels and hearing damage	• Unlikely • Unlikely • Unlikely • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience, HASP, and PDSA[d]	• Low • Low • Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. *In Situ* Grouting treatability testing includes both laboratory and field testing (Abbott and Santee 2004; Miller 2001).

d. The HASP is the *Health and Safety Plan* for the *In Situ* Grouting Treatability Study (Miller 2001) and PDSA is the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004).

Table 57, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
3.4 Grout selected areas for *contaminant immobilization*	Anticipated	• Failure of high-pressure grout system resulting in projectiles or grout release • Inadvertent criticality (fissile material) • Dose from external radiation • Contaminated grout returns to surface • Failure of containment system results in exposure to hazardous contaminants	• Probable • Unlikely • Probable • Unlikely • Probable	• Severe • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience, PDSA[a]	• High • Low • Low • Low • Low
3.5 Dismantle, move, and install ISG equipment for subsurface stabilization activities	Occasional[b]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Drill penetrates pressurized cylinder or one containing H_2 resulting in explosion • Leak in drill shroud or filter releasing hazardous material • High noise levels and hearing damage	• Unlikely • Unlikely • Probable • Possible	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and PDSA[a]	• Low • Low • Low • Low
3.6 Grout designated areas for *subsurface stabilization*	Anticipated	• Failure of high-pressure grout system resulting in projectiles or grout release • Inadvertent criticality (fissile material) • Dose from external radiation • Contaminated grout returns to surface • Failure of containment system results in exposure to hazardous contaminants	• Probable • Unlikely • Probable • Unlikely • Possible	• Severe • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience, PDSA[a]	• High • Low • Low • Low • Low

a. The PDSA is the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004).

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 57, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
3.7 Dismantle and decontaminate ISG equipment	Occasional[a]	• Disturb surface resulting in airborne rad/ toxic chemical inhalation exposure • Construction-related traumatic injury • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Possible	• Marginal • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker	Previous, similar experience, and PDSA[b]	• Low • Significant • Low • Significant
3.8 Dispose of ISG equipment (under surface barrier)	Occasional[a]	• Construction-related traumatic injury[c]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant
TASKS 4 THROUGH 7 ARE NOT APPLICABLE							
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
No change from Alternative 1B: Please refer to Table 56 for details							
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
No change from Alternative 1A: Please refer to Table 55 for details							
TASK 10 IS NOT APPLICABLE							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. The PDSA is the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004).

c. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 56.

Hazard Analysis Tables for the SDA Retrieve, Treat, and Dispose Alternative

The hazard analyses in Table 58 and Table 59 are for Alternative 2, which involves retrieving SDA buried wastes for treatment and disposal elsewhere. The hazard tables provide the following information for each task associated with a remedial alternative:

- Task Frequency
- How likely is it? (Event Probability)
- What is the severity of the consequences?
- Overall contribution to risk

The definitions in Exhibit 1 (Chapter III) are used for the tables that follow.

Table 58. Hazard Evaluation for Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2A)

1. BURIAL SITE CHARACTERIZATION							
No change from Option 1A: Please refer to Table 55 for details							
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION							
No change from Remedial Option 1B: Please refer to Table 56 for details							
TASKS 3 IS NOT APPLICABLE							
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.1 Identify retrieval methods	Occasional[a]	• No additional hazards[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.2 Determine extent of retrieval	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.3 Plan and manage retrieval of buried wastes	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For example, there are hazards associated with the Pit 9 retrieval study that has already been completed (Snook 2004) and the active Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), but these hazards are not considered here as the Pit 4 Accelerated Retrieval Project is being carried out regardless of the alternative selected for the SDA buried wastes.

c. For example, the SDA areas will likely be targeted using process and historical knowledge as well as the results of the Integrated Probing Project whose risks were indicated in Burial Site Characterization, Table 55. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this report.

Table 58, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.4 Excavate soil overburden and store soil 4.5 Install retrieval equipment for selected retrieval area(s)	Occasional[a]	• Overburden removal resulting in airborne rad/toxic chemical exposure • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Possible • Probable • Probable • Possible • Probable • Possible	• Marginal • Critical • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Significant • Low • Low • Low • Significant
4.6 Retrieve wastes from selected area(s)—spent fuel or analogous materials or pyrophoric materials may be uncovered that require special handling	Anticipated	• Disturb waste area and failure of dust suppression resulting in airborne rad/toxic chemical inhalation exposure • Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure resulting in rad/chemical exposure • Large sloughing event resulting in airborne release of contaminants • Subsidence external to retrieval facility • Undesired criticality during operations	• Unlikely • Unlikely • Possible • Unlikely • Unlikely • Possible • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Critical • Marginal • Severe	• Worker • Worker • Worker • Worker Public • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Low • Low • Low • Low • Significant • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Using the SDA as an example, "Pit 4 Plan" refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and "Pit 9 HazID" is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation.

Table 58, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.6 (Continued) Retrieve wastes from selected area(s)—spent fuel or analogous materials or pyrophoric materials may be uncovered that require special handling	Anticipated	• Fire or explosion during operations • Loaded tote-bin dropped (outside confinement) releasing radionuclides • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Uncovering high-radiation source during retrieval • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Probable • Possible • Unlikely • Unlikely • Unlikely • Unlikely • Unlikely	• Critical • Critical • Severe • Marginal • Marginal • Severe • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, Pit 9 HazID, and OSHA[a]	• Low • Significant • Significant • Low • Low • Low • Low • Low
4.7 Excavate soil underburden (if present)	Occasional[a] (if present)	• Underburden removal resulting in airborne rad/toxic chemical exposure • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, and struck by • High noise levels and hearing damage • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Dose from external radiation • Heat stress or hypothermia	• Possible • Probable • Probable • Possible • Possible • Unlikely • Unlikely • Probable • Possible	• Marginal • Critical • Marginal • Marginal • Severe • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[a]	• Low • Significant • Low • Low • Significant • Low • Low • Low • Significant

a. Using the SDA as an example, "Pit 4 Plan" refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), "Pit 9 HazID" is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation, and OSHA refers to the OSHA Excavations Manual 2226 (USDOL 2002).

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 58, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.8 Segregate retrieved material into TRU (if present) and non-TRU (e.g., low-level and mixed low-level wastes) fractions—special-handled materials segregated further	Occasional[a]	• Rad/toxic chemical exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure and resulting rad/chemical exposure	• Unlikely • Possible • Unlikely • Unlikely	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker Public • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Low • Low • Low
4.9 Temporarily store retrieved and segregated wastes	Anticipated	• Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling	• Unlikely • Possible	• Marginal • Marginal	• Worker • Worker	Previous, similar experience	• Low • Low
4.10 Back-fill areas from which wastes have been retrieved (excavated overburden first)	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Injuries from construction-related activities including borrow soil transport • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Using the SDA as an example, "Pit 4 Plan" refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), "Pit 9 HazID" is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation.

Table 58, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.11 Dismantle, test, and decontaminate retrieval equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction-related injuries • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant
4.12 Dispose of retrieval equipment in burial site prior to surface barrier installation	Occasional[a]	• Construction-related traumatic injury[b]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant

5. *EX SITU* TREATMENT (E.G., COMPACTION)							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
5.1 Determine treatment requirements and methods	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
5.2 Develop technology and perform treatability studies	Occasional[a]	• Direct contact and resulting exposure to simulated waste materials • Heat stress or hypothermia • High noise levels and hearing damage	• Possible • Possible • Possible	• Marginal • Critical • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Significant • Low
5.3 Construct necessary facilities and install equipment	Occasional[a]	• Construction injuries including pinch points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation	• Probable • Probable • Unlikely	• Marginal • Marginal • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 56.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, etc.) are not usually considered significant nor do they relate to chemical/radioactive exposure and are not considered.

Table 58, Continued

5. *EX SITU* TREATMENT (E.G., COMPACTION)—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
5.4 Perform treatment on retrieved and segregated wastes	Anticipated	• Containment/ventilation system failure and resulting rad/chemical exposure • Over pressurization while compacting pressurized container resulting in radiological/toxic chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical exposure • Undesired criticality during operations • Fire or explosion during operation • High noise levels and hearing damage • Dose from external radiation	• Probable • Possible • Unlikely • Unlikely • Unlikely • Probable • Unlikely	• Marginal • Critical • Marginal • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker Public • Worker • Worker • Worker • Worker	Previous, similar experience and Pit 9 HazID[a]	• Low • Significant • Low • Low • Low • Low • Low
5.5 Dismantle, test, and decontaminate treatment equipment and structures	Occasional[b]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction-related traumatic injury • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Possible	• Marginal • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Significant • Low • Significant
5.6 Dispose of treatment equipment in burial site prior to surface barrier installation	Occasional[b]	• Construction-related traumatic injury[c]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant

a. For example, the "Pit 9 HazID" refers to the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation and some treatment activities.

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

c. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 56.

Table 58, Continued

6. PACKAGE RETRIEVED WASTES AND SOIL							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
6.1 Install packaging equipment (if necessary)	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation	• Unlikely • Probable • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low
6.2 Transfer treated wastes to packaging facility	Anticipated	• High noise levels and hearing damage • Direct contact and resulting exposure to waste materials	• Probable • Unlikely	• Marginal • Marginal	• Worker • Worker	Previous, similar experience	• Low • Low
6.3 Package non-transuranic (non-TRU) wastes and soils for on-site disposal	Anticipated	• Containment/ventilation system failure and radionuclide/chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical release • Undesired criticality during operations • Direct contact and resulting exposure to waste materials	• Probable • Unlikely • Unlikely • Possible	• Marginal • Marginal • Severe • Marginal	• Worker • Worker Public • Worker • Worker	Previous, similar experience and Pit 9 HazID[b]	• Low • Low • Low • Low
6.4 Package transuranic (TRU) wastes and soils for disposal at the Waste Isolation Pilot Plant (WIPP)	Anticipated	• Containment/ventilation system failure and radionuclide/chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical release • Undesired criticality during operations • Direct contact and resulting exposure to waste materials	• Probable • Unlikely • Unlikely • Possible	• Marginal • Marginal • Severe • Marginal	• Worker • Worker Public • Worker • Worker	Previous, similar experience and Pit 9 HazID[b]	• Low • Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For example, the "Pit 9 HazID" refers to the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation and some treatment activities.

Table 58, Continued

6. PACKAGE RETRIEVED WASTES AND SOILS –CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
6.5 Handle special materials on a case-by-case basis	Unlikely	• Containment/ventilation system failure and resulting rad/chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical release • Undesired criticality during operations • Direct contact and resulting exposure to waste materials • External radiation dose (non-waste)	• Possible • Unlikely • Unlikely • Possible • Unlikely	• Severe • Severe • Severe • Critical • Marginal	• Worker • Worker Public • Worker • Worker • Worker	Previous, similar experience and Pit 9 HazID[a]	• Significant • Low • Low • Significant • Low
7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
7.1 Construct or identify necessary storage facilities	Occasional[b]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation	• Unlikely • Probable • Possible • Unlikely	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low
7.2 Store wastes prior to final disposal	Anticipated	• Containment/ventilation system failure and radionuclide/chemical exposure	• Unlikely	• Marginal	• Worker Public	Previous, similar experience and Pit 9 HazID[a]	• Low

a. For example, "Pit 9 HazID" refers to the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation and treatment activities.

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this report.

Table 58, Continued

7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
7.3 Determine performance requirements for on-site waste and soil disposal	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Not considered	• Not considered
7.4 Dispose of non-Transuranic (non-TRU) waste and contaminated soil on-site in original burial site	Frequent	• Radiological exposure from proximity to waste containers • Toxic chemical exposure from proximity to waste containers • Construction injuries including pinch points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Unlikely • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience and ICDF HASP[c]	• Low • Low • Low • Low • Low • Low
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
No change from Alternative 1B: Please refer to Table 56 for details							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. The "ICDF HASP" refers to the Health and Safety Plan for operation of the Idaho Site CERCLA Disposal Facility (ICDF) (INEEL 2004).

Table 58, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
9.1 Determine needed long-term monitoring, maintenance, and institutional controls (ICs)	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
9.2 Implement long-term monitoring and ICs	Occasional[a]	• Construction-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia • Failure of Long-term Stewardship	• Possible • Unlikely • Possible • Probable • Possible • Probable	• Critical • Critical • Critical • Marginal • Critical • Severe	• Worker • Worker • Worker • Worker • Worker • Public	Judgment and unlined landfill experience	• Significant • Low • Significant • Low • Significant • High
9.3 Routine maintenance, repair, and replacement	Anticipated	• Maintenance-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Unlikely • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Low • Low • Low • Low • Significant
9.4 Non-routine maintenance, repair, and replacement	Occasional[a]	• Maintenance -related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Possible • Possible • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Significant • Significant • Low • Low • Significant

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

Table 58, Continued

10. OFF-SITE SHIPMENT AND DISPOSAL AT THE WASTE ISOLATION PILOT PLANT (WIPP)							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
10.1 Plan and manage waste shipments	Anticipated	• Office hazards not considered[a]	• Not considered	• Not considered	• Not considered	• Not considered	• Not considered
10.2 Load TRU waste packages into carrier	Frequent	• Contact and exposure to waste materials • Construction injuries including pinch-points, struck by, and drum handling • Dose from external radiation (if package does not meet shipping requirements)	• Possible • Possible • Unlikely	• Marginal • Marginal • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low
10.3 Load carriers onto conveyance	Frequent	• Injuries from heavy equipment operation • Proximity to waste materials resulting in exposure • Dose from external radiation • Heat stress or hypothermia	• Probable • Possible • Unlikely • Unlikely	• Critical • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience	• Significant • Low • Low • Low
10.4 Transport transuranic (TRU) wastes to WIPP via road or rail	Frequent	• Vehicular accident resulting in high temperature fire, container/carrier breach, and exposure • Intentional sabotage resulting in high temperature fire, container/carrier breach, and exposure	• Possible • Unlikely	• Critical • Critical	• Worker Public • Worker Public	Previous, similar experience	• Significant • Low

a. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

Table 58, Continued

10. OFF-SITE SHIPMENT AND DISPOSAL AT THE WASTE ISOLATION PILOT PLANT (WIPP)—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
10.5 Off-load transuranic (TRU) wastes at WIPP	Frequent	• Crane/waste hoist failure or forklift accident resulting in breach of waste container and exposure to waste • Natural event (e.g., seismic or tornado) resulting in container breach & exposure • Intentional sabotage resulting in high temperature fire, container/carrier breach, exposure, and other injuries	• Possible • Unlikely • Unlikely	• Marginal • Marginal • Severe	• Worker • Worker Public • Worker Public	Previous, similar experience and WIPP CH DSA[a]	• Low • Low • Low
10.6 Store transuranic (TRU) wastes at WIPP	Frequent	• Drop waste container by forklift operator resulting in breach of waste container and exposure to waste • Underground roof cave-in resulting in worker injury and/or exposure to waste materials (if container is breached)	• Unlikely • Unlikely	• Marginal • Severe	• Worker • Worker	Previous, similar experience and WIPP CH DSA[a]	• Low • Significant
10.7 Dispose of transuranic (TRU) wastes at WIPP	Frequent	• Radiological exposure from proximity to waste containers • Toxic chemical exposure from proximity to waste containers • Construction injuries including pinch points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Unlikely Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience (INEEL 2004)	• Low • Low • Low • Low • Low • Low

a. "WIPP CH DSA" refers to the Documented Safety Analysis for Contact-Handled TRU wastes at the Waste Isolation Pilot Plant (WIPP 2005).

Table 59. Hazard Evaluation for Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2B)

Task	Task Frequency	What can go wrong? (Failure mode event)	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis?	Overall Contribution to Risk
1. BURIAL SITE CHARACTERIZATION							
No change from Option 1A: Please refer to Table 55 for details							
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION							
No change from Option 1B: Please refer to Table 56 for details							
TASKS 3 IS NOT APPLICABLE							
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES							
4.1 Identify retrieval methods	Occasional[a]	• No additional hazards[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.2 Determine extent of retrieval	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.3 Plan and manage retrieval of buried wastes	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For example, there are hazards associated with the Pit 9 retrieval study that has already been completed (Snook 2004) and the active Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), but these hazards are not considered here as the Pit 4 Accelerated Retrieval Project is being carried out regardless of the alternative selected for the SDA buried wastes.

c. For example, the SDA areas will likely be targeted using process and historical knowledge as well as the results of the Integrated Probing Project whose risks were indicated in Burial Site Characterization, Table 55. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this report..

Table 59, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.4 Excavate soil overburden and store soil 4.5 Install retrieval equipment for designated retrieval area(s)	Occasional[a]	• Overburden removal resulting in airborne rad/toxic chemical exposure • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Possible • Probable • Probable • Probable • Probable • Possible	• Marginal • Critical • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Significant • Low • Low • Low • Significant
4.6 Retrieve wastes from designated area(s)—spent fuel or analogous materials or pyrophoric materials may be uncovered that require special handling	Anticipated	• Disturb waste area and failure of dust suppression resulting in airborne rad/toxic chemical inhalation exposure • Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure resulting in rad/chemical exposure • Large sloughing event resulting in airborne release of contaminants • Subsidence external to retrieval facility • Undesired criticality during operations	• Unlikely • Unlikely • Possible • Unlikely • Unlikely • Possible • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Critical • Marginal • Severe	• Worker • Worker • Worker • Worker Public • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Low • Low • Low • Low • Significant • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Using the SDA as an example, "Pit 4 Plan" refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and "Pit 9 HazID" is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation.

Table 59, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.6 (Continued) Retrieve wastes from selected area(s)—spent fuel or analogous materials or pyrophoric materials may be uncovered that require special handling	Anticipated	• Fire or explosion during operations • Loaded tote-bin dropped (outside confinement) releasing radionuclides • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Uncovering high-radiation source during retrieval • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Probable • Possible • Unlikely • Unlikely • Unlikely • Unlikely • Unlikely	• Critical • Critical • Severe • Marginal • Marginal • Severe • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, Pit 9 HazID, and OSHA[a]	• Low • Significant • Significant • Low • Low • Low • Low • Low
4.7 Excavate soil underburden (if present)	Occasional[a] (if present)	• Underburden removal resulting in airborne rad/toxic chemical exposure • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, and struck by • High noise levels and hearing damage • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Dose from external radiation • Heat stress or hypothermia	• Possible • Probable • Probable • Possible • Possible • Unlikely • Unlikely • Probable • Possible	• Marginal • Critical • Marginal • Marginal • Severe • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[a]	• Low • Significant • Low • Low • Significant • Low • Low • Low • Significant

a. Using the SDA as an example, "Pit 4 Plan" refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), "Pit 9 HazID" is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation, and OSHA refers to the OSHA Excavations Manual 2226 (USDOL 2002).

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 59, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.8 Segregated retrieved material into TRU (if present) and non-TRU (e.g., low-level and mixed low-level wastes) fractions—special-handled materials segregated further	Occasional[a]	• Rad/toxic chemical exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure and resulting rad/chemical exposure	• Unlikely • Possible • Unlikely • Unlikely	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker Public • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Low • Low • Low
4.9 Temporarily store retrieved and segregated wastes	Anticipated	• Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling	• Unlikely • Possible	• Marginal • Marginal	• Worker • Worker	Previous, similar experience	• Low • Low
4.10 Back-fill areas from which wastes have been retrieved (excavated overburden first)	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Injuries from construction-related activities including borrow soil transport • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Using the SDA as an example, “Pit 4 Plan” refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), “Pit 9 HazID” is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation.

Table 59, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.11 Dismantle, test, and decontaminate retrieval equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction-related injuries • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant
4.12 Dispose of retrieval equipment in burial site prior to capping	Occasional[a]	• Construction-related traumatic injury[b]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant
5. *EX SITU* TREATMENT (E.G., COMPACTION)							
No change from Remedial Option 2A: For details, please refer to Table 58							
6. PACKAGE RETRIEVED WASTES AND SOIL							
No change from Remedial Option 2A: For details, please refer to Table 58							
7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL							
No change from Remedial Option 2A: For details, please refer to Table 58							
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
No change from Remedial Option 2A: For details, please refer to Table 58							
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
No change from Remedial Option 2A: For details, please refer to Table 58							
10. OFF-SITE SHIPMENT AND DISPOSAL AT THE WASTE ISOLATION PILOT PLANT (WIPP)							
No change from Remedial Option 2A: For details, please refer to Table 58							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 56.

Gap Analysis Tables for the SDA Manage-in-Place Remedial Alternative

The information available concerning the necessary tasks, process steps, and alternatives and how important each is or would be to protecting human health and the environment must be evaluated. To that end, a set of detailed gap analysis results for the SDA is provided in Table 60 through Table 64 based on CERCLA remedial investigation reports (Becker et al. 1998; Holdren et al. 2006; Holdren et al. 2002; Schofield 2002).

In the gap analysis tables in this appendix, column definitions were standardized where possible. The standardized columns are

- How important [is the gap]?
- How large a gap?

where other columns are self-explanatory (Brown et al. 2005). It is realized that there is not likely to be unanimous agreement on any set of definitions for the gap analysis tables; nonetheless, a common basis is again needed for assessing the tasks in question. A set of definitions for the two aforementioned columns is provided in Exhibit 3 (Chapter III).

The gap and uncertainty analyses in Table 60 through Table 62 are for Alternative 1, which involves managing the SDA buried wastes in-place. That is, no wastes are retrieved from the buried waste site in this alternative.

Alternative 1: Manage in Place
1A. No Action Option

Table 60. Gap Analysis for Manage-in-Place Alternative, No Action Option (1A)

1. BURIAL SITE CHARACTERIZATION					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
1.1 Determine contaminant waste forms, inventories, distributions, and fluxes from the burial site	• Potential for facilitated plutonium transport through the vadose zone • Presence and location of spent fuel or similar high-activity material • Saturated zone contaminant transport properties and model validity • Vadose zone contaminant transport properties and model validity • Geospatial distribution of contaminants and waste forms • Physical and chemical forms • Release mechanisms and rates • Infiltration rate into burial site • Locations to insert probes to determine extent of contaminant migration	• Critical • Critical • Important • Important • Critical • Inconsequential[b] • Inconsequential[b] • Inconsequential[b] • Important	• Large • Large • Intermediate • Large • Large • Intermediate • Intermediate • Intermediate • Intermediate	• (Batcheller and Redden 2004) • STRE, PERA, 2nd Addendum • (INEEL 2005) • (INEEL 2005) • ABRA • ABRA • ABRA • ABRA • (Miller 2003; Salomon 2004)	The gaps in knowledge, particularly those relating to the presence and location of spent fuel (or analogous) material and possible facilitated plutonium transport, are high risk/large gap that can lead to significant risks to workers and the general public.
1.2 Complete analysis of remedial activities	• Pit 4 Accelerated Retrieval Project • Extraction of organic contaminants in the vadose zone (OCVZ)[c] • On-going low-level and mixed low-level waste disposal operations	• Inconsequential • Important • Inconsequential	• Large • Large • Intermediate	• (USDOE-ID 2004c; Wooley 2004) • (Housley 2004; USDOE-ID 1994) • IRA, ABRA	The tasks related to Pit 4 and OCVZ tend to reduce risks further and thus can be omitted to provide a reasonable bounding case; however, there are on-going low-level and mixed low-level waste disposal activities that will increase the inventory.

a. STRE is the Short-term Risk Evaluation (Schofield 2002), IRA is the Interim Risk Assessment (Becker et al. 1998), PERA is the Preliminary Evaluation of Remedial Alternatives (Zitnik et al. 2002), ABRA is the Ancillary Basis for Risk Analysis (Holdren and Broomfield 2004), 2nd Addendum is the Addendum to RI/FS (Holdren and Broomfield 2004), and RBES is the Draft Idaho Site Risk-Based End State Vision document (USDOE-ID 2004d).

b. These gaps are considered to have a small impact on the overall task because reasonable assumptions (e.g., solubility-limited releases) can be made to provide reasonably conservative estimates for the contaminant fluxes from the burial site.

c. Since 1996, soil vapor extraction has been employed to remove organic contamination in the vadose zone (OCVZ) below the Subsurface Disposal Area (SDA). The vadose zone has been contaminated by volatile organic compounds migrating from the buried wastes (Housley 2004).

Alternative 1: Manage in Place
1A. No Action Option

Table 60, Continued

Task	What information is missing?	How important?	How large a gap?	Sources[a]	Comment
1. BURIAL SITE CHARACTERIZATION—CONTINUED					
1.3 Complete conceptual model(s) for the burial site	• Contaminant transport pathways • Exposure methods • Residential and worker scenarios	• Critical • Critical • Important	• Small • Small • Intermediate	IRA, ABRA, RBES	An important gap is whether the acute well-drilling intruder scenario (i.e., the only scenario evaluated by Idaho Site personnel) is the only important scenario.
TASKS 2 THROUGH 8 ARE NOT APPLICABLE					
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
9.1 Determine long-term monitoring, maintenance, and institutional controls (ICs)	• Future land use scenarios and population pressures • Maintenance requirements for the site • Current and future regulatory, permitting, funding, and authority issues • The incentives and procedures needed to ensure longevity of protective state? • Types of institutional controls (e.g., use restrictions, notification measures, etc.) that are necessary and enforceable • Environmental monitoring needed • How will future risks be assessed	• Important • Important • Important • Important • Important • Important • Important	• Intermediate • Intermediate • Large • Large • Intermediate • Intermediate • Intermediate	• (USDOE-ID 2004d) • (Kratina 2002) • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995)	There is likely to be great uncertainty in how legacy management will be implemented for the SDA. Some degree of flexibility should be built into the controls as conditions (e.g., due to contaminant migration) are bound to change unexpectedly in the future. There must also be consideration of public acceptance of the controls selected as well as any actions (e.g., groundwater use restrictions) that might be needed outside the Idaho Site boundary.
9.2 Implement long-term monitoring and ICs	• Efficacy of environmental monitoring and institutional controls over time • Changes in site conditions, regulations, funding, contaminant distributions, etc. • Geospatial and temporal distribution of wastes and waste forms	• Critical • Important • Critical	• Intermediate • Large • Large	• (ELI 1995) • (ELI 1995) • Judgment	The primary consideration is how to provide incentives and procedures to assure the efficacy of the monitoring and controls with changing site and regulatory conditions.

a. IRA is the Interim Risk Assessment (Becker et al. 1998), ABRA is the Ancillary Basis for Risk Analysis (Holdren and Broomfield 2004), 2nd Addendum is the Addendum to RI/FS (Holdren and Broomfield 2004), and RBES is the Draft Idaho Site Risk-Based End State Vision document (USDOE-ID 2004d).

Table 60, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
9.3 Routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for routine maintenance	• Important	• Intermediate	• Judgment	Usual and customary practices for defining the level of staffing and expertise necessary should provide reasonable estimates for this information
9.4 Non-routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for non-routine maintenance	• Important	• Large	• Judgment	It will be difficult to provide reasonable estimates for this information because of the unexpected nature of these operations.
TASK 10 IS NOT APPLICABLE					

Table 61. Gap Analysis for Manage-in-Place Alternative, Surface Barrier Option (1B)

Task	What information is missing?	How important?	How large a gap?	Sources[a]	Comment
1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 60 for details					
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION					
2.1 Determine performance criteria	• Areas and extent to which subsurface must be stabilized against subsidence • Compaction and loading limits on subsurface	• Important • Important	• Intermediate • Intermediate	(Holdren et al. 2002; Stephens 2004; USDOE-ID 1999b)	Much of the risk associated with this task is based upon how long the in situ grouting operation will take and what kind of equipment must be used.
2.2 Method development and treatability testing	• Changes that will have to be made to the study based on intermediate results • The data and other information that will be obtained from the study	• Important • Important	• Intermediate • Intermediate	• Judgment • Judgment (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004)	One cannot know what will be obtained from the grouting treatability studies; however, there have been previous tests and applications of this technology (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004) from which relevant information can be drawn.
2.3 Install ISG equipment	• Area needed to be grouted to stabilize the subsurface against subsidence	• Important	• Intermediate	• (Holdren et al. 2002; Stephens 2004; USDOE-ID 1999b)	Much of the risk associated with this task is based upon how long the in situ grouting operation will take and what kind of equipment must be used.
2.4 Grout designated areas for subsurface stabilization	• Areas that must be grouted to prevent subsidence • Resources required to complete needed in situ grouting in the SDA • Time (and worker hours) needed to complete grouting	• Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate	• (Holdren et al. 2002; Stephens 2004) • Judgment (Zitnik et al. 2002) • (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004; Zitnik et al. 2002)	There is some information concerning those areas with drums that may contain voids or areas where waste was emplaced in such a way as to likely leave voided areas.

Table 61, Continued

2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
2.5 Dismantle and decontaminate ISG equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes have been contaminated	• Inconsequential • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
2.6 Dispose of ISG equipment (under surface barrier)	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for contaminated material/equipment until the site is available. Much of the risk associated with this task is based upon how long the internment operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) will be required.
TASKS 3 THROUGH 7 ARE NOT APPLICABLE					

Table 61, Continued

8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
8.1 Determine performance criteria	• Regulatory and other including site-specific requirements that must be met • Performance measurements available to assess performance versus criteria • Land-use scenarios	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	• Judgment (Mattson et al. 2004) • Judgment (Mattson et al. 2004) • Judgment (USDOE 2003)	The specific regulations that will have to be satisfied by the surface barrier are unknown at the present.
8.2 Prepare work plans and safety analyses and obtain permits	• Presence and locations of spent fuel or similar high-activity material • Burial site and container states as well as waste forms	• Critical • Important	• Large • Intermediate	• Judgment (Holdren and Broomfield 2004; Schofield 2002; Zitnik et al. 2002) • Judgment (Holdren et al. 2002)	It is standard procedure to mitigate known hazards when necessary to protect workers and much of this will not change based upon the waste inventory. One difference involves the discovery of high activity wastes, which require special handling.
8.3 Determine type of surface barrier required	• Burial site/local conditions that promote contaminant release and migration • Specific performance criteria that must be satisfied	• Important • Important	• Intermediate • Intermediate	Judgment (Mattson et al. 2004)	It is likely that an evapotranspiration (ET) type of cap will satisfy the requirements foreseen for the SDA engineered barrier.
8.4 Prepare burial site for surface barrier installation	• Resources and equipment required to complete preparation (e.g., grading) • Time (and worker hours) needed to complete preparation • Types of active systems (e.g., leachate collection) needed	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (Mattson et al. 2004)	There is likely to be significant preparation (e.g., grading, excavation, etc.) that will be needed prior to surface barrier installation.

Table 61, Continued

8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
8.5 Install surface barrier over burial site	• Resources and equipment required to complete installation • Time (and worker hours) needed to complete installation • Availability/location of borrow material • State of low-level waste disposal activities (in Pits 17-20)	• Important • Important • Critical • Important	• Intermediate • Intermediate • Intermediate • Intermediate	• Judgment (Mattson et al. 2004) • Judgment, (Mattson et al. 2004) • Judgment (Zitnik et al. 2002) • Judgment (Holdren et al. 2002)	There is a substantial quantity of borrow material that will be needed to complete the surface barrier. If material from the spreading areas (which are less than one mile from the SDA) can be used, this will reduce the travel distance considerably with the risks. There are also on-going low-level waste disposal activities in the SDA that may require the surface barrier installation to be carried out in stages.
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
No change from Alternative 1A: Please refer to Table 60 for details					
TASK 10 IS NOT APPLICABLE					

Table 62. Gap Analysis for Manage-in-Place Alternative, *In Situ* Grouting Option (1C)

Task	What information is missing?	How important?	How large a gap?	Sources[a]	Comment
1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 60 for details					
TASK 2 IS NOT APPLICABLE					
3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION					
3.1 Determine performance criteria	• Geospatial distribution of wastes and waste forms • Applicable or Relevant and Appropriate Requirements (ARARs) • Results from the Pit 4 Accelerated Retrieval Project • Projected treatment endpoint for organic contamination in the vadose zone • Future land-use decisions	• Critical • Important • Important • Inconsequential • Critical	• Large • Intermediate • Intermediate • Large • Intermediate	• (Holdren et al. 2002; USDOE-ID 1999b) • (Holdren and Broomfield 2004; USDOE-ID 1999b; Zitnik et al. 2002) • (USDOE-ID 2004c) • (Housley 2004; USDOE-ID 1994) • (USDOE-ID 2004d)	The treatment or stabilization requirements will be based upon historic as well as on-going project information, relevant regulations, and other considerations such as worker health. For example, there is reasonably complete information concerning what was buried in the SDA; however, the distributions of contaminants are less well known as are the requirements that the site must satisfy in the future, which are a function of future land-use decisions.
3.2 Method development and treatability testingc	• Changes that will have to be made to the study based on intermediate results • The data and other information that will be obtained from the study	• Important • Important	• Large • Large	(Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004)	One cannot know the results of future ISG treatability studies; however, there have been previous tests and applications of the technology (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004).
3.3 Install ISG equipment and enclosure	• Optimal location to install enclosure during grouting operations • Areas/extent to which grouting needed • Enclosure and subsurface conditions sufficient to prevent contaminated grout from surfacing outside enclosure	• Important • Important • Critical	• Intermediate • Intermediate • Intermediate	(Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004)	There have been previous tests and applications of this technology (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004) from which information can be drawn concerning the ability to control such events.

Table 62, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**	**Comment**
3.4 Grout selected areas for *contaminant immobilization*	• Area and depth needed to immobilize the contaminants of concern in the SDA • Resources required to complete needed in situ grouting in the SDA • Time (and worker hours) needed to complete grouting	• Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate	• (Holdren et al. 2002; Stephens 2004) • Judgment (Zitnik et al. 2002) • Judgment (Zitnik et al. 2002)	There is reasonably complete information concerning what was buried in the SDA; however, the distributions of the contaminants are less well known.
3.5 Dismantle, move, and install ISG equipment for subsurface stabilization activities	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Inconsequential • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling and moving operations will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
3.6 Grout designated areas for *subsurface stabilization*	• Areas that must be grouted to prevent subsidence • Resources required to complete needed in situ grouting in the SDA • Time (and worker hours) needed to complete in situ grouting	• Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate	• (Holdren et al. 2002; Stephens 2004) • Judgment (Zitnik et al. 2002) • (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004; Zitnik et al. 2002)	There is some information concerning those areas with drums that may contain voids or areas where waste was emplaced in such a way as to likely leave voided areas.

Table 62, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**	**Comment**
3.7 Dismantle and decontaminate ISG equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Inconsequential • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling and moving operations will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
3.8 Dispose of ISG equipment (under surface barrier)	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material to be interred • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for contaminated material/equipment until the site is available. Much of the risk associated with this task is based upon how long the internment operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) will be required.
TASKS 4 THROUGH 7 ARE NOT APPLICABLE					
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT					
No change from Remedial Option 1B: Please refer to Table 61 for details					
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
No change from Remedial Option 1A: Please refer to Table 60 for details					
TASK 10 IS NOT APPLICABLE					

Gap Analysis Tables for the SDA Retrieve, Treat, and Dispose Alternative

The gap and uncertainty analyses in Table 63 and Table 64 are for Alternative 2, which involves excavation and retrieval of SDA buried wastes for treatment and disposal elsewhere. In the gap analysis tables, column definitions were standardized where possible. The standardized columns are

- How important [is the gap]?
- How large a gap?

where other columns are self-explanatory (Brown et al. 2005). The uncertainty and gap definitions in Exhibit 3 (Chapter III) are used for the tables that follow.

Table 63. Gap Analysis for Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2A)

1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 60 for details					
2. IN SITU GROUTING (ISG) FOR SUBSURFACE STABILIZATION					
No change from Remedial Option 1B: Please refer to Table 61 for details					
TASK 3 IS NOT APPLICABLE					
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
4.1 Identify retrieval methods	• Available, sufficient, and cost-effective retrieval alternative (pending Pit 4 work) • Results of the Pit 4 Accelerated Retrieval Project	• Important • Important	• Large • Intermediate	• (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002) • (USDOE-ID 2004c)	There have been previous waste retrieval demonstrations in the SDA (Holdren et al. 2002; McKinley and McKinney 1978; Miller 2004; Thompson 1972; Zitnik et al. 2002). The most recent was that for Pit 9 using the Glovebox Excavator Method (GEM) where a 40 ft x 40 ft area was investigated (USDOE-ID 2004b). However, the method tested was excessively expensive to be used for the entire SDA—hence, the Pit 4 Accelerated Retrieval Project.
4.2 Determine extent of retrieval	• Geospatial distribution of wastes and waste forms • Future legal decisions and resulting actions • Future land-use decisions	• Critical • Critical • Important	• Large • Large • Intermediate	• (Holdren et al. 2002) • Judgment • Judgment (USDOE-ID 2004d)	The extent to which buried waste must be retrieved from the SDA is controversial and may ultimately be the result of future legal decisions concerning ultimate disposition of Rocky Flats Plant waste that was buried in the SDA prior to 1970.

Table 63, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.3 Plan and manage retrieval of buried wastes	• Resources and equipment needed to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Retrieval method to be used • Extent of retrieval needed (from 4..2)	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	• (Zitnik et al. 2002) • (Zitnik et al. 2002) • (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002) • Judgment (Holdren et al. 2002)	The primary gaps will be programmatic in nature.
4.4 Excavate soil overburden 4.5 Install equipment	• Extent of soil overburden to remove to uncover designated retrieval areas • Locations to install retrieval equipment	• Important • Important	• Intermediate • Intermediate	• Judgment • Judgment (Holdren et al. 2002)	The locations for the enclosure will be based upon a number of factors including experience, historical records, etc.
4.6 Retrieve wastes from selected area(s)	• Resources and equipment required to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (Holdren et al. 2002; USDOE-ID 2004b; c; Zitnik et al. 2002)	The majority of the risk associated with this task is based on how long the retrieval operations will take and what kind of equipment must be used. The integrity of the waste containers will also play a major role. As indicated elsewhere, there have been numerous waste retrieval demonstrations in the SDA (Holdren et al. 2002; McKinley and McKinney 1978; Miller 2004; Thompson 1972; Zitnik et al. 2002).

Table 63, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.7 Excavate underburden (if present)	• Extent of underburden to remove • Resources and equipment required to complete excavation operations • Time (and worker hours) needed to complete excavation operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	The primary gaps will be programmatic in nature.
4.8 Segregate retrieved material into TRU (if present) and non-TRU fractions	• Resources and equipment required to complete waste segregating operations • Time (and worker hours) needed to complete segregation operations • State of the retrieved waste containers	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c)	The risk associated with this task depends primarily on the duration of the handling and treatment tasks as well as the integrity of the waste containers upon removal from the SDA.
4.9 Temporarily store retrieved and segregated wastes	• The quantities and forms of waste that will have to be stored • The types of waste that will have to be stored • The lengths of time that the wastes will have to be stored • Permits required for extended storage	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment (USDOE-ID 2004b; c)	The wastes that will be retrieved from the SDA under this option are from the Rocky Flats Plant and will be treated and packaged. Thus the types of wastes that must be stored will be reasonably known; however, the storage duration will be dependent upon a number of factors including regulatory and site-specific.
4.10 Back-fill areas from which wastes have been retrieved	• Volume of borrow material required • Location of borrow area and distance of borrow area to SDA • Resources and equipment needed to complete backfill operations • Time (and worker hours) needed to complete backfill operations	• Critical • Critical • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c; Zitnik et al. 2002)	The primary gaps are the location of the borrow site and the amount of borrow material that will be needed.

Table 63, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.11 Dismantle, test, and decontaminate retrieval equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c)	Much of the risk associated with this task is based upon how long the dismantling operation will take, to what degree the equipment has been contaminated, and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
4.12 Dispose of retrieval equipment in burial site prior to surface barrier installation	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c)	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for the material/equipment until the site is available. Much of the risk associated with this task is based on how long the internment operation will take and what kind of equipment (e.g., cutting torches, equipment, etc.) will be required.

5. *EX SITU* TREATMENT (E.G., COMPACTION)					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
5.1 Determine treatment requirements and methods	• Results of the Pit 4 Accelerated Retrieval Project • New treatment and safety technology applicable to waste retrieval activities • Stakeholder input	• Important • Important • Important	• Large • Large • Large	• (USDOE-ID 2004c) • Judgment • Judgment	The regulatory and site-specific requirements should be well-known prior to defining these criteria.
5.2 Develop technology and perform treatability studies	• Changes that will have to be made based on intermediate results • The data and other information that will be obtained from the study • Waste form & contaminant distributions	• Important • Important • Important	• Intermediate • Large • Large	Judgment (Landman et al. 2003; USDOE-ID 1999a)	One cannot know what will be obtained from the ex situ treatability studies; however, there have been previous tests and applications of this technology (both at the Idaho Site and other sites) from which relevant information can be drawn.

Table 63, Continued

5. *EX SITU* TREATMENT (E.G., COMPACTION)—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
5.3 Construct necessary facilities and install equipment	• Resources required to complete construction and installation • Time (and worker hours) needed to complete construction and installation	• Important • Important	• Intermediate • Intermediate	(Landman et al. 2003; Zitnik et al. 2002)	Once the *ex situ* treatment method has been selected, there should be few gaps other than the resources and time required to install the necessary equipment.
5.4 Perform treatment on retrieved and segregated wastes	• Waste forms and contaminant distributions • Relative fractions and amounts of contaminated soils, TRU wastes, and non-TRU/soil wastes to be treated	• Important • Important	• Large • Large	(Landman et al. 2003; Zitnik et al. 2002)	Information such as the integrity of the waste containers, amount of material that must be treated, and extent to which the material is contaminated will drive the risks associated with this treatment.
5.5 Dismantle, test, and decontaminate treatment equipment and structures	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling operation will take, the extent to which the equipment is contaminated, and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
5.6 Dispose of treatment equipment in burial site prior to surface barrier installation	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for contaminated material/ equipment until the site is available. Much of the risk associated with this task is based upon how long the internment operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) will be required.

Table 63, Continued

6. PACKAGE RETRIEVED WASTES AND SOIL					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
6.1 Install packaging equipment	• No *known* gaps	• Not applicable	• Not applicable	Judgment	No known gaps.
6.2 Transfer treated wastes to packaging facility	• Resources and equipment required to complete transfer operations • Time (and worker hours) needed to complete transfer operations • Degree to which retrieved waste is contaminated and activity levels	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	The duration of the handling and packaging tasks as well as the integrity of the waste containers upon removal from SDA are critical to reducing risk.
6.3 Package non-transuranic (non-TRU) wastes and soils for on-site disposal	• Resources and equipment required to complete packaging operations • Time (and worker hours) needed to complete packaging operations • State of the retrieved waste containers • Degree to which retrieved waste is contaminated and activity levels	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment (USDOE-ID 2004b; c)	The duration of the handling and packaging tasks as well as the integrity of the waste containers upon removal from SDA are critical to reducing risk.
6.4 Package TRU wastes and soils for disposal at WIPP	• Resources and equipment required to complete packaging operations • Time (and worker hours) needed to complete packaging operations • State of the retrieved waste containers • Degree to which retrieved waste is contaminated and activity levels	• Important • Important • Important • Critical	• Intermediate • Large • Large • Intermediate	Judgment (USDOE-ID 2004b; c)	The duration of the handling and packaging tasks as well as the integrity of the waste containers upon removal from SDA are critical to reducing risk.
6.5 Handle special materials on a case-by-case basis	• Presence and location of spent nuclear fuel or analogous high activity materials	• Critical	• Large	Judgment (Zitnik et al. 2002)	This handling is potentially very high risk and thus the presence and location of such material is very important.

Table 63, Continued

7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
7.1 Construct or identify necessary storage facilities	• Resources and equipment required to complete construction operations • Time (and worker hours) needed to complete packaging operations • Types (including activity) and volumes of wastes that must be stored	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Important knowledge gaps include required storage capacity as well as the duration that wastes must be stored.
7.2 Store wastes prior to final disposal	• Durations that wastes must be stored • Monitoring required • Maintenance, repair, and replacement required	• Important • Important • Important	• Large • Small • Intermediate	Judgment	The primary knowledge gaps concern the duration that wastes must be stored and the future maintenance and repairs that will be required.
7.3 Determine performance requirements for on-site waste and soil disposal	• Types, amounts, distributions, and forms of contaminants of concern • Future environmental conditions (e.g., precipitation, evapotranspiration, etc.) • Future land-use decisions • Disposal cell site selection criteria • Regulatory and other pertinent criteria including Applicable or Relevant and Appropriate Requirements (ARARs)	• Important • Important • Important • Important • Important	• Intermediate • Large • Intermediate • Intermediate • Intermediate	• Judgment • Judgment • Judgment (USDOE-ID 2004d) • Judgment • Judgment (USDOE-ID 2004d)	Disposal cell requirements will be based upon historic and on-going project information, relevant regulations, and other considerations such as worker health. For example, there is reasonably complete information concerning what was buried in the SDA; however, the distributions of contaminants are less well known as are the future requirements that the site must satisfy, which are a function of future land-use decisions.
7.4 Dispose of non-TRU waste and soil	• Types and amounts of wastes and soil to be disposed	• Important	• Intermediate	Judgment	Disposal will be permanent; thus only the types and amounts of wastes and soils will be needed.
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT					
No change from Alternative 1B: Please refer to Table 61 for details					

Table 63, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
9.1 Determine long-term monitoring, maintenance, and institutional controls (ICs)	• Future land use scenarios and population pressures • Maintenance requirements for the site • Current and future regulatory, permitting, funding, and authority issues • The incentives and procedures needed to ensure longevity of protective state • Types of institutional controls (e.g., use restrictions, notification measures, etc.) that are necessary and enforceable • Environmental monitoring needed • How will current and future risks be assessed	• Important • Important • Important • Important • Important • Important • Important	• Intermediate • Intermediate • Large • Large • Intermediate • Intermediate • Intermediate	• (USDOE-ID 2004d) • (Kratina 2002) • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995)	There is likely to be great uncertainty in how legacy management will be implemented for the SDA. Some degree of flexibility should be built into the controls as conditions (e.g., due to contaminant migration) are bound to change unexpectedly in the future. There must also be consideration of public acceptance of the controls selected as well as any actions (e.g., groundwater use restrictions) that might be needed outside the Idaho Site boundary.
9.2 Implement long-term monitoring and ICs	• Efficacy of environmental monitoring and institutional controls over time • Changes in site conditions, regulations, funding, contaminant distributions, etc. • Geospatial and temporal distribution of wastes and waste forms	• Critical • Important • Critical	• Intermediate • Large • Large	• (ELI 1995) • (ELI 1995) • Judgment	The primary consideration is how to provide incentives and procedures to assure the efficacy of the monitoring and controls with changing site and regulatory conditions.
9.3 Routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for routine maintenance	• Important	• Intermediate	• Judgment	Usual and customary practices for defining the level of staffing and expertise necessary should provide reasonable estimates for this information
9.4 Non-routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for non-routine maintenance	• Important	• Large	• Judgment	It will be difficult to provide reasonable estimates for this information because of the unexpected nature of these operations.

Table 63, Continued

10. OFF-SITE SHIPMENT AND DISPOSAL AT THE WASTE ISOLATION PILOT PLANT (WIPP)					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**	**Comment**
10.1 Plan and manage waste shipments	• Amount of waste retrieved that must be transported to and disposed of in WIPP • Amounts of remote- and contact-handled wastes retrieved from SDA • Packaging waste acceptance criteria	• Important • Important • Important	• Large • Large • Small	• Judgment (Holdren et al. 2002) • Judgment (Holdren et al. 2002) • Judgment (USDOE 2006)	Characteristics such as permissible activity levels and packaging have been defined by regulation (USDOE 2006).
10.2 Load TRU waste packages into carrier	• Type(s) of carrier that will be used • Availability of carrier for transportation to WIPP	• Important • Important	• Small • Large	Judgment (WIPP 2005)	Carriers already exist for these types of wastes; however, the availability of the carriers is not known.
10.3 Load carriers onto conveyance	• Resources and equipment required to complete loading operations • Time (and worker hours) needed to complete loading operations	• Important • Important	• Small • Small	Judgment (WIPP 2005)	There is abundant experience of how to perform these activities.
10.4 Transport TRU wastes to WIPP via road or rail	• Transportation method selected • Route selected for waste transportation	• Important • Important	• Small • Small	Judgment (WIPP 2005)	It is possible that either road or rail transportation may be used to transport wastes to WIPP.
10.5 Off-load TRU wastes at WIPP	• Resources and equipment required to complete loading operations • Time (and worker hours) needed to complete loading operations	• Important • Important	• Small • Small	Judgment (WIPP 2005)	There is abundant experience of how to perform these activities.
10.6 Store TRU wastes at WIPP	• No additional knowledge gaps[a]	• Not applicable	• Not applicable	Judgment	Not applicable
10.7 Dispose of TRU wastes at WIPP	• No additional knowledge gaps[a]	• Not applicable	• Not applicable	Judgment	Not applicable

a. There are no gaps that have been identified apart from those considered in the WIPP program.

Table 64. Gap Analysis or Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2B)

Task	What information is missing?	How important?	How large a gap?	Sources[a]	Comment
1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 60 for details					
2. IN SITU GROUTING (ISG) FOR SUBSURFACE STABILIZATION					
No change from Remedial Option 1B: Please refer to Table 61 for details					
TASK 3 IS NOT APPLICABLE					
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES					
4.1 Identify retrieval methods	• Available, sufficient, and cost-effective retrieval alternative (pending Pit 4 work) • Results of the Pit 4 Accelerated Retrieval Project	• Important • Important	• Intermediate • Large	• (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002) • (USDOE-ID 2004c)	There have been previous waste retrieval demonstrations in the SDA (Holdren et al. 2002; McKinley and McKinney 1978; Miller 2004; Thompson 1972; Zitnik et al. 2002). The most recent was that for Pit 9 using the Glovebox Excavator Method (GEM) where a 40 ft x 40 ft area was investigated (USDOE-ID 2004b). However, the method tested was excessively expensive to be used for the entire SDA—hence, the Pit 4 Accelerated Retrieval Project.
4.2 Determine extent of retrieval	• Geospatial distribution of wastes and waste forms • Future legal decisions and resulting actions • Future land-use decisions	• Critical • Critical • Important	• Large • Large • Intermediate	• (Holdren et al. 2002) • Judgment • Judgment (USDOE-ID 2004d)	The extent to which buried waste must be retrieved from the SDA is controversial and may ultimately be the result of future legal decisions concerning ultimate disposition of Rocky Flats Plant waste that was buried in the SDA prior to 1970.

Table 64, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.3 Plan and manage retrieval of buried wastes	• Resources and equipment needed to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Retrieval method to be used • Extent of retrieval needed (from 4..2)	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	• (Zitnik et al. 2002) • (Zitnik et al. 2002) • (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002) • Judgment (Holdren et al. 2002)	The primary gaps will be programmatic in nature.
4.4 Excavate soil overburden 4.5 Install equipment	• Extent of soil overburden to remove to uncover designated retrieval areas • Locations to install retrieval equipment	• Important • Important	• Intermediate • Intermediate	• Judgment • Judgment (Holdren et al. 2002)	The locations for the enclosure will be based upon a number of factors including experience, historical records, etc.
4.6 Retrieve wastes from selected area(s)	• Resources and equipment required to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (Holdren et al. 2002; USDOE-ID 2004b; c; Zitnik et al. 2002)	The majority of the risk associated with this task is based on how long the retrieval operations will take and what kind of equipment must be used. The integrity of the waste containers will also play a major role. As indicated elsewhere, there have been numerous waste retrieval demonstrations in the SDA (Holdren et al. 2002; McKinley and McKinney 1978; Miller 2004; Thompson 1972; Zitnik et al. 2002).

Table 64, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.7 Excavate underburden (if present)	• Extent of underburden to remove • Resources and equipment required to complete excavation operations • Time (and worker hours) needed to complete excavation operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	The primary gaps will be programmatic in nature.
4.8 Segregated retrieved material into TRU (if present) and non-TRU fractions	• Resources and equipment required to complete waste segregating operations • Time (and worker hours) needed to complete segregation operations • State of the retrieved waste containers	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c)	The risk associated with this task depends primarily on the duration of the handling and treatment tasks as well as the integrity of the waste containers upon removal from the SDA
4.9 Temporarily store retrieved and segregated wastes	• The quantities and forms of waste that will have to be stored • The types of waste that will have to be stored • The lengths of time that the wastes will have to be stored • Permits required for extended storage	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment (USDOE-ID 2004b; c)	The wastes that will be retrieved from the SDA under this option are from the Rocky Flats Plant and will be treated and packaged. Thus the types of wastes that must be stored will be reasonably known; however, the storage duration will be dependent upon a number of factors including regulatory and site-specific.
4.10 Back-fill areas from which wastes have been retrieved	• Volume of borrow material required • Location of borrow area and distance of borrow area to SDA • Resources and equipment needed to complete backfill operations • Time (and worker hours) needed to complete backfill operations	• Critical • Critical • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c; Zitnik et al. 2002)	The primary gaps are the location of the borrow site and the amount of borrow material that will be needed.

Table 64, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.11 Dismantle, test, and decontaminate retrieval equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c)	Much of the risk associated with this task is based upon how long the dismantling operation will take, to what degree the equipment has been contaminated, and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
4.12 Dispose of retrieval equipment in burial site prior to surface barrier installation	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004b; c)	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for the material/equipment until the site is available. Much of the risk associated with this task is based on how long the internment operation will take and what kind of equipment (e.g., cutting torches, equipment, etc.) will be required.

Table 64, Continued

5. *EX SITU* TREATMENT (E.G., COMPACTION)
No change from Remedial Option 2A: Please refer to Table 63 for details
6. PACKAGE RETRIEVED WASTES AND SOIL
No change from Remedial Option 2A: Please refer to Table 63 for details
7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL
No change from Remedial Option 2A: Please refer to Table 63 for details
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT
No change from Alternative 1B: Please refer to Table 61 for details
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE
No change from Remedial Option 2A: Please refer to Table 63 for details
10. OFF-SITE SHIPMENT AND DISPOSAL AT THE WASTE ISOLATION PILOT PLANT (WIPP)
No change from Remedial Option 2A: Please refer to Table 63 for details

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APPENDIX B

OAK RIDGE BEAR CREEK BURIAL GROUNDS (BCBG) REMEDIAL ALTERNATIVES RISK AND UNCERTAINTY EVALUATION

The overall risk assessment framework and methodology for the disposition of Department of Energy (DOE) buried waste sites are described in detail in Chapter III. The results of applying the qualitative elements of the framework and methodology to the Oak Ridge Bear Creek Burial Grounds (BCBG) were described in Chapter IV. The results of the analysis indicted that, because of lack of specific information for the BCBG, the remedial alternative evaluation for the BCBG closely resembled that for the Idaho Site Subsurface Disposal Area (SDA) except for the different hazards associated with pyrophoric and unstable materials buried in the BCBG. Additional details (including detailed hazard and gap analyses) of the application of the qualitative elements of the risk analysis framework and methodology to the BCBG are provided in this appendix.

Acceptable remedial alternatives initially are defined for the buried waste site as described in the methodology[198]. In this research, possible remedial alternatives for buried waste sites are grouped in terms of whether the wastes are managed in-place or retrieved for treatment and disposal. For the BCBG, the process steps for implementing remedial alternatives can be described as shown in Table 17 in Chapter IV. When compared to the steps needed to disposition the SDA, the step involving transporting transuranic wastes to the Waste Isolation Pilot Plant (WIPP) is omitted because this type of waste is not expected in the BCBG.

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[198] For example, one common way of defining acceptable remedial alternatives is to apply three of the nine CERCLA evaluation criteria (i.e., effectiveness, implementability, and cost) (CFR 1994).

The retrieval and treatment of any pyrophoric or unstable wastes are likely to be managed differently than the wastes that would be retrieved from the SDA. For example, because pyrophoric materials rapidly oxidize when exposed to oxygen, an enclosure and other special equipment would have to be used during retrieval operations to prevent exposure of these materials to air. *Ex situ* treatment by compaction (as used in the SDA) may be ineffective for most of the retrieved wastes from the BCBG because the wastes were not originally buried in drums. For retrieved wastes that are not pyrophoric, the material will be packaged for on-site disposal. For pyrophoric materials, treatment is assumed to consist of calcining the wastes to oxidize uranium metal to oxide[199]. The resulting oxide form is packaged (like the other retrieved wastes) for on-site disposal.

As described in Chapter III, remedial alternative risks are initially evaluated by completing the following steps for each acceptable remedial alternative:

- A *task list* is developed in conjunction with a *management flow diagram* that describes the primary subtasks required to implement the alternative. The task list for the BCBG is provided in Exhibit 6 in Chapter IV and the management flow diagram is illustrated in Figure 25 in Chapter IV.

- A *risk flow diagram* is developed that indicates the sequence of activities that have the potential to pose significant health risks to workers or the general public. The risk flow diagrams for the BCBG are provided in Figure 26 and Figure 27 in Chapter IV.

- A set of uniform terminologies and categories are developed to characterize both hazards and knowledge gaps in a meaningful fashion. The definitions used in this research were originally developed by Brown et al. (2005) and are reproduced in Exhibit 1 through Exhibit 4 in Chapter III for clarification.

- *A detailed hazard analysis is developed. For each primary subtask, the following is determined: the task frequency, what can potentially go wrong, how likely is the adverse event to occur, the severity of the consequences, the impacted population,*

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[199] Beginning in 1956, a calcining system was operated at the Rocky Flats Plant to convert pyrophoric uranium fines, turnings, chips, chunks, etc. to a stable uranium oxide form (Holdren et al. 2002). The maximum annual mass of uranium converted to oxide and shipped to the Idaho Site was over 53,000 kg.

the basis for characterizing the risk, and the contribution of the subtask to overall risk of the remedial alternative.

- *A detailed gap analysis describing key knowledge barriers, missing information, and uncertainties involved in implementing the remedial alternative. For each primary subtask, knowledge gaps were identified and then characterized by: what information is missing, how important the missing information is, and how large the knowledge gap is according to the aforementioned uniform terminology.*

- An integrated hazard and gap analysis is performed and the results provided in the form of a summary table of the most important potential risks and information gaps for the remedial alternative. The summary table for the SDA remedial alternatives is provided in Table 20 in Chapter IV.

The italicized items in the above list are described in this appendix. The complementary items are described in Chapter III and Chapter IV as indicated above.

Hazard Analysis Tables for the BCBG Manage-in-Place Remedial Alternative

The hazard analyses in Table 65 through Table 67 are for Alternative 1, involving managing the buried wastes in the Bear Creek Burial Grounds (BCBG) in-place. That is, no wastes will be retrieved from the buried waste site in this alternative. The hazard tables provide the following information for each task associated with a remedial alternative:

- Task Frequency
- How likely is it? (Event Probability)
- What is the severity of the consequences?
- Overall contribution to risk

The definitions in Exhibit 1 (Chapter III) are used to characterize this information.

Alternative 1: Manage in Place
1A. No Action Option

Table 65. Hazard Evaluation for Manage-in-Place Alternative, No Action Option (1A)

1. BURIAL SITE CHARACTERIZATION							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
1.1 Determine contaminant waste forms, inventories, distributions, and fluxes from the burial site[a]	Occasional[b]	• Disturbing unstable or uncovering pyrophoric materials during sampling • Construction-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Probable • Possible • Unlikely • Possible • Possible • Possible	• Severe • Critical • Critical • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker	Judgment and similar activity	• High • Significant • Low • Significant • Low • Significant
1.2 Complete analysis of remedial activities	Occasional[b]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
1.3 Complete conceptual model(s) for the burial site	Occasional[b]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
TASKS 2 THROUGH 8 ARE NOT APPLICABLE							

a. According to the Bear Creek Valley remedial investigation information, areas likely containing unstable (i.e., shock-sensitive or explosive) and pyrophoric materials were considered too dangerous to characterize via sampling (SAIC 1996b).

b. “Occasional” in this context refers to an activity that is conducted a single time, however, over a long period of time.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

Table 65, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
9.1 Determine needed long-term monitoring, maintenance, and institutional controls (ICs)	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
9.2 Implement long-term monitoring and ICs	Occasional[a]	• Construction-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia • Failure of Long-term Stewardship	• Possible • Unlikely • Possible • Probable • Possible • Probable	• Critical • Critical • Critical • Marginal • Critical • Severe	• Worker • Worker • Worker • Worker • Worker • Public	Judgment and unlined landfill experience	• Significant • Low • Significant • Low • Significant • High
9.3 Routine maintenance, repair, and replacement	Anticipated	• Maintenance-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Unlikely • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Low • Low • Low • Low • Significant
9.4 Non-routine maintenance, repair, and replacement	Occasional[a]	• Maintenance -related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Possible • Possible • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Significant • Significant • Low • Low • Significant

a. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

b. “Occasional” in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 66. Hazard Evaluation for Manage-in-Place Alternative, Surface Barrier Option (1B)

1. BURIAL SITE CHARACTERIZATION							
No change from Alternative 1A: Please refer to Table 65 for details							
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
2.1 Determine performance criteria	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
2.2 Method development and treatability testing[c]	Occasional[a]	• Usual and customary laboratory hazards • Direct contact and resulting exposure to simulated waste materials • Heat stress or hypothermia during field treatability testing • High noise levels and hearing damage	• Unlikely • Possible • Possible • Probable	• Marginal • Marginal • Critical • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[d]	• Low • Low • Significant • Low
2.3 Install ISG equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Drill penetrates pressurized cylinder or one containing H_2 resulting in explosion • Leak in drill shroud or filter releasing hazardous material • High noise levels and hearing damage	• Unlikely • Possible • Possible • Probable	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[d]	• Low • Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. *In Situ* Grouting treatability testing includes both laboratory and field testing.

d. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. Specifically, the *Health and Safety Plan* for the *In Situ* Grouting Treatability Study (Miller 2001) and Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004) were used.

Table 66, Continued

2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
2.4 Grout designated areas for subsurface stabilization	Anticipated	• Failure of high-pressure grout system resulting in projectiles or grout release • Dose from external radiation • Contaminated grout returns to surface • Failure of containment system results in exposure to hazardous contaminants	• Probable • Probable • Unlikely • Possible	• Severe • Marginal • Severe • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[b]	• High • Low • Low • Low
2.5 Dismantle and decontaminate ISG equipment	Occasional[a]	• Disturb surface resulting in airborne rad/ toxic chemical inhalation exposure • Construction-related traumatic injury • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Possible	• Marginal • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[b]	• Low • Significant • Low • Significant
2.6 Dispose of ISG equipment (under surface barrier)	Occasional[a]	• Construction-related traumatic injury[c]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant
TASKS 3 THROUGH 7 ARE NOT APPLICABLE							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. Specifically, the *Health and Safety Plan* for the *In Situ* Grouting Treatability Study (Miller 2001) and the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004) were consulted.

c. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, this table.

Table 66, Continued

Task	Task Frequency	What can go wrong? (Failure mode event)	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis?	Overall Contribution to Risk
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
8.1 Determine performance criteria	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
8.2 Prepare work plans and safety analyses and obtain permits	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
8.3 Determine type of surface barrier required	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
8.4 Prepare burial site for surface barrier installation	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Uncovering pyrophoric and/or unstable materials resulting in injury/exposure • Construction-related injuries • High noise levels and hearing damage • Heat stress or hypothermia	• Probable • Probable • Possible • Possible • Possible	• Marginal • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker Worker • Worker	Previous, similar experience	• Low • High • Low • Low • Low
8.5 Install surface barrier over burial site	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Construction-related injuries including those for borrow soil transport • High noise levels and hearing damage	• Probable • Probable • Possible	• Marginal • Marginal • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
No change from Alternative 1A: Please refer to Table 65 for details							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

Alternative 1: Manage in Place
1C. *In Situ* Grouting Option (Stabilization and Immobilization)

Table 67. Hazard Evaluation for Manage-in-Place Alternative, *In Situ* Grouting Option (1C)

1. BURIAL SITE CHARACTERIZATION							
No change from Alternative 1A: Please refer to Table 65 for details							
TASK 2 IS NOT APPLICABLE							
3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
3.1 Determine performance criteria	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
3.2 Method development and treatability testing[c]	Occasional[a]	• Usual and customary laboratory hazards • Direct contact and resulting exposure to simulated waste materials • Heat stress or hypothermia during field treatability testing • High noise levels and hearing damage	• Unlikely • Possible • Possible • Probable	• Marginal • Marginal • Critical • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[d]	• Low • Low • Significant • Low
3.3 Install ISG equipment and enclosure	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Drill penetrates pressurized cylinder or one containing H_2 resulting in explosion • Construction-related injuries • Leak in drill shroud or filter releasing hazardous material • High noise levels and hearing damage	• Unlikely • Unlikely • Unlikely • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[d]	• Low • Low • Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. *In Situ* Grouting treatability testing includes both laboratory and field testing.

d. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. Specifically, the *Health and Safety Plan* for the *In Situ* Grouting Treatability Study (Miller 2001) and the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004) were used to generate the information in this table.

Table 67, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
3.4 Grout selected areas for *contaminant immobilization*	Anticipated	• Failure of high-pressure grout system resulting in projectiles or grout release • Dose from external radiation • Contaminated grout returns to surface • Failure of containment system results in exposure to hazardous contaminants	• Probable • Probable • Unlikely • Probable	• Severe • Marginal • Severe • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA and analogue[a]	• High • Low • Low • Low
3.5 Dismantle, move, and install ISG equipment for subsurface stabilization activities	Occasional[b]	• Disturb surface resulting in airborne rad/ toxic chemical inhalation exposure • Drill penetrates pressurized cylinder or one containing H_2 resulting in explosion • Leak in drill shroud or filter releasing hazardous material • High noise levels and hearing damage	• Unlikely • Unlikely • Probable • Possible	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[a]	• Low • Low • Low • Low
3.6 Grout designated areas for *subsurface stabilization*	Anticipated	• Failure of high-pressure grout system resulting in projectiles or grout release • Dose from external radiation • Contaminated grout returns to surface • Failure of containment system results in exposure to hazardous contaminants	• Probable • Probable • Unlikely • Possible	• Severe • Marginal • Severe • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[a]	• High • Low • Low • Low

a. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. Specifically, the Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004) was used.

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 67, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
3.7 Dismantle and decontaminate ISG equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Construction-related traumatic injury • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Possible	• Marginal • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[b]	• Low • Significant • Low • Significant
3.8 Dispose of ISG equipment (under surface barrier)	Occasional[a]	• Construction-related traumatic injury[c]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant
TASKS 4 THROUGH 7 ARE NOT APPLICABLE							
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
No change from Alternative 1B: Please refer to Table 66 for details							
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
No change from Alternative 1A: Please refer to Table 65 for details							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Feasibility Study *Preliminary Documented Safety Analysis* (PDSA) for *In Situ* Grouting (ISG) in the Subsurface Disposal Area (Abbott and Santee 2004) was consulted.

c. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 65.

Hazard Analysis Tables for the BCBG Retrieve, Treat, and Dispose Alternative

The hazard analyses in Table 68 and Table 69 are for Alternative 2, which involves excavation and retrieval of SDA buried wastes for treatment and disposal elsewhere. The hazard tables provide the following information for each task associated with a remedial alternative:

- Task Frequency
- How likely is it? (Event Probability)
- What is the severity of the consequences?
- Overall contribution to risk

The definitions in Exhibit 1 (Chapter III) are used for the tables that follow.

Alternative 2: Retrieve, Treat, and Dispose
2A. Targeted Retrieval

Table 68. Hazard Evaluation for Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2A)

1. BURIAL SITE CHARACTERIZATION							
No change from Option 1A: Please refer to Table 65 for details							
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION							
No change from Remedial Option 1B: Please refer to Table 66 for details							
TASKS 3 IS NOT APPLICABLE							
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.1 Identify retrieval methods	Occasional[a]	• No additional hazards[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.2 Determine extent of retrieval[b]	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.3 Plan and manage retrieval of buried wastes	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For example, the BCBG areas will likely be targeted using process and historical knowledge as well as the results of any on-going analytical and field studies. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this research.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this report.

Table 68, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.4 Excavate soil overburden and store soil 4.5 Install retrieval equipment for selected retrieval area(s)	Occasional[a]	• Uncovering pyrophoric or unstable materials resulting in exposure or injury • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Probable • Probable • Probable • Possible • Probable • Possible	• Severe • Critical • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[b]	• High • Significant • Low • Low • Low • Significant
4.6 Retrieve wastes from selected area(s)—explosive or pyrophoric materials may be uncovered that require special handling	Anticipated	• Disturb waste area and failure of dust suppression resulting in airborne rad/toxic chemical inhalation exposure • Rad/toxic chemical exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure resulting in rad/chemical exposure • Large sloughing event resulting in airborne release of contaminants • Subsidence external to retrieval facility • Undesired criticality during operations	• Unlikely • Unlikely • Possible • Unlikely • Unlikely • Possible • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Critical • Marginal • Severe	• Worker • Worker • Worker • Worker Public • Worker • Worker • Worker • Worker	Previous, similar experience, and SDA as analogue[b]	• Low • Low • Low • Low • Low • Significant • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation, were used as the basis for the information in this table.

Table 68, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.6 (Continued) Retrieve wastes from selected area(s)—explosive or pyrophoric materials may be uncovered that require special handling	Anticipated	• Uncovering pyrophoric or unstable materials resulting in exposure or injury • Loaded tote-bin dropped (outside confinement) releasing radionuclides • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Dose from external radiation • Heat stress or hypothermia	• Probable • Probable • Possible • Unlikely • Unlikely • Unlikely • Unlikely	• Severe • Critical • Severe • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, SDA as analogue, and OSHA[a]	• High • Significant • Significant • Low • Low • Low • Low
4.7 Excavate soil underburden (if present)	Occasional[a] (if present)	• Under burden removal resulting in airborne rad/toxic chemical exposure • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, and struck by • High noise levels and hearing damage • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Dose from external radiation • Heat stress or hypothermia	• Possible • Probable • Probable • Possible • Possible • Unlikely • Unlikely • Probable • Possible	• Marginal • Critical • Marginal • Marginal • Severe • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, SDA as analogue, and OSHA[a]	• Low • Significant • Low • Low • Significant • Low • Low • Low • Significant

a. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003) were used. OSHA refers to the OSHA Excavations Manual 2226 (USDOL 2002).

b. “Occasional” in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 68, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.8 Segregate pyrophoric and unstable wastes from other wastes	Occasional[a]	• Rad/toxic chemical exposure from contact with wastes or containers • Exposure or injury from handling pyrophoric or unstable materials • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure and resulting rad/chemical exposure	• Unlikely • Probable • Possible • Unlikely • Unlikely	• Marginal • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker Public • Worker	Previous, similar experience, and SDA as analogue[b]	• Low • High • Low • Low • Low
4.9 Temporarily store retrieved and segregated wastes	Anticipated	• Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling	• Unlikely • Possible	• Marginal • Marginal	• Worker • Worker	Previous, similar experience	• Low • Low
4.10 Back-fill areas from which wastes have been retrieved (excavated overburden first)	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Injuries from construction-related activities including borrow soil transport • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003) were used.

Table 68, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.11 Dismantle, test, and decontaminate retrieval equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction-related injuries • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant
4.12 Dispose of retrieval equipment in burial site prior to surface barrier installation	Occasional[a]	• Construction-related traumatic injury[b]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant

5. *EX SITU* TREATMENT (E.G., CALCINING)							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
5.1 Determine treatment requirements and methods	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
5.2 Develop technology and perform treatability studies	Occasional[a]	• Direct contact and resulting exposure to simulated waste materials (if hazardous) • Heat stress or hypothermia • High noise levels and hearing damage	• Possible • Possible • Possible	• Marginal • Critical • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Significant • Low
5.3 Construct necessary facilities and install equipment	Occasional[a]	• Construction injuries including pinch points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation	• Probable • Probable • Unlikely	• Marginal • Marginal • Marginal	• Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 65.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, etc.) are not usually considered significant nor do they relate to chemical/radioactive exposure and are not considered.

Table 68, Continued

5. *EX SITU* TREATMENT (E.G., CALCINING)—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
5.4a Perform treatment (e.g., calcining) on retrieved and segregated pyrophoric and unstable wastes	Anticipated	• Containment/ventilation system failure and resulting fire, exposure, and injury • Off-gas treatment system failure resulting in rad/toxic exposure • Fire or explosion during operations resulting in exposure and injury • High temperature hazards • High noise levels and hearing damage • Dose from external radiation	• Probable • Unlikely • Probable • Possible • Probable • Unlikely	• Critical • Marginal • Critical • Critical • Marginal • Marginal	• Worker • Worker Public • Worker • Worker • Worker • Worker	Previous, similar experience and SDA as analogue[a]	• Significant • Low • Significant • Significant • Low • Low
5.4b Perform treatment on remaining retrieved and segregated wastes	Occasional[b]	• Containment/ventilation system failure • Off-gas treatment system failure • Fire or explosion during operations • High noise levels and hearing damage • Dose from external radiation	• Probable • Unlikely • Unlikely • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Low
5.5 Dismantle, test, and decontaminate treatment equipment and structures	Occasional[b]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction-related traumatic injury • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Probable • Possible	• Marginal • Critical • Marginal • Critical	• Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Significant • Low • Significant
5.6 Dispose of treatment equipment in burial site prior to surface barrier installation	Occasional[b]	• Construction-related traumatic injury[c]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant

a. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation and some treatment activities, was used to develop this table.

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

c. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 65.

Table 68, Continued

6. PACKAGE RETRIEVED WASTES AND SOIL							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
6.1 Install packaging equipment (if necessary)	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical inhalation exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation	• Unlikely • Probable • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low
6.2 Transfer treated wastes to packaging facility	Anticipated	• High noise levels and hearing damage • Direct contact and resulting exposure to waste materials	• Probable • Unlikely	• Marginal • Marginal	• Worker • Worker	Previous, similar experience	• Low • Low
6.3 Package treated pyrophoric wastes for on-site disposal	Anticipated	• Containment/ventilation system failure and radionuclide/chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical release • Direct contact and resulting exposure to waste materials	• Probable • Unlikely • Possible	• Marginal • Marginal • Marginal	• Worker • Worker Public • Worker	Previous, similar experience and SDA as analogue[b]	• Low • Low • Low
6.4 Package remaining wastes and soils for on-site disposal	Anticipated	• Containment/ventilation system failure and radionuclide/chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical release • Direct contact and resulting exposure to waste materials	• Probable • Unlikely • Possible	• Marginal • Marginal • Marginal	• Worker • Worker Public • Worker	Previous, similar experience and SDA as analogue[b]	• Low • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation and some treatment activities.

Table 68, Continued

6. PACKAGE RETRIEVED WASTES AND SOILS –CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
6.5 Handle special (e.g., shock-sensitive, unstable, etc.) materials on a case-by-case basis	Unlikely	• Containment/ventilation system failure and resulting rad/chemical exposure • Off-gas treatment system failure resulting in rad/toxic chemical release • Undesired explosion or other event during operations resulting in injury • Direct contact and resulting exposure to waste materials • External radiation dose (non-waste)	• Possible • Unlikely • Possible • Possible • Unlikely	• Severe • Severe • Severe • Critical • Marginal	• Worker • Worker Public • Worker • Worker • Worker	Previous, similar experience and SDA as analogue[a]	• Significant • Low • Significant • Significant • Low
7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
7.1 Construct or identify necessary storage facilities	Occasional[b]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation	• Unlikely • Probable • Possible • Unlikely	• Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low
7.2 Store wastes prior to final disposal	Anticipated	• Containment/ventilation system failure and radionuclide/chemical exposure	• Unlikely	• Marginal	• Worker Public	Previous, similar experience and SDA analogue[a]	• Low

a. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation and treatment activities, was used.

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this report.

Table 68, Continued

7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
7.3 Determine performance requirements for on-site waste and soil disposal	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Not considered	• Not considered
7.4 Dispose of waste and contaminated soil on-site in BCBG area that is not inundated	Frequent	• Radiological exposure from proximity to waste containers • Toxic chemical exposure from proximity to waste containers • Construction injuries including pinch points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Unlikely • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience and SDA as analogue[c]	• Low • Low • Low • Low • Low • Low
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
No change from Alternative 1B: Please refer to Table 66 for details							

a. “Occasional” in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

c. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Health and Safety Plan for operation of the Idaho Site CERCLA Disposal Facility (ICDF) (INEEL 2004) was used.

Table 68, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
9.1 Determine needed long-term monitoring, maintenance, and institutional controls (ICs)	Occasional[a]	• Office hazards not considered[b]	• Not considered	• Not considered	• Not considered	Judgment and similar activity	• Not considered
9.2 Implement long-term monitoring and ICs	Occasional[a]	• Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia • Failure of Long-term Stewardship	• Unlikely • Possible • Probable • Possible • Probable	• Critical • Critical • Marginal • Critical • Critical	• Worker • Worker • Worker • Worker • Public	Judgment and unlined landfill experience	• Low • Significant • Low • Significant • High
9.3 Routine maintenance, repair, and replacement	Anticipated	• Maintenance-related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Unlikely • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Low • Low • Low • Low • Significant
9.4 Non-routine maintenance, repair, and replacement	Occasional[a]	• Maintenance -related traumatic injury • Radiological uptake via dust inhalation • Toxic VOC uptake via inhalation • Dose from external radiation • Heat stress or hypothermia	• Possible • Possible • Possible • Unlikely • Possible	• Critical • Critical • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Judgment and unlined landfill experience	• Significant • Significant • Low • Low • Significant

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered.

Table 69. Hazard Evaluation for Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2B)

Task	Task Frequency	What can go wrong? (Failure mode event)	How likely is it? (Event probability)	What is the severity of the consequences?	Who is the impacted population?	What is the risk evaluation basis?	Overall Contribution to Risk
1. BURIAL SITE CHARACTERIZATION							
No change from Option 1A: Please refer to Table 65 for details							
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION							
No change from Option 1B: Please refer to Table 66 for details							
TASKS 3 IS NOT APPLICABLE							
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES							
4.1 Identify retrieval methods	Occasional[a]	• No additional hazards[b]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.2 Determine extent of retrieval	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered
4.3 Plan and manage retrieval of buried wastes	Occasional[a]	• Office hazards not considered[c]	• Not considered	• Not considered	• Not considered	Previous, similar experience	• Not considered

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For example, the BCBG areas will likely be targeted using process and historical knowledge as well as the results of any on-going analytical and field studies. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this research.

c. Office hazards (e.g., carpal tunnel syndrome, tripping, slipping, etc.) are not usually considered significant nor do they relate to chemical or radioactive exposure and thus are not considered in this report..

Table 69, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.4 Excavate soil overburden and store soil 4.5 Install retrieval equipment for designated retrieval area(s)	Occasional[a]	• Uncovering pyrophoric or unstable materials resulting in exposure or injury • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, struck by, and drum handling • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Probable • Probable • Probable • Probable • Probable • Possible	• Severe • Critical • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• High • Significant • Low • Low • Low • Significant
4.6 Retrieve wastes from designated area(s)—spent fuel or analogous materials or pyrophoric materials may be uncovered that require special handling	Anticipated	• Disturb waste area and failure of dust suppression resulting in airborne rad/toxic chemical inhalation exposure • Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure resulting in rad/chemical exposure • Large sloughing event resulting in airborne release of contaminants • Subsidence external to retrieval facility • Undesired criticality during operations	• Unlikely • Unlikely • Possible • Unlikely • Unlikely • Possible • Probable • Unlikely	• Marginal • Marginal • Marginal • Marginal • Marginal • Critical • Marginal • Severe	• Worker • Worker • Worker • Worker Public • Worker • Worker • Worker • Worker	Previous, similar experience, Pit 4 Plan, HASP, and Pit 9 HazID[b]	• Low • Low • Low • Low • Low • Significant • Low • Low

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Using the SDA as an example, "Pit 4 Plan" refers to the Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), HASP is the Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and "Pit 9 HazID" is the Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003), which involved excavation.

Table 69, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.6 (Continued) Retrieve wastes from selected area(s)—spent fuel or analogous materials or pyrophoric materials may be uncovered that require special handling	Anticipated	• Uncovering pyrophoric or unstable materials resulting in exposure or injury • Loaded tote-bin dropped (outside confinement) releasing radionuclides • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Dose from external radiation • Heat stress or hypothermia	• Probable • Probable • Possible • Unlikely • Unlikely • Unlikely • Unlikely	• Severe • Critical • Severe • Marginal • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, SDA as analogue, and OSHA[a]	• High • Significant • Significant • Low • Low • Low • Low
4.7 Excavate soil underburden (if present)	Occasional[a] (if present)	• Underburden removal resulting in airborne rad/toxic chemical exposure • Contaminated soil removal resulting in rad/chemical exposure • Construction injuries including pinch-points, and struck by • High noise levels and hearing damage • Cave-in occurs during excavation operation and buries worker • Worker slips and falls in excavation site • Back-hoe falls into excavation site • Dose from external radiation • Heat stress or hypothermia	• Possible • Probable • Probable • Possible • Possible • Unlikely • Unlikely • Probable • Possible	• Marginal • Critical • Marginal • Marginal • Severe • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker • Worker	Previous, similar experience, SDA as analogue, and OSHA[a]	• Low • Significant • Low • Low • Significant • Low • Low • Low • Significant

a. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003) were used. OSHA refers to the OSHA Excavations Manual 2226 (USDOL 2002).

b. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

Table 69, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.8 Segregate pyrophoric and unstable wastes from other wastes	Occasional[a]	• Rad/toxic chemical exposure from contact with wastes or containers • Exposure or injury from handling pyrophoric or unstable materials • Construction injuries including pinch points, struck by, and drum handling • Off-gas treatment system failure resulting in rad/toxic chemical release • Containment/ventilation system failure and resulting rad/chemical exposure	• Unlikely • Probable • Possible • Unlikely • Unlikely	• Marginal • Severe • Marginal • Marginal • Marginal	• Worker • Worker • Worker • Worker Public • Worker	Previous, similar experience, and SDA as analogue[b]	• Low • High • Low • Low • Low
4.9 Temporarily store retrieved and segregated wastes	Anticipated	• Rad/toxic chemical inhalation exposure from contact with waste containers • Construction injuries including pinch points, struck by, and drum handling	• Unlikely • Possible	• Marginal • Marginal	• Worker • Worker	Previous, similar experience	• Low • Low
4.10 Back-fill areas from which wastes have been retrieved (excavated overburden first)	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Injuries from construction-related activities including borrow soil transport • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. For lack of specific information, the available information for the Idaho Site Subsurface Disposal Area (SDA) was used. The Removal Action Plan for the Pit 4 Accelerated Retrieval Project (USDOE-ID 2004c), Health and Safety Plan for the Pit 4 Accelerated Retrieval Project (Wooley 2004), and Hazard Identification Document for the Pit 9 Stage III Project (INEEL 2003) were used.

Table 69, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED							
Task	**Task Frequency**	**What can go wrong? (Failure mode event)**	**How likely is it? (Event probability)**	**What is the severity of the consequences?**	**Who is the impacted population?**	**What is the risk evaluation basis?**	**Overall Contribution to Risk**
4.11 Dismantle, test, and decontaminate retrieval equipment	Occasional[a]	• Disturb surface resulting in airborne rad/toxic chemical exposure • Construction-related injuries • High noise levels and hearing damage • Dose from external radiation • Heat stress or hypothermia	• Unlikely • Possible • Possible • Probable • Possible	• Marginal • Marginal • Marginal • Marginal • Critical	• Worker • Worker • Worker • Worker • Worker	Previous, similar experience	• Low • Low • Low • Low • Significant
4.12 Dispose of retrieval equipment in burial site prior to capping	Occasional[a]	• Construction-related traumatic injury[b]	• Possible	• Critical	• Worker	Previous, similar experience	• Significant
5. *EX SITU* TREATMENT (E.G., COMPACTION)							
No change from Remedial Option 2A: For details, please refer to Table 68							
6. PACKAGE RETRIEVED WASTES AND SOIL							
No change from Remedial Option 2A: For details, please refer to Table 68							
7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL							
No change from Remedial Option 2A: For details, please refer to Table 68							
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT							
No change from Remedial Option 2A: For details, please refer to Table 68							
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE							
No change from Remedial Option 2A: For details, please refer to Table 68							

a. "Occasional" in this context refers to an activity that is conducted a single time, however, over a long period of time.

b. Other hazards are related to surface barrier emplacement. These hazards are the same as those for Surface Barrier Selection, Preparation, and Emplacement, Table 65.

Gap Analysis Tables for the BCBG Manage-in-Place Remedial Alternative

The information available concerning the necessary tasks, process steps, and alternatives and how important each is or will be to protecting human health and the environment must be evaluated. A set of detailed gap analysis results for the Oak Ridge Bear Creek Burial Grounds (BCBG) is provided in Table 70 through Table 74 based on CERCLA remedial investigation reports (SAIC 1996a; d) and pertinent Idaho Site Subsurface Disposal Area (SDA) information from Appendix A. The uncertainty information provided in the BCBG remedial investigation report focused on dose-response issues (e.g., additive risk models, reference doses, slope factors, etc.), land-use scenarios, contaminants of concern selection, exposure media concentrations, etc.

In the gap analysis tables in Table 70 through Table 74, column definitions were standardized where possible. The standardized columns are

- How important [is the gap]?
- How large a gap?

where the other columns are considered self-explanatory. It is realized that there is not likely to be unanimous agreement on any set of definitions for the gap analysis tables; nonetheless, a common basis is again needed for assessing the tasks in question. A set of definitions for the two aforementioned columns is provided in Exhibit 3 (Chapter III).

The gap and uncertainty analyses in Table 70 through Table 72 are for Alternative 1, which involves managing BCBG buried wastes in-place. That is, no wastes are retrieved from the buried waste site in this alternative.

Table 70. Gap Analysis for Manage-in-Place Alternative, No Action Option (1A)

1. BURIAL SITE CHARACTERIZATION					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**	**Comment**
1.1 Determine contaminant waste forms, inventories, distributions, and fluxes from the burial site	• Presence and location of pyrophoric or explosive material • Saturated zone contaminant transport properties and model validity • Vadose zone contaminant transport properties and model validity • Geospatial distribution of contaminants and waste forms • Physical and chemical forms • Release mechanisms and rates • Infiltration rate into burial site	• Critical • Important • Important • Critical • Inconsequential[a] • Inconsequential[a] • Inconsequential[a]	• Large • Intermediate • Large • Large • Intermediate • Intermediate • Intermediate	• (SAIC 1996a; b) • (SAIC 1996a; c) • (SAIC 1996a; c) • (SAIC 1996a; c) • (SAIC 1996a; b; c) • (SAIC 1996a; b; c) • (SAIC 1996a; c)	The gaps in knowledge, particularly those relating to the presence and location of pyrophoric, unstable, shock-sensitive, or explosive material are high risk/large gap that can lead to significant risks to remedial workers.
1.2 Complete analysis of remedial activities	• Impacts of BCBG RCRA closure actions on the ability to disposition remaining BCBG wastes	• Important	• Large	• (SAIC 1996a; d)	RCRA actions have been completed on certain BCBG areas including capping. This may have an impact on the ability to disposition the wastes.
1.3 Complete conceptual model(s) for the burial site	• Contaminant transport pathways • Exposure methods • Residential and worker scenarios	• Critical • Critical • Important	• Small • Small • Intermediate	• (SAIC 1996a; d) • (SAIC 1996a; c) • (SAIC 1996a; c)	An important gap is whether the four land uses (i.e., current maintenance worker, future industrial worker, future recreational receptor, and future resident) evaluated in the RI report are the only important scenarios.

a. These gaps are considered to have a small impact on the overall task because reasonable assumptions (e.g., solubility-limited releases) can be made to provide reasonably conservative estimates for the contaminant fluxes from the burial site.

Table 70, Continued

TASKS 2 THROUGH 8 ARE NOT APPLICABLE					
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
9.1 Determine long-term monitoring, maintenance, and institutional controls (ICs)	• Future land use scenarios and population pressures • Maintenance requirements for the site • Current and future regulatory, permitting, funding, and authority issues • The incentives and procedures needed to ensure longevity of protective state • Types of institutional controls (e.g., use restrictions, notification measures, etc.) that are necessary and enforceable • Environmental monitoring needed • How will current and future risks be assessed	• Important • Important • Important • Important • Important • Important • Important	• Intermediate • Intermediate • Large • Large • Intermediate • Intermediate • Intermediate	• (SAIC 1996a; d) • Judgment • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995)	There is likely to be uncertainty in how legacy management will be implemented for the BCBG. Some degree of flexibility should be built into the controls as conditions (e.g., due to contaminant migration) are bound to change unexpectedly in the future. There must also be consideration of public acceptance of the controls selected as well as any actions (e.g., groundwater use restrictions) that might be needed outside the Idaho Site boundary.
9.2 Implement long-term monitoring and ICs	• Efficacy of environmental monitoring and institutional controls over time • Changes in site conditions, regulations, funding, contaminant distributions, etc. • Geospatial and temporal distribution of wastes and waste forms	• Critical • Important • Critical	• Intermediate • Large • Large	• (ELI 1995) • (ELI 1995) • Judgment	The primary consideration is how to provide incentives and procedures to assure the efficacy of the monitoring and controls with changing site and regulatory conditions.
9.3 Routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for routine maintenance	• Important	• Intermediate	• Judgment	Usual and customary practices for defining the level of staffing and expertise necessary should provide reasonable estimates for this information
9.4 Non-routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for non-routine maintenance	• Important	• Large	• Judgment	It will be difficult to provide reasonable estimates for this information because of the unexpected nature of these operations.

Table 71. Gap Analysis for Manage-in-Place Alternative, Surface Barrier Option (1B)

1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 70 for details					
2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
2.1 Determine performance criteria	• Areas and extent to which subsurface must be stabilized against subsidence • Compaction and loading limits on subsurface	• Important • Important	• Intermediate • Intermediate	SDA as analogue[a]	Much of the risk associated with this task is based upon how long the *in situ* grouting operation will take and what kind of equipment must be used.
2.2 Method development and treatability testing	• Changes that will have to be made to the study based on intermediate results • The data and other information that will be obtained from the study	• Important • Important	• Intermediate • Intermediate	• Judgment • Judgment SDA as analogue[b]	One cannot know what will be obtained from the grouting treatability studies; however, there have been previous tests and applications of this technology (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004; Zitnik et al. 2002) from which relevant information can be drawn.
2.3 Install ISG equipment	• Area needed to be grouted to stabilize the subsurface against subsidence	• Important	• Intermediate	• SDA as analogue[a]	Much of the risk associated with this task is based upon how long the in situ grouting operation will take and what kind of equipment must be used.
2.4 Grout designated areas for subsurface stabilization	• Areas that must be grouted to prevent subsidence • Resources required to complete needed *in situ* grouting in the BCBG • Time (and worker hours) needed to complete grouting	• Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate	• SDA as analogue[a] • Judgment SDA as analogue[b] • SDA as analogue[b]	There is some information concerning those areas with drums that may contain voids or areas where waste was emplaced in such a way as to likely leave voided areas.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002; Stephens 2004; USDOE-ID 1999b).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004; Zitnik et al. 2002).

Table 71, Continued

2. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
2.5 Dismantle and decontaminate ISG equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes have been contaminated	• Inconsequential • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
2.6 Dispose of ISG equipment (under surface barrier)	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for contaminated material/equipment until the site is available. For example, retrieved wastes should not be place back in a site inundated with groundwater. Much of the risk associated with this task is based upon how long the internment operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) will be required.
TASKS 3 THROUGH 7 ARE NOT APPLICABLE					

Table 71, Continued

8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
8.1 Determine performance criteria	• Performance measurements available to assess performance versus criteria • Land-use scenarios	• Important • Important	• Intermediate • Intermediate	• Judgment (SAIC 1996a; d) • Judgment (USDOE 2003)	Most likely a RCRA Subtitle 'C' type cover will be required for the BCBG. This type of cover has been used in the Bear Creek Valley areas that have been addressed under RCRA.
8.2 Prepare work plans and safety analyses and obtain permits	• Presence and locations of unstable, explosive, or pyrophoric material • Burial site and container states as well as waste forms	• Critical • Important	• Intermediate • Intermediate	• Judgment (SAIC 1996a; b) • Judgment	It is standard procedure to mitigate known hazards when necessary to protect workers and much of this will not change based upon the waste inventory. One difference involves the discovery of unstable and pyrophoric materials, which require special handling.
8.3 Determine type of surface barrier required	• Burial site/local conditions that promote contaminant release and migration • Specific performance criteria that must be satisfied	• Important • Important	• Intermediate • Intermediate	Judgment (SAIC 1996a; d)	It is likely that a RCRA Subtitle 'C' type cover will be required for the BCBG.
8.4 Prepare burial site for surface barrier installation	• Resources and equipment required to complete preparation (e.g., grading) • Time (and worker hours) needed to	• Important • Important	• Intermediate • Intermediate	Judgment (SAIC 1996a; d)	There is likely to be significant preparation (e.g., grading, excavation, etc.) that will be needed prior to surface barrier installation.
8.5 Install surface barrier over burial site	• Resources and equipment required to complete installation • Time (and worker hours) needed to complete installation • Availability/location of borrow material	• Important • Important • Critical	• Intermediate • Intermediate • Intermediate	Judgment (SAIC 1996a; d) SDA as analogue[a]	There is a substantial quantity of borrow material that will be needed to complete the surface barrier. It is not apparent from the literature survey that the borrow area has been defined.
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
No change from Alternative 1A: Please refer to Table 70 for details					

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002; Mattson et al. 2004; Zitnik et al. 2002).

Table 72. Gap Analysis for Manage-in-Place Alternative, *In Situ* Grouting Option (1C)

1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 70 for details					
TASK 2 IS NOT APPLICABLE					
3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
3.1 Determine performance criteria	• Geospatial distribution of wastes and waste forms • Applicable or Relevant and Appropriate Requirements (ARARs) • Future land-use decisions	• Critical • Important • Critical	• Large • Intermediate • Intermediate	• (SAIC 1996a; b) SDA as analogue[a] • (SAIC 1996a; d) SDA as analogue[a] • (USDOE-ID 2004d)	The treatment or stabilization requirements will be based upon historic as well as on-going project information, relevant regulations, and other considerations such as worker health. For example, there is reasonably complete information concerning what was buried in the BCBG; however, the distributions of contaminants are less well known.
3.2 Method development and treatability testingc	• Changes that will have to be made to the study based on intermediate results • The data and other information that will be obtained from the study	• Important • Important	• Large • Large	Judgment and SDA as analogue[b]	One cannot know the results of future ISG treatability studies; however, there have been previous tests and applications of the technology.
3.3 Install ISG equipment and enclosure	• Optimal location to install enclosure during grouting operations • Areas/extent to which grouting needed • Enclosure and subsurface conditions sufficient to prevent contaminated grout from surfacing outside enclosure	• Important • Important • Critical	• Intermediate • Intermediate • Intermediate	Judgment and SDA as analogue[b]	There have been previous tests and applications of this technology from which information can be drawn concerning the ability to control such events.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren and Broomfield 2004; USDOE-ID 1999b; Zitnik et al. 2002).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004).

Table 72, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**	**Comment**
3.4 Grout selected areas for *contaminant immobilization*	• Area and depth needed to immobilize contaminants of concern • Resources required to complete needed in situ grouting • Time (and worker hours) needed to complete grouting	• Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate	• SDA as analogue[a] • Judgment SDA as analogue[b] • Judgment SDA as analogue[b]	There is reasonably complete information concerning what was buried in the BCBG; however, the distributions of the contaminants are less well known.
3.5 Dismantle, move, and install ISG equipment for subsurface stabilization activities	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Inconsequential • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling and moving operations will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
3.6 Grout designated areas for *subsurface stabilization*	• Areas that must be grouted to prevent subsidence • Resources required to complete needed in situ grouting in the SDA • Time (and worker hours) needed to complete in situ grouting	• Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate	• SDA as analogue[a] • Judgment SDA as analogue[b] • SDA as analogue[c]	There is some information concerning those areas with drums although not information concerning subsidence within the BCBG.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002; Stephens 2004).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Zitnik et al. 2002).

c. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Loomis and Thompson 1995; Loomis et al. 1996; Loomis et al. 1998; Stephens 2004; Zitnik et al. 2002).

Table 72, Continued

3. *IN SITU* GROUTING (ISG) FOR SUBSURFACE STABILIZATION AND CONTAMINANT IMMOBILIZATION—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**	**Comment**
3.7 Dismantle and decontaminate ISG equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Inconsequential • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling and moving operations will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
3.8 Dispose of ISG equipment (under surface barrier)	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material to be interred • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	An appropriate site must be identified and made available to receive the contaminated material and equipment from the dismantling operations, and interim storage may be required for contaminated material/equipment until the site is available. Much of the risk associated with this task is based upon how long the internment operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) will be required.
TASKS 4 THROUGH 7 ARE NOT APPLICABLE					
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT					
No change from Remedial Option 1B: Please refer to Table 71 for details					
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
No change from Remedial Option 1A: Please refer to Table 70 for details					

Gap Analysis Tables for the BCBG Retrieve, Treat, and Dispose Alternative

The gap and uncertainty analyses in Table 73 and Table 74 are for Alternative 2, which involves excavation and retrieval of BCBG buried wastes for treatment and disposal. In the gap analysis tables, column definitions were standardized where possible. The standardized columns are

- How important [is the gap]?
- How large a gap?

where other columns are self-explanatory (Brown et al. 2005). The uncertainty and gap definitions in Exhibit 3 (Chapter III) are used for the tables that follow.

Table 73. Gap Analysis for Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2A)

Task	What information is missing?	How important?	How large a gap?	Sources[a]	Comment
1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to Table 70 for details					
2. IN SITU GROUTING (ISG) FOR SUBSURFACE STABILIZATION					
No change from Remedial Option 1B: Please refer to Table 71 for details					
TASK 3 IS NOT APPLICABLE					
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES					
4.1 Identify retrieval methods	• Available, sufficient, and cost-effective retrieval alternative • Results of other retrieval results	• Important • Important	• Large • Intermediate	SDA as analogue[a]	There have been previous waste retrieval demonstrations in the Idaho Site SDA (Helm et al. 2003; Holdren et al. 2006; McKinley and McKinney 1978; Miller 2004; Thompson 1972; USDOE-ID 2004a; b; c; Zitnik et al. 2002). Although site conditions are different, this information can still be useful.
4.2 Determine extent of retrieval	• Geospatial distribution of wastes and waste forms • Future legal decisions and resulting actions • Future land-use decisions	• Critical • Critical • Important	• Large • Large • Intermediate	• Judgment and SDA as analogue[b] • Judgment • Judgment (USDOE-ORO 2004)	It appears that Oak Ridge has leeway in defining which areas to retrieve wastes. For example, the Walk-In Pits and other BCBG areas have already been closed by capping under RCRA.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2006).

Table 73, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.3 Plan and manage retrieval of buried wastes	• Resources and equipment needed to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Retrieval method to be used • Extent of retrieval needed (from 4.2)	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	• SDA as analogue[a] • SDA as analogue[a] • SDA as analogue[b] • Judgment SDA as analogue[c]	The primary gaps will be programmatic in nature.
4.4 Excavate soil overburden 4.5 Install equipment	• Extent of soil overburden to remove to uncover designated retrieval areas • Locations to install retrieval equipment including enclosure	• Important • Important	• Intermediate • Intermediate	• Judgment • Judgment SDA as analogue[c]	The locations for the enclosure will be based upon a number of factors including experience, historical records, etc.
4.6 Retrieve wastes from selected area(s)	• Resources and equipment required to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[d]	The majority of the risk associated with this task is based on how long the retrieval operations will take and what kind of equipment must be used. The integrity of the waste containers will also play a major role. As indicated elsewhere, there have been numerous waste retrieval demonstrations in the Idaho Site SDA (Helm et al. 2003; Holdren et al. 2006; McKinley and McKinney 1978; Miller 2004; Thompson 1972; USDOE-ID 2004a; b; c; Zitnik et al. 2002).

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Zitnik et al. 2002).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002).

c For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002).

d. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002; USDOE-ID 2004b; c; Zitnik et al. 2002).

Table 73, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.7 Excavate underburden (if present)	• Extent of underburden to remove • Resources and equipment required to complete excavation operations • Time (and worker hours) needed to complete excavation operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	The primary gaps will be programmatic in nature.
4.8 Segregate retrieved material into pyrophoric and remaining fractions	• Resources and equipment required to complete waste segregating operations • Time (and worker hours) needed to complete segregation operations • State of the retrieved wastes	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[a]	The risk associated with this task depends primarily on the duration of the handling and treatment tasks as well as the integrity of the waste containers upon retrieval.
4.9 Temporarily store retrieved and segregated wastes	• The quantities and forms of waste that will have to be stored • The types of waste that will have to be stored • The lengths of time that the wastes will have to be stored • Permits required for extended storage	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment SDA as analogue[a]	At least some of the wastes retrieved from the BCBG are unstable, explosive, or pyrophoric and must be treated before disposal. Thus the types of wastes that might be stored is reasonably well known; however, the storage duration will be dependent upon a number of factors including regulatory and site-specific.
4.10 Back-fill areas from which wastes have been retrieved	• Volume of borrow material required • Location of borrow area and distance of borrow area to BCBG • Resources and equipment needed to complete backfill operations • Time (and worker hours) needed to complete backfill operations	• Critical • Critical • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[b]	The primary gaps are the location of the borrow site and the amount of borrow material that will be needed.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (USDOE-ID 2004b; c).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (USDOE-ID 2004b; c; Zitnik et al. 2002).

Table 73, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.11 Dismantle, test, and decontaminate retrieval equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[a]	Much of the risk associated with this task is based upon how long the dismantling operation will take, to what degree the equipment has been contaminated, and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
4.12 Dispose of retrieval equipment in burial site prior to surface barrier installation	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[a]	A site must be identified and made available to receive the contaminated material and equipment, and interim storage may be required for the material/equipment until the site is available. Much of the risk associated with this task is based on how long the internment operation will take and what kind of equipment (e.g., cutting torches, equipment, etc.) will be required.

5. *EX SITU* TREATMENT (E.G., CALCINING)					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
5.1 Determine treatment requirements and methods	• New treatment and safety technology applicable to waste retrieval activities • Stakeholder input	• Important • Important	• Large • Large	• Judgment • Judgment	The regulatory and site-specific requirements should be well-known prior to defining these criteria.
5.2 Develop technology and perform treatability studies	• Changes that will have to be made based on intermediate results • The data and other information that will be obtained from the study • Waste form & contaminant distributions	• Important • Important • Important	• Intermediate • Large • Large	Judgment SDA as analogue[b]	One cannot know what will be obtained from the ex situ treatability studies; however, there have been previous tests and applications of this technology (at RFP and other sites) from which relevant information can be drawn.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (USDOE-ID 2004b; c).

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2006; Landman et al. 2003; USDOE-ID 1999a).

Table 73, Continued

5. *EX SITU* TREATMENT (E.G., CALCINING)—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
5.3 Construct necessary facilities and install equipment	• Resources required to complete construction and installation • Time (and worker hours) needed to complete construction and installation	• Important • Important	• Intermediate • Intermediate	Judgment	Once the final *ex situ* treatment method has been selected, there should be few gaps other than the resources and time required to install the necessary equipment.
5.4 Perform treatment on retrieved and segregated wastes	• Waste forms and contaminant distributions • Relative fractions and amounts of unstable, explosive, and pyrophoric materials to be treated	• Important • Important	• Large • Large	Judgment (SAIC 1996a; b; d)	Information such as the integrity of any waste containers, amount of material that must be treated, and extent to which the material is contaminated will drive the risks associated with this treatment.
5.5 Dismantle, test, and decontaminate treatment equipment and structures	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	Much of the risk associated with this task is based upon how long the dismantling operation will take, the extent to which the equipment is contaminated, and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
5.6 Dispose of treatment equipment in burial site prior to surface barrier installation	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Inconsequential • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	A site must be identified and made available to receive the contaminated material and equipment, and interim storage may be required for contaminated material/ equipment until the site is available. Much of the risk associated with this task is based upon how long the internment operation will take and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) will be required.

Table 73, Continued

6. PACKAGE RETRIEVED WASTES AND SOIL					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
6.1 Install packaging equipment	• No *known* gaps	• Not applicable	• Not applicable	Judgment	No known gaps.
6.2 Transfer treated wastes to packaging facility	• Resources and equipment required to complete transfer operations • Time (and worker hours) needed to complete transfer operations • Degree to which retrieved waste is contaminated and activity levels	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment	The duration of the handling and packaging tasks as well as the integrity of any waste containers or waste incompatibilities upon removal from the BCBG are critical to reducing risk.
6.3 Package treated pyrophoric wastes for on-site disposal	• Resources and equipment required to complete packaging operations • Time (and worker hours) needed to complete packaging operations • State of the retrieved waste containers • Degree to which retrieved waste is contaminated and activity levels	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment (SAIC 1996a; b; d)	The duration of the handling and packaging tasks as well as the integrity of any waste containers or waste incompatibilities upon removal from the BCBG are critical to reducing risk. Upon completion of treatment, the oxide waste form should not be more hazardous than other typical forms removed from the BCBG.
6.4 Package remaining wastes and soils for on-site disposal	• Resources and equipment required to complete packaging operations • Time (and worker hours) needed to complete packaging operations • State of the retrieved wastes • Degree to which retrieved waste is contaminated and activity levels	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment	The duration of the handling and packaging tasks as well as the integrity of the waste containers upon removal from he BCBG are critical to reducing risk.
6.5 Handle special materials on a case-by-case basis	• Presence and location of unstable, explosive, shock-sensitive materials	• Critical	• Large	Judgment	This handling is potentially very high risk and thus the presence and location of such material is very important.

Table 73, Continued

7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
7.1 Construct or identify necessary storage facilities	• Resources and equipment required to complete construction operations • Time (and worker hours) needed to complete packaging operations • Types (including activity) and volumes of wastes that must be stored	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment (USDOE-ID 2004d)	Important knowledge gaps include required storage capacity as well as the duration that wastes must be stored.
7.2 Store wastes prior to final disposal	• Durations that wastes must be stored • Monitoring required • Maintenance, repair, and replacement required	• Important • Important • Important	• Large • Small • Intermediate	Judgment	The primary knowledge gaps concern the duration that wastes must be stored and the future maintenance and repairs that will be required.
7.3 Determine performance requirements for on-site waste and soil disposal	• Types, amounts, distributions, and forms of contaminants of concern • Future environmental conditions (e.g., precipitation, evapotranspiration, etc.) • Future land-use decisions • Disposal cell site selection criteria • Regulatory and other pertinent criteria including Applicable or Relevant and Appropriate Requirements (ARARs)	• Important • Important • Important • Important • Important	• Intermediate • Large • Intermediate • Intermediate • Intermediate	• Judgment • Judgment • Judgment (USDOE-ORO 2004) • Judgment • Judgment (USDOE-ORO 2004)	Disposal cell requirements will be based upon historic and on-going project information, relevant regulations, and other considerations such as worker health. For example, there is reasonably complete information concerning what was buried in the BCBG; however, the distributions of contaminants are less well known.
7.4 Dispose of waste and soil	• Types and amounts of wastes and soil to be disposed	• Important	• Intermediate	Judgment	Disposal will be permanent; thus only the types and amounts of wastes and soils will be needed.

8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT
No change from Alternative 1B: Please refer to ***Error! Reference source not found.*** *for details*

Table 73, Continued

9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
9.1 Determine long-term monitoring, maintenance, and institutional controls (ICs)	• Future land use scenarios and population pressures • Maintenance requirements for the site • Current and future regulatory, permitting, funding, and authority issues • The incentives and procedures needed to ensure longevity of protective state • Types of institutional controls (e.g., use restrictions, notification measures, etc.) that are necessary and enforceable • Environmental monitoring needed • How will current and future risks be assessed	• Important • Important • Important • Important • Important • Important • Important	• Intermediate • Intermediate • Large • Large • Intermediate • Intermediate • Intermediate	• (USDOE-ORO 2004) • Judgment • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995) • (ELI 1995)	There is likely to be great uncertainty in how the issues of implementing legacy management for the BCBG. Some degree of flexibility should be built into the controls as conditions (e.g., due to contaminant migration) are bound to change unexpectedly in the future. There must also be consideration of public acceptance of the controls selected as well as any actions (e.g., groundwater use restrictions) that might be needed outside the Idaho Site boundary.
9.2 Implement long-term monitoring and ICs	• Efficacy of environmental monitoring and institutional controls over time • Changes in site conditions, regulations, funding, contaminant distributions, etc. • Geospatial and temporal distribution of wastes and waste forms	• Critical • Important • Critical	• Intermediate • Large • Large	• (ELI 1995) • (ELI 1995) • Judgment	The primary consideration is how to provide incentives and procedures to assure the efficacy of the monitoring and controls with changing site and regulatory conditions.
9.3 Routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for routine maintenance	• Important	• Intermediate	• Judgment	Usual and customary practices for defining the level of staffing and expertise necessary should provide reasonable estimates for this information
9.4 Non-routine maintenance, repair, and replacement	• What procedures, expertise/staffing level, funding, materials, etc. will be required for non-routine maintenance	• Important	• Large	• Judgment	It will be difficult to provide reasonable estimates for this information because of the unexpected nature of these operations.

Table 74. Gap Analysis or Retrieve, Treat, and Dispose Alternative, Targeted Retrieval Option (2B)

1. BURIAL SITE CHARACTERIZATION					
No change from Alternative 1A: Please refer to ***Error! Reference source not found.*** *for details*					
2. IN SITU GROUTING (ISG) FOR SUBSURFACE STABILIZATION					
No change from Remedial Option 1B: Please refer to ***Error! Reference source not found.*** *for details*					
TASK 3 IS NOT APPLICABLE					
4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.1 Identify retrieval methods	• Available, sufficient, and cost-effective retrieval alternative • Results of other retrieval results	• Important • Important	• Large • Intermediate	SDA as analogue[a]	There have been previous waste retrieval demonstrations in the Idaho Site SDA (Helm et al. 2003; Holdren et al. 2006; McKinley and McKinney 1978; Miller 2004; Thompson 1972; USDOE-ID 2004a; b; c; Zitnik et al. 2002). Although site conditions are different, this information can still be useful.
4.2 Determine extent of retrieval	• Geospatial distribution of wastes and waste forms • Future legal decisions and resulting actions • Future land-use decisions	• Critical • Critical • Important	• Large • Large • Intermediate	• Judgment and SDA as analogue[b] • Judgment • Judgment (USDOE-ORO 2004)	It appears that Oak Ridge has leeway in defining which areas to retrieve wastes. For example, the Walk-In Pits and other BCBG areas have already been closed by capping under RCRA.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2006).

Table 74, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
4.3 Plan and manage retrieval of buried wastes	• Resources and equipment needed to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Retrieval method to be used • Extent of retrieval needed (from 4.2)	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	• SDA as analogue[a] • SDA as analogue[a] • SDA as analogue[b] • Judgment SDA as analogue[c]	The primary gaps will be programmatic in nature.
4.4 Excavate soil overburden 4.5 Install equipment	• Extent of soil overburden to remove to uncover designated retrieval areas • Locations to install retrieval equipment	• Important • Important	• Intermediate • Intermediate	• Judgment • Judgment SDA as analogue[c]	The locations for the enclosure will be based upon a number of factors including experience, historical records, etc.
4.6 Retrieve wastes from selected area(s)	• Resources and equipment required to complete retrieval operations • Time (and worker hours) needed to complete retrieval operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[d]	The majority of the risk associated with this task is based on how long the retrieval operations will take and what kind of equipment must be used. The integrity of the waste containers will also play a major role. As indicated elsewhere, there have been numerous waste retrieval demonstrations in the Idaho Site SDA (Helm et al. 2003; Holdren et al. 2006; McKinley and McKinney 1978; Miller 2004; Thompson 1972; USDOE-ID 2004a; b; c; Zitnik et al. 2002).

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Zitnik et al. 2002).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Helm et al. 2003; USDOE-ID 2004a; c; Zitnik et al. 2002).

c For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002).

d. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (Holdren et al. 2002; USDOE-ID 2004b; c; Zitnik et al. 2002).

Table 74, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources[a]**	**Comment**
4.7 Excavate underburden (if present)	• Extent of underburden to remove • Resources and equipment required to complete excavation operations • Time (and worker hours) needed to complete excavation operations • Level to which equipment and any secondary wastes are contaminated	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment	The primary gaps will be programmatic in nature.
4.8 Segregate retrieved material into pyrophoric and remaining fractions	• Resources and equipment required to complete waste segregating operations • Time (and worker hours) needed to complete segregation operations • State of the retrieved wastes	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[a]	The risk associated with this task depends primarily on the duration of the handling and treatment tasks as well as the integrity of the waste containers upon retrieval.
4.9 Temporarily store retrieved and segregated wastes	• The quantities and forms of waste that will have to be stored • The types of waste that will have to be stored • The lengths of time that the wastes will have to be stored • Permits required for extended storage	• Important • Important • Important • Important	• Intermediate • Large • Large • Intermediate	Judgment SDA as analogue[a]	At least some of the wastes retrieved from the BCBG are unstable, explosive, or pyrophoric and must be treated before disposal. Thus the types of wastes that might be stored is reasonably well known; however, the storage duration will be dependent upon a number of factors including regulatory and site-specific.
4.10 Back-fill areas from which wastes have been retrieved	• Volume of borrow material required • Location of borrow area and distance of borrow area to BCBG • Resources and equipment needed to complete backfill operations • Time (and worker hours) needed to complete backfill operations	• Critical • Critical • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[b]	The primary gaps are the location of the borrow site and the amount of borrow material that will be needed.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (USDOE-ID 2004b; c).

b. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (USDOE-ID 2004b; c; Zitnik et al. 2002).

Table 74, Continued

4. EXCAVATE, RETRIEVE, AND SEGREGATE BURIED WASTES—CONTINUED					
Task	**What information is missing?**	**How important?**	**How large a gap?**	**Sources**[a]	**Comment**
4.11 Dismantle, test, and decontaminate retrieval equipment	• Resources and equipment required to complete dismantling operations • Time (and worker hours) needed to complete dismantling operations • Level to which equipment and secondary wastes are contaminated	• Important • Important • Important	• Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[a]	Much of the risk associated with this task is based upon how long the dismantling operation will take, to what degree the equipment has been contaminated, and what kind of equipment (e.g., cutting torches, heavy equipment, etc.) must be used.
4.12 Dispose of retrieval equipment in burial site prior to surface barrier installation	• Site/volume available for contaminated equipment/material disposal • Need for interim storage of contaminated equipment/material • Resources and equipment required to complete internment operations • Time (and worker hours) needed to complete internment operations	• Important • Important • Important • Important	• Intermediate • Intermediate • Intermediate • Intermediate	Judgment SDA as analogue[a]	A site must be identified and made available to receive the contaminated material and equipment, and interim storage may be required for the material/equipment until the site is available. Much of the risk associated with this task is based on how long the internment operation will take and what kind of equipment (e.g., cutting torches, equipment, etc.) will be required.

a. For lack of specific information, available information for the Subsurface Disposal Area (SDA) was used (USDOE-ID 2004b; c).

Table 74, Continued

5. *EX SITU* TREATMENT (E.G., CALCINING)
No change from Remedial Option 2A: Please refer to Table 73 for details
6. PACKAGE RETRIEVED WASTES AND SOIL
No change from Remedial Option 2A: Please refer to Table 73 for details
7. INTERMEDIATE STORAGE AND HANDLING OF RETRIEVED AND PACKAGED WASTES AND SOIL
No change from Remedial Option 2A: Please refer to Table 73 for details
8. SURFACE BARRIER SELECTION, PREPARATION, AND EMPLACEMENT
No change from Alternative 1B: Please refer to Table 73 for details
9. LONG-TERM STEWARDSHIP ACTIVITIES FOR THE ORIGINAL BURIAL SITE
No change from Remedial Option 2A: Please refer to Table 73 for details

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APPENDIX C

PROPERTIES OF THE MATERIALS USED IN THE GOLDSIM SCREENING RISK TOOL

Reference Fluids

There are two reference fluids (i.e., air and water) and several solid media used to model fate, transport, and exposure for the Conceptual Burial Site Model defined in Chapter V and implemented in the GoldSim Monte Carlo simulation software (GTG 2005a; b; c) as described in Chapter VI. Each of the reference fluids including properties as used in this research is defined in this appendix.

Water—Diffusivities and Solubilities

Two important contaminant-specific[200] properties are required for any reference fluid used in the GoldSim simulation model (GTG 2005a): 1) the diffusivity relative to that of a "standard" or "reference" constituent in the fluid and 2) the solubility. Tritium is selected as the reference constituent for diffusivity in water. A value of the molecular diffusivity coefficient in water for solutions is provided in Freeze and Cherry (1979) as 1.5×10^{-9} m^2/s. A range of 3×10^{-10} to 2×10^{-9} m^2/s was suggested in the generic performance assessment (PA) model by Tauxe (2004). Molecular diffusivity coefficients are also provided in the Risk Assessment Information System (RAIS)[201] for many of the organic compounds in the model. For those constituents not provided in the RAIS (i.e.,

[200] The constituents included in the model are defined in Appendix D.

[201] The Risk Assessment Information System (RAIS) is available at http://rais.ornl.gov/ (accessed March 13, 2008) (Dolislager 2006).

radionuclides[202] and elements), a single coefficient is selected from the range given in Tauxe (2004) for probabilistic simulations or the value from Freeze and Cherry (1979) is used for deterministic calculations. The values used in the model are provided in the model.

As illustrated in Chapter VII, solubility constraints can be important to the extent of migration of a contaminant in the environment surrounding a contaminated burial site. The solubilities used in this research were collected from a number of sources pertinent to the prototype sites studied when possible. From available information, the ranges of molar solubilities provided in Table 75 were defined for the inorganic constituents (including the radionuclides) for both the Idaho Site Subsurface Disposal Area (SDA) and Oak Ridge Bear Creek Burial Grounds (BCBG). The solubilities for many of the constituents can vary widely based upon site conditions; however, the available information was not adequate to distinguish inorganic constituent solubilities on a site-specific basis (or temporally based on changing subsurface conditions). The ranges are thus used to capture the possible variation in solubility for the inorganic constituents at the sites. The ranges are likely most appropriate for the SDA conditions where a much broader range of inorganic and radioactive constituents may be of concern.

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[202] The GoldSim software uses the assumption that all isotopes of an element are chemically identical on a molar basis and thus forces the relative diffusivities for all isotopes of an element to be equal (GTG 2005a).

Table 75. Molar Solubility Limits for Inorganic Constituents

	Deterministic		Minimum		Maximum	
	Sol (M)	Basis[a]	Sol (M)	Basis[a,b]	Sol (M)	Basis[a,b,c]
H	7.8E-04	(Lide 2007)	7.8E-05	Judgment	1.0E+00	(Tauxe 2004)
He	3.9E-04	(Lide 2007)	3.9E-05	Judgment	1.0E+00	Assumed
Li	5.2E+00	(Lide 2007) as LiOH (reacts)	5.2E-01	Assumed	5.2E+01	Judgment
Be	3.2E-07	(Dicke 1997)	0.0E+00	(USDOE 1994) (insoluble)	1.1E-04	(USDOE 1994)
B	0.0E+00	(Lide 2007) (insoluble)	0.0E+00	(Lide 2007) (insoluble)	9.2E-05	(USDOE 1994) (method)
C	8.9E-03	(Holdren et al. 2006)	8.9E-04	Judgment	1.0E+00	(Tauxe 2004)
N	6.6E-04	(Lide 2007) as N_2	6.6E-05	Judgment	1.0E+00	(Tauxe 2004) (method)
Ne	4.5E-04	(Lide 2007)	4.5E-05	Judgment	1.0E+00	(Tauxe 2004)
Na	4.3E-02	(USDOE 1994)	4.3E-03	Judgment	2.5E+01	(Lide 2007) as NaOH (reacts)
Mg	1.0E-03	(USDOE 1994)	0.0E+00	Assumed	1.0E-02	Judgment
P	1.1E-05	(USDOE 1994) as PO_4	1.1E-06	Judgment	8.8E-01	(Lide 2007) as Na_3PO_4
S	2.6E-04	(USDOE 1994) as SO_4	2.6E-05	Judgment	2.0E+00	(Lide 2007) as Na_2SO_4
Cl	2.8E-02	(USDOE 1994) as Chloride	2.8E-02	Judgment	1.0E+00	(Tauxe 2004)
Ar	1.4E-03	(Lide 2007)	1.4E-04	Judgment	1.0E+00	(Tauxe 2004)
K	3.1E-06	(USDOE 1994)	3.1E-06	(Tauxe 2004)	1.0E+00	(Tauxe 2004)
Ca	6.2E-04	(USDOE 1994)	6.2E-05	Judgment	2.2E-02	(Lide 2007), 20°C as $Ca(OH)_2$ (reacts)
Sc	1.0E-06	(Dicke 1997)	1.0E-07	Judgment	1.0E-05	Judgment
Ti	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	2.1E-05	(USDOE 1994) (method)
V	4.9E-04	(USDOE 1994)	4.9E-05	Judgment	4.9E-03	Judgment
Cr	1.0E-06	(Dicke 1997)	1.0E-07	Judgment	1.0E-05	Judgment
Mn	1.8E-05	(USDOE 1994)	1.8E-06	Judgment	1.8E-04	Judgment
Fe	1.8E-05	(USDOE 1994)	1.8E-06	Judgment	1.8E-04	Judgment
Co	1.0E-08	(Dicke 1997)	1.0E-09	Judgment	1.0E+00	(Tauxe 2004)
Ni	2.5E-06	(Dicke 1997)	2.5E-07	Judgment	1.0E+00	(Tauxe 2004)
Cu	3.9E-04	(USDOE 1994)	3.9E-05	Judgment	3.9E-03	Judgment
Zn	3.8E-04	(USDOE 1994)	3.8E-05	Judgment	3.8E-03	Judgment
As	1.3E-02	(USDOE 1994)	1.3E-03	Judgment	1.3E-01	Judgment
Se	1.3E-02	(USDOE 1994)	1.3E-03	Judgment	1.3E-01	Judgment
Br	1.3E-02	(USDOE 1994) (very soluble)	1.3E-03	Judgment	1.3E-01	Judgment
Kr	2.5E-03	(Lide 2007)	2.5E-04	Judgment	1.0E+00	(Tauxe 2004)
Rb	1.7E+01	(Lide 2007) as RbOH	1.7E+00	Judgment	1.7E+02	Judgment

a. All conditions are at 25°C and 1 atm unless otherwise indicated.

b. If no minimum or maximum solubility can be identified in the literature, values (based upon Judgment) of 1/10th and 10x the deterministic solubility value are used, respectively, to bracket possible solubilities.

c. If a constituent is known or assumed insoluble, the method described in the Hanford Environmental Restoration Disposal Facility (ERDF) remedial investigation/feasibility study is employed where the (maximum) solubility is assumed to be 1 mg/L (converted to moles/L) (USDOE 1994).

Table 75, Continued

	Deterministic		Minimum		Maximum	
	Sol (M)	**Basis**[a]	**Sol (M)**	**Basis**[a,b]	**Sol (M)**	**Basis**[a,b,c]
Sr	7.1E-06	(Holdren et al. 2006)	7.1E-07	Judgment	1.0E+00	(Tauxe 2004)
Y	2.0E-01	(Tauxe 2004) (for unknowns)	1.0E-01	(Tauxe 2004) (for unknowns)	1.0E+00	(Tauxe 2004) (for unknowns)
Zr	1.1E-05	(USDOE 1994)	1.1E-06	Judgment	1.1E-04	Judgment
Nb	8.5E-17	(Holdren et al. 2006)	8.5E-18	Judgment	8.5E-16	Judgment
Mo	0.0E+00	(Lide 2007) (insoluble)	0.0E+00	Judgment	1.0E-05	(USDOE 1994) (method)
Tc	1.6E-01	(Holdren et al. 2006)	1.0E-01	(Tauxe 2004)	1.0E+00	(Tauxe 2004)
Ru	9.9E-03	(USDOE 1994)	9.9E-04	Judgment	9.9E-02	Judgment
Rh	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	9.7E-06	(USDOE 1994) (method)
Pd	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	9.4E-06	(USDOE 1994) (method)
Ag	2.3E-04	(USDOE 1994)	2.3E-05	Judgment	2.3E-03	Judgment
Cd	3.2E-07	(Dicke 1997)	3.2E-08	Judgment	3.2E-06	Judgment
In	1.0E-07	(Dicke 1997)	1.0E-08	Judgment	1.0E-06	Judgment
Sn	5.5E-10	(Wood et al. 1995) as Sn(IV)	5.5E-11	Judgment	1.0E+00	(Tauxe 2004)
Sb	6.3E-05	(Dicke 1997)	6.3E-06	Judgment	6.3E-04	Judgment
Te	0.0E+00	(Lide 2007) insoluble	0.0E+00	(Lide 2007) insoluble	7.8E-06	(USDOE 1994) (method)
I	7.9E-03	(USDOE 1994), Assume very soluble	7.9E-04	Judgment	1.0E+00	(Tauxe 2004)
Xe	4.4E-03	(Lide 2007)	4.4E-04	Judgment	4.4E-02	Judgment
Cs	7.5E-03	(USDOE 1994)	7.5E-04	Judgment	1.0E+00	(Tauxe 2004)
Ba	7.3E-06	(USDOE 1994)	7.3E-07	Judgment	7.3E-05	Judgment
La	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	7.2E-06	(USDOE 1994) (method)
Ce	7.1E-03	(USDOE 1994)	7.1E-04	Judgment	7.1E-02	Judgment
Pr	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	7.1E-06	(USDOE 1994) (method)
Nd	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	6.9E-06	(USDOE 1994) (method)
Pm	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	6.9E-06	(USDOE 1994) (method)
Sm	4.9E-09	(Wood et al. 1995) as Sm(III) in GW	4.9E-10	Judgment	4.9E-08	Judgment

a. All conditions are at 25°C and 1 atm unless otherwise indicated.

b. If no minimum or maximum solubility can be identified in the literature, values (based upon Judgment) of 1/10th and 10x the deterministic solubility value are used, respectively, to bracket possible solubilities. For some unknown constituents, the method in Tauxe (2004) of bracketing the solubility between 0.1 M and 1.0 M was used.

c. If a constituent is known or assumed insoluble, the method described in the Hanford Environmental Restoration Disposal Facility (ERDF) remedial investigation/feasibility study is employed where the (maximum) solubility is assumed to be 1 mg/L (converted to moles/L) (USDOE 1994).

Table 75, Continued

	Deterministic		Minimum		Maximum	
	Sol (M)	**Basis[a]**	**Sol (M)**	**Basis[a,b]**	**Sol (M)**	**Basis[a,b,c]**
Eu	1.0E-07	(Dicke 1997)	1.0E-08	Judgment	1.0E+00	(Tauxe 2004)
Gd	1.0E-06	(Dicke 1997)	1.0E-07	Judgment	1.0E-05	Judgment
Er	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	6.0E-06	(USDOE 1994) (method)
Tm	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.9E-06	(USDOE 1994) (method)
Yb	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.8E-06	(USDOE 1994) (method)
Lu	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.7E-06	(USDOE 1994) (method)
Hf	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.6E-06	(USDOE 1994) (method)
Ta	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.5E-06	(USDOE 1994) (method)
W	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.4E-06	(USDOE 1994) (method)
Re	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.4E-06	(USDOE 1994) (method)
Os	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.3E-06	(USDOE 1994) (method)
Ir	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.2E-06	(USDOE 1994) (method)
Pt	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.1E-06	(USDOE 1994) (method)
Au	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	5.1E-06	(USDOE 1994) (method)
Hg	2.5E-04	(Dicke 1997)	2.5E-05	Judgment	2.5E-03	Judgment
Tl	4.9E-06	(USDOE 1994)	4.9E-07	Judgment	4.9E-05	Judgment
Pb	8.2E-09	(Holdren et al. 2006)	2.0E-10	(Tauxe 2004)	5.0E-06	(Tauxe 2004)
Bi	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	4.8E-06	(USDOE 1994) (method)
Po	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	4.8E-06	(USDOE 1994) (method)
At	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	4.8E-06	(USDOE 1994) (method)
Rn	9.3E-03	(Lide 2007)	9.3E-04	Judgment	1.0E+00	(Tauxe 2004)
Fr	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	4.5E-06	(USDOE 1994) (method)
Ra	4.3E-08	(Holdren et al. 2006)	9.0E-09	(Tauxe 2004)	9.0E-07	(Tauxe 2004)
Ac	9.0E-12	(Holdren et al. 2006)	9.0E-13	Judgment	4.0E-03	(Tauxe 2004)
Th	1.1E-05	(Holdren et al. 2006)	6.0E-08	(Tauxe 2004)	1.1E-04	Judgment
Pa	4.7E-03	(Holdren et al. 2006)	1.0E-05	(Tauxe 2004)	3.0E-01	(Tauxe 2004)
U	3.8E-06	(Holdren et al. 2006)	2.0E-06	(Tauxe 2004)	7.0E-03	(Tauxe 2004)
Np	4.6E-03	(Holdren et al. 2006)	1.0E-05	(Tauxe 2004)	3.0E-01	(Tauxe 2004)
Pu	2.5E-14	(Holdren et al. 2006)	2.5E-15	Judgment	5.0E-06	(Tauxe 2004)
Am	9.1E-12	(Holdren et al. 2006)	9.1E-13	Judgment	4.0E-03	(Tauxe 2004)
Cm	1.0E-07	(Dicke 1997)	1.0E-08	Judgment	1.0E-06	Judgment
Cf	0.0E+00	Assumed insoluble	0.0E+00	Assumed insoluble	4.0E-06	(USDOE 1994) (method)

a. All conditions are at 25°C and 1 atm unless otherwise indicated.

b. If no minimum or maximum solubility can be identified in the literature, values (based upon Judgment) of 1/10[th] and 10x the deterministic solubility value are used, respectively, to bracket possible solubilities.

c. If a constituent is known or assumed insoluble, the method described in the Hanford Environmental Restoration Disposal Facility (ERDF) remedial investigation/feasibility study is employed where the (maximum) solubility is assumed to be 1 mg/L (converted to moles/L) (USDOE 1994).

Unlike the inorganic constituents described in Table 75, the solubilities for many of the organic contaminants can be distinguished on a site-specific basis using available information. The molar solubilities used to model the Idaho Site SDA in the screening risk tool are provided in Table 76. In the modeling performed to support the CERCLA process for the SDA, nitrates and volatile organic compounds (VOCs) were assumed to not be solubility-limited (Becker et al. 1998; Holdren et al. 2006; Holdren et al. 2002). As illustrated in the table, the solubilities that will be used in the screening risk tool are instead primarily taken from the RAIS (Dolislager 2006). The impact of the infinite-solubility assumption is tested for the SDA as illustrated in Chapter VII and Appendix G.

The molar solubilities used to model the Oak Ridge BCBG in the screening risk tool are provided in Table 77. As illustrated in the table, the solubilities used in the screening risk tool for the BCBG are primarily taken from the CERCLA remedial investigation reports for the Bear Creek Valley (SAIC 1996a; b). Although the infinite-solubility assumption was not tested for the Bear Creek Valley in the Oak Ridge CERCLA investigations, the impact of this assumption is tested for the BCBG is illustrated in Chapter VII and Appendix G.

Table 76. Molar Solubility Limits for Organic Constituents in the SDA

	Deterministic		Minimum		Maximum	
	Sol (M)	**Basis[a]**	**Sol (M)**	**Basis[a,b]**	**Sol (M)**	**Basis[a,b]**
Acetaldehyde[c]	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)
Acetone[c]	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)
Nitrates[d]	1.6E-02	(USDOE 1994)	1.6E-03	Judgment	1.6E-01	Judgment
Ammonia	5.9E-02	(USDOE 1994)	5.9E-03	Judgment	5.9E-01	Judgment
Anthracene	4.2E-07	(USDOE 1994)	4.2E-08	Judgment	4.2E-06	Judgment
Asbestos	0.0E+00	Insoluble	0.0E+00	Judgment	0.0E+00	Judgment
Benzidine	1.7E-03	(Dolislager 2006)	1.7E-04	Judgment	1.7E-02	Judgment
Benzene	2.3E-02	(USDOE 1994)	2.3E-03	Judgment	2.3E-01	Judgment
MEK	3.1E+00	(Dolislager 2006)	3.1E-01	Judgment	3.1E+01	Judgment
Carbon Tetrachloride[d]	5.0E-03	(USDOE 1994)	5.0E-04	Judgment	5.0E-02	Judgment
Chloroethane	1.0E-01	(Dolislager 2006)	1.0E-02	Judgment	1.0E+00	Judgment
Chloromethane	1.1E-01	(Dolislager 2006)	1.1E-02	Judgment	1.1E+00	Judgment
Chloroform	7.1E-02	(USDOE 1994)	7.1E-03	Judgment	7.1E-01	Judgment
DDE	1.7E-07	(USDOE 1994)	1.7E-08	Judgment	1.7E-06	Judgment
DDT	1.6E-08	(Dolislager 2006)	1.6E-09	Judgment	1.6E-07	Judgment
Dichloroethane, 1,1-	5.1E-02	(Dolislager 2006)	5.1E-03	Judgment	5.1E-01	Judgment
Dichloroethylene, 1,1-	2.5E-02	(Dolislager 2006)	2.5E-03	Judgment	2.5E-01	Judgment
Dichloroethane, 1,2-	5.2E-02	(Dolislager 2006)	5.2E-03	Judgment	5.2E-01	Judgment
cis-Dichloroethylene, 1,2-	3.6E-02	(Dolislager 2006)	3.6E-03	Judgment	3.6E-01	Judgment
trans-Dichloroethylene, 1,2-	3.6E-02	(Dolislager 2006)	3.6E-03	Judgment	3.6E-01	Judgment
Dioxane, 1,4-[c,d]	-1.0E+00	(Dolislager 2006)	-1.0E+00	Judgment	-1.0E+00	Judgment
Ethylbenzene	1.3E-03	(USDOE 1994)	1.3E-04	Judgment	1.3E-02	Judgment
Formaldehyde	1.3E+01	(Dolislager 2006)	1.3E+00	Judgment	1.3E+02	Judgment
Hydrazine[c]	-1.0E+00	(Dolislager 2006)	-1.0E+00	Judgment	-1.0E+00	Judgment
Methanol[c]	-1.0E+00	(Dolislager 2006)	-1.0E+00	Judgment	-1.0E+00	Judgment
MIBK	1.7E-01	(USDOE 1994)	1.7E-02	Judgment	1.7E+00	Judgment
Dichloromethane[d]	2.4E-01	(USDOE 1994)	2.4E-02	Judgment	2.4E+00	Judgment
Naphthalene (and PAHs)	1.7E-04	(USDOE 1994)	1.7E-05	Judgment	1.7E-03	Judgment
PCBs	9.5E-07	(Dolislager 2006)	9.5E-08	Judgment	9.5E-06	Judgment
Phenol	8.7E-01	(USDOE 1994)	8.7E-02	Judgment	8.7E+00	Judgment
PCA	1.9E-02	(USDOE 1994)	1.9E-03	Judgment	1.9E-01	Judgment
PCE[d]	1.2E-03	(Dolislager 2006)	1.2E-04	Judgment	1.2E-02	Judgment
Toluene	5.6E-03	(USDOE 1994)	5.6E-04	Judgment	5.6E-02	Judgment
TCA	3.3E-02	(USDOE 1994)	3.3E-03	Judgment	3.3E-01	Judgment
Trichloroethane, 1,1,2-	8.2E-03	(Dolislager 2006)	8.2E-04	Judgment	8.2E-02	Judgment
TCE[d]	8.4E-03	(USDOE 1994)	8.4E-04	Judgment	8.4E-02	Judgment
Vinyl Chloride	4.3E-02	(USDOE 1994)	4.3E-03	Judgment	4.3E-01	Judgment
Xylenes	1.4E-03	(USDOE 1994)	1.4E-04	Judgment	1.4E-02	Judgment

a. All conditions are at 25°C and 1 atm unless otherwise indicated.

b. If no minimum or maximum solubility can be identified in the literature, values (based upon Judgment) of 1/10th and 10x the deterministic solubility value are used, respectively, to bracket possible solubilities.

c. If the constituent is not solubility-limited, this can be indicated in GoldSim by a solubility of -1.

d. Nitrates and VOCs were assumed not solubility-limited for SDA modeling (Holdren et al. 2006).

Table 77. Molar Solubility Limits for Inorganic Constituents in the BCBG

	Deterministic		Minimum		Maximum	
	Sol (M)	**Basis[a]**	**Sol (M)**	**Basis[a,b]**	**Sol (M)**	**Basis[a,b]**
Acetaldehyde[c]	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)
Acetone[c]	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)	-1.0E+00	(Lide 2007)
Nitrates	1.61E-02	(USDOE 1994)	1.61E-03	Judgment	1.61E-01	Judgment
Ammonia	5.87E-02	(USDOE 1994)	5.87E-03	Judgment	5.87E-01	Judgment
Anthracene	7.24E-06	(SAIC 1996a; b)	7.24E-07	Judgment	7.24E-05	Judgment
Asbestos	0.00E+00	Insoluble	0.00E+00	Judgment	0.00E+00	Judgment
Benzidine	2.17E-03	(SAIC 1996a; b)	2.17E-04	Judgment	2.17E-02	Judgment
Benzene	2.28E-02	(SAIC 1996a; b)	2.28E-03	Judgment	2.28E-01	Judgment
MEK	3.09E+00	(Dolislager 2006)	3.09E-01	Judgment	3.09E+01	Judgment
Carbon Tetrachloride	5.01E-03	(USDOE 1994)	5.01E-04	Judgment	5.01E-02	Judgment
Chloroethane	8.90E-02	(SAIC 1996a; b)	8.90E-03	Judgment	8.90E-01	Judgment
Chloromethane	1.05E-01	(Dolislager 2006)	1.05E-02	Judgment	1.05E+00	Judgment
Chloroform	7.79E-02	(SAIC 1996a; b)	7.79E-03	Judgment	7.79E-01	Judgment
DDE	1.26E-07	(SAIC 1996a; b)	1.26E-08	Judgment	1.26E-06	Judgment
DDT	8.74E-09	(SAIC 1996a; b)	8.74E-10	Judgment	8.74E-08	Judgment
Dichloroethane, 1,1-	5.56E-02	(SAIC 1996a; b)	5.56E-03	Judgment	5.56E-01	Judgment
Dichloroethylene, 1,1-	2.17E-03	(SAIC 1996a; b)	2.17E-04	Judgment	2.17E-02	Judgment
Dichloroethane, 1,2-	5.15E-02	(Dolislager 2006)	5.15E-03	Judgment	5.15E-01	Judgment
cis-Dichloroethylene, 1,2-	8.25E-03	(SAIC 1996a; b)	8.25E-04	Judgment	8.25E-02	Judgment
trans-Dichloroethylene, 1,2-	8.25E-03	(SAIC 1996a; b)	8.25E-04	Judgment	8.25E-02	Judgment
Dioxane, 1,4-[c]	-1.00E+00	(Dolislager 2006)	-1.00E+00	Judgment	-1.00E+00	Judgment
Ethylbenzene	1.43E-03	(SAIC 1996a; b)	1.43E-04	Judgment	1.43E-02	Judgment
Formaldehyde	1.33E+01	(Dolislager 2006)	1.33E+00	Judgment	1.33E+02	Judgment
Hydrazine[c]	-1.00E+00	(Dolislager 2006)	-1.00E+00	Judgment	-1.00E+00	Judgment
Methanol[c]	-1.00E+00	(Dolislager 2006)	-1.00E+00	Judgment	-1.00E+00	Judgment
MIBK	1.70E-01	(USDOE 1994)	1.70E-02	Judgment	1.70E+00	Judgment
Dichloromethane	1.97E-01	(SAIC 1996a; b)	1.97E-02	Judgment	1.97E+00	Judgment
Naphthalene (and PAHs)	2.34E-04	(SAIC 1996a; b)	2.34E-05	Judgment	2.34E-03	Judgment
PCBs	9.49E-07	(Dolislager 2006)	9.49E-08	Judgment	9.49E-06	Judgment
Phenol	8.50E-01	(SAIC 1996a; b)	8.50E-02	Judgment	8.50E+00	Judgment
PCA	1.19E-03	(SAIC 1996a; b)	1.19E-04	Judgment	1.19E-02	Judgment
PCE	9.05E-04	(SAIC 1996a; b)	9.05E-05	Judgment	9.05E-03	Judgment
Toluene	5.59E-03	(SAIC 1996a; b)	5.59E-04	Judgment	5.59E-02	Judgment
TCA	3.30E-02	(SAIC 1996a; b)	3.30E-03	Judgment	3.30E-01	Judgment
Trichloroethane, 1,1,2-	3.37E-02	(SAIC 1996a; b)	3.37E-03	Judgment	3.37E-01	Judgment
TCE	8.37E-03	(SAIC 1996a; b)	8.37E-04	Judgment	8.37E-02	Judgment
Vinyl Chloride	1.76E-05	(SAIC 1996a; b)	1.76E-06	Judgment	1.76E-04	Judgment
Xylenes	1.43E-03	(USDOE 1994)	1.43E-04	Judgment	1.43E-02	Judgment

a. All conditions are at 25°C and 1 atm unless otherwise indicated.

b. If no minimum or maximum solubility can be identified in the literature, values (based upon Judgment) of 1/10th and 10x the deterministic solubility value are used, respectively, to bracket possible solubilities.

c. If the constituent is not solubility-limited, this can be indicated in GoldSim by a solubility of -1.

Air—Diffusion Coefficients and Henry's Law Constants

Two important constituent-specific properties are required for a reference fluid in the GoldSim simulation software (GTG 2005a): 1) the "free-air" diffusivity relative to that of a "standard" or "reference" constituent in the fluid, in this case air, and 2) the solubility, or in the case of air, the Henry's Law constant will be used. A value of 1 cm^2/s was used as the reference diffusivity in air (Tauxe 2004)[203]. The free-air diffusivity is a function of temperature, and data and relationships were found for the following gases of potential interest for the screening risk model: H_2, He, CO_2, CO, H_2O (i.e., for HTO where T denotes tritium), and Ar (Marrero and Mason 1972).

When possible, the diffusivity versus temperature data from Marrero and Mason (1972) were fit to a power law (or modified power law) function. Functions were provided (or fit to available data) for the following gases (Marrero and Mason 1972)[204]:

$$D_{He-air} = 3.78 \times 10^{-5} T^{1.729} \pm 2\% \text{ for } 282K \le T(K) \le 10{,}000K$$

$$D_{H2-air} = 3.64 \times 10^{-5} T^{1.750} \pm 2\% \text{ for } 282K \le T(K) \le 10{,}000K$$

$$D_{CO2-air} = \frac{2.70 \times 10^{-5} T^{1.590}}{\exp(102.1/T)} \pm 3\% \text{ for } 280K \le T(K) \le 1{,}800K$$

$$D_{CO-air} = 9.09 \times 10^{-6} T^{1.753} \exp(25.6/T) \pm 3\% \text{ for } 282K \le T(K) \le 10{,}000K$$

$$D_{H2O-air} = 1.87 \times 10^{-6} T^{2.072} \pm 5\% \text{ for } 282K \le T(K) \le 450K$$

$$D_{Ar-air} = 9.17 \times 10^{-6} T^{1.749} \pm 3\% \text{ for } 282K \le T(K) \le 10{,}000K$$

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[203] The value selected for the reference diffusivity in air is "moot" because of the manner in which the diffusivities are defined for use in a GoldSim model (Tauxe 2004).

[204] No power law functions were provided for the CO-air and Ar-air systems in Marrero and Mason (1972) so the data were fit to the modified power law functions shown. Furthermore, the available data were refit for the systems considered potentially relevant for the screening risk tool and all resulting models possessed adjuste R^2 values very close to unity.

The diffusion coefficient expressions were grouped by uncertainty and temperature as indicated above (Marrero and Mason 1972). The relative uncertainties provided were interpreted as $\pm 2\sigma$ limits, and the corresponding diffusion coefficients were sampled from log-normal distributions using these relative standard deviations.

For those gaseous constituents not described in Marrero and Mason (1972), the method in Reid and Sherwood (1966) based on the Lennard-Jones relationship is used to estimate diffusion coefficients for binary gas systems (i.e., non-polar molecules) at low pressures. The diffusion coefficient expression from Reid and Sherwood (1966) is[205]

$$D_{12} = 0.001858T^{1.5} \frac{\sqrt{(M_1 + M_2)/M_1 M_2}}{P\sigma_{12}^2 \Omega_D(T)} \qquad [32]$$

where T is the temperature (K), M_1 and M_2 are the molecular weights, P is the pressure (atm), σ_{12} is the Lennard-Jones force constant (angstroms), and Ω_D is the collision potential. The σ_{12} and Ω_D parameters are estimated from tabulated force constants for the pure gases (and temperature in the case of the collision integral, Ω_D) and *combining rules* (Reid and Sherwood 1966). Tabulated coefficients are available for the following constituents of potential concern: Ar, He, Kr, Ne, Xe, carbon tetrachloride, chloroform, methylene chloride, methanol, n-hexane, CO, CO_2, ethyl chloride, acetone, ammonia, benzene, mercury, and water. No uncertainty information was provided with predictions from Equation 32 (Reid and Sherwood 1966). For lack of better information, the maximum uncertainty of ±10% from the predictions in Marrero and Mason (1972) in the same temperature range was used for predictions from Equation 32.

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[205] The expression from which Equation 32 was derived included a second-order correction factor, f_d, that usually varied between 1.00 and 1.03 (Reid and Sherwood 1966). This factor was instead included in the definition as a stochastic factor sampled from a uniform distribution ranging from 1.00 to 1.03.

The diffusion coefficients obtained from the above relationships are functions of the soil temperature, which was assumed to vary normally about a mean of 15°C with a standard deviation of 1°C (Tauxe 2004). However, the above expressions were tested and the results indicated that the predicted diffusion coefficients are not highly sensitive to the variation in soil temperature for ranges of temperature expected for the prototype sites[206]. Therefore, the fact that diffusivity versus temperature relationships are not available for all gaseous constituents was not considered problematic for the screening risk model.

For those constituents not included in the above sources, other sources provide basic properties for the constituents of potential concern for the prototype sites. One excellent source that has links to other reference sources and databases can be located at the Pennsylvania Department of Environmental Protection home page (BLRWM 2007). The ranges of diffusion coefficients (and Henry's Law constants for convenience) from this source are provided in Table 78 and supplemental with the information provided from the SDA (Holdren et al. 2006) or Bear Creek Valley remedial investigation (SAIC 1996a; b). For the screening risk tool, coefficients are sampled from triangular distributions from the ranges provided with default best values from the Risk Assessment Information System (RAIS) (Dolislager 2006) supplemented with site-specific values as indicated.

[206] A variation of 5°C in mean soil temperature resulted in a maximum variation of just over 3% for the predicted diffusion coefficients using the expressions from (Marrero and Mason 1972). The results based on Equation 32 from Reid and Sherwood (1966) show less variation.

Table 78. Relevant Property Data for Selected Constituents of Potential Concern

	Diffusion coefficient, cm^2/s				**Henry's law constant, M/atm**			
	Min[a]	**Max[a]**	**RAIS[b]**	**BCBG[c]**	**Min[a]**	**Max[a]**	**RAIS[b]**	**BCBG[c]**
Mercury, Hg	3.07E-02	1.12E-01	3.07E-02	---	8.77E-02	1.41E+06	8.77E-02	---
Acetaldehyde	1.24E-01	1.42E-01	1.24E-01	---	1.14E+01	1.50E+01	1.50E+01	---
Acetone	1.09E-01	1.24E-01	1.24E-01	1.10E-01	2.58E+01	1.47E+02	2.52E+01	1.95E+03
Nitrates	---	---	---	---	---	---	---	---
Ammonia	0.00E+00	1.00E-20	0.00E+00	---	3.12E+00	6.21E+01	6.21E+01	---
Anthracene	3.24E-02	4.21E-02	3.24E-02	4.20E-02	8.00E-01	5.18E+01	1.80E+01	1.16E+01
Asbestos	---	---	---	---	---	---	---	---
Benzidine	2.98E-02	3.40E-02	3.40E-02	3.00E-03	3.33E+03	2.20E+08	1.42E+07	1.43E+05
Benzene	7.70E-02	9.32E-02	8.80E-02	9.30E-02	1.80E-01	1.89E-01	1.80E-01	1.80E-01
MEK	8.08E-02	8.95E-02	8.08E-02	---	7.69E+00	9.52E+01	1.75E+01	---
Carbon Tetrachloride	7.80E-02	8.28E-02	8.30E-02	*7.80E-02*	3.28E-02	3.39E-01	5.45E-02	*3.62E-02*
Chloroethane	1.04E-01	2.71E-01	2.71E-01	1.07E-01	6.76E-03	1.18E-01	9.00E-02	9.01E-02
Chloromethane	1.09E-01	1.26E-01	1.26E-01	---	2.63E-03	1.13E-01	1.13E-01	---
Chloroform	8.88E-02	1.04E-01	1.04E-01	9.10E-02	2.08E-01	3.47E-01	2.73E-01	2.95E-01
DDE	1.15E-02	1.73E-02	1.44E-02	4.10E-02	8.20E-01	9.90E+01	2.40E+01	1.75E+03
DDT	1.10E-02	1.64E-02	1.37E-02	3.90E-02	1.08E+01	1.23E+02	1.20E+02	2.57E+01
Dichloroethane, 1,1-	7.42E-02	9.19E-02	7.42E-02	9.10E-02	2.42E-02	2.35E-01	1.78E-01	1.84E-01
Dichloroethylene, 1,1-	9.00E-02	1.14E-01	9.00E-02	1.14E-01	5.26E-03	6.67E-02	3.82E-02	6.71E-02
Dichloroethane, 1,2-	8.32E-02	1.25E-01	1.04E-01	---	7.09E-01	1.09E+00	8.48E-01	---
cis-Dichloroethylene, 1,2-	5.89E-02	8.83E-02	7.36E-02	1.14E-01	2.77E-02	2.97E-01	2.45E-01	1.52E-01
trans-Dichloroethylene, 1,2-	7.07E-02	1.14E-01	7.07E-02	1.14E-01	1.49E-02	1.52E-01	1.07E-01	1.52E-01
Dioxane, 1,4-	1.83E-01	2.75E-01	2.29E-01	*2.29E-01*	9.09E+01	1.40E+03	1.95E+02	*2.09E+02*
Ethylbenzene	6.58E-02	7.50E-02	7.50E-02	7.50E-02	1.14E-01	1.52E-01	1.27E-01	1.55E-01
Formaldehyde	1.73E-01	1.78E-01	1.78E-01	---	1.96E+00	5.99E+03	2.96E+03	---
Hydrazine	3.33E-01	5.00E-01	4.16E-01	---	1.64E+03	5.78E+05	4.90E+04	---
Methanol	1.32E-01	1.50E-01	1.50E-01	1.57E-01	5.88E+00	9.09E+02	2.20E+02	2.15E+02
MIBK	6.00E-02	9.00E-02	7.50E-02	---	2.56E+00	1.06E+01	7.25E+00	---
Dichloromethane	1.01E-01	1.04E-01	1.01E-01	1.04E-01	3.13E-01	4.93E-01	7.05E-01	3.14E-01
Naphthalene (and PAHs)	5.13E-02	5.90E-02	5.90E-02	5.90E-02	8.70E-01	2.36E+00	2.27E+00	2.07E+00
PCBs	1.40E-02	2.10E-02	1.75E-02	4.90E-02	3.85E-01	5.00E+00	2.92E+00	2.27E+00
Phenol	5.13E-02	5.90E-02	5.90E-02	8.70E-02	7.69E+02	3.00E+03	3.01E+03	7.68E+02
PCA	5.68E-02	8.52E-02	7.10E-02	7.30E-02	2.00E+00	3.85E+00	2.73E+00	9.09E-02
PCE	5.76E-02	8.64E-02	7.20E-02	7.70E-02	3.48E-02	1.20E-01	9.25E-02	3.48E-02
Toluene	8.49E-02	8.80E-02	8.70E-02	8.70E-02	1.49E-01	1.68E-01	1.51E-01	1.69E-01
TCA	7.80E-02	7.94E-02	7.80E-02	1.90E-02	3.33E-02	2.03E-01	5.81E-02	2.45E-01
Trichloroethane, 1,1,2-	6.24E-02	9.36E-02	7.80E-02	7.90E-02	8.33E-01	1.35E+00	1.21E+00	3.40E+01
TCE	7.90E-02	8.75E-02	7.90E-02	8.80E-02	1.63E-02	1.12E-01	1.01E-01	8.54E-02
Vinyl Chloride	1.06E-01	1.23E-01	1.06E-01	1.06E-01	1.23E-02	9.35E-02	3.59E-02	3.60E-02
Xylenes	7.14E-02	7.22E-02	7.14E-02	---	1.43E-01	1.96E-01	1.51E-01	---

a. The minima and maxima obtained from the Pennsylvania Department of Environmental Protection home page (BLRWM 2007). When a single value is given, the range is defined as (0.8×value, 1.2×value) to reasonably span a ±10% uncertainty. Ranges are adjusted in GoldSim to cover site-specific values.

b. The most likely values were obtained from the Risk Assessment Information Systems (RAIS) (Dolislager 2006) supplemented by the values from the SDA remedial investigation (Holdren et al. 2006) for carbon tetrachloride, tetrachloroethylene (PCA), methylene chloride (dichloromethane), and 1,4-dioxane.

c. The values for carbon tetrachloride and 1,4-dioxane (in italics) are from the RAIS (Dolislager 2006) and those missing (indicated by '---') will use the default RAIS values.

As illustrated in this appendix, different diffusion coefficients may be available for the same constituent based on the source of information[207]. Two examples will be used to illustrate this point. For example, the free diffusion coefficient expected for the water-air system from the sources cited in this appendix (Marrero and Mason 1972; Reid and Sherwood 1966) are 0.233 cm^2/s and 0.201 cm^2/s at a soil temperature of 15°C. For carbon tetrachloride, the value computed from Equation 32 is 0.071 cm^2/s (at 15°C), which falls outside the range (i.e., 0.078-0.083 cm^2/s) suggested in Table 78. Because there is no clear indication of which value would be preferable, the logic in assigning a free-air diffusion coefficient is as follows:

- The coefficient estimated from the information in Table 78 is given preference because it based on the most comprehensive source information and includes the available site-specific data,
- Because there is no clear basis for decision, the maximum of the sampled coefficients using the methods provided in Marrero and Masson (1972) and Reid and Sherwood (1966) is used.

For gaseous constituents of potential concern, partitioning between the aqueous and gas phases is estimated using Henry's Law constants (GTG 2005a). The constants used in this research were collected from a number of sources pertinent to the prototype sites studied whenever possible. Ranges of Henry's Law constants were previously provided in Table 78 (BLRWM 2007). Additional constants are provided in Table 79 from an excellent compilation of data for constituents of concern for environmental applications (NIST 2005; Sander 1999).

[207] For one important constituent, radon, a single value for the free-air diffusion coefficient, i.e., 0.11 cm^2/s, was found in the literature (Rogers and Nielson 1991). It is assumed that a ±10% uncertainty can be applied to this value for random sampling purposes.

Table 79. Henry's Law Constants (M/atm) for Constituents of Potential Concern[a]

Constituent	Minimum	Maximum	Constituent	Minimum	Maximum
CO_2	3.13E-02	4.55E-02	DDT	1.92E+01	2.83E+01
CO	8.28E-04	7.48E-03	Chloroform	1.52E-01	9.09E-01
Rn[b]	7.52E-03	1.13E-02	1,1-DCA	1.31E-01	2.02E-01
He	3.74E-04	3.84E-04	1,1-DCE	5.25E-03	6.57E-02
Ar[b]	1.13E-03	1.70E-03	1,2-DCA	6.47E-01	1.11E+00
N_2	6.06E-04	6.57E-04	*cis*-1,2-DCE	1.31E-01	3.03E-01
Ne[b]	3.64E-04	5.46E-04	*trans*-1,2-DCE	7.07E-02	1.92E-01
SO_2	1.11E+00	1.52E+00	1,4-dioxane	1.41E+02	2.22E+02
Kr	2.42E-03	2.53E-03	Ethylbenzene	1.11E-01	1.72E-01
HCl	1.11E+00	2.02E+06	Formaldehyde	3.03E+03	1.41E+04
HBr	7.27E-01	1.31E+09	Methanol	1.41E+02	2.32E+02
HI	2.22E+09	2.53E+09	Methyl isobutyl ketone	2.22E+00	5.25E+00
Xe[b]	3.48E-03	5.21E-03	Methylene chloride	3.13E-01	1.21E+00
Hg[b]	7.44E-02	1.12E-01	Naphthalene	8.08E-01	2.42E+00
Acetaldehyde	1.72E+00	1.72E+01	Phenol	7.88E-02	3.03E+03
Acetone	3.03E+00	3.54E+01	PCA	1.82E+00	3.03E+00
Ammonia	1.01E+01	7.88E+01	PCE	3.43E-02	1.21E-01
Anthracene	1.41E+00	5.66E+01	Toluene	1.31E-01	2.12E-01
Benzene	1.21E-01	2.22E-01	TCA	2.73E-02	2.22E-01
Methyl ethyl ketone	4.14E+00	2.12E+01	1,1,2-TCA	8.49E-01	1.31E+00
Carbon Tetrachloride	2.83E-02	5.15E-02	TCE	7.48E-02	2.42E-01
Ethyl chloride	6.87E-02	5.15E-01	Vinyl chloride	8.28E-04	4.65E-02
Methyl chloride	2.93E-02	1.31E-01	Xylenes	1.21E-01	2.93E-01

a. The minima and maxima obtained from the NIST Chemistry WebBook (NIST 2005; Sander 1999).

b. When a single value is given, the range is defined as (0.8×value, 1.2×value) to reasonably span a ±10% uncertainty. Ranges are adjusted in GoldSim to cover site-specific values.

A number of assumptions are used to define Henry's Law constants for use in the screening risk model. Because there is no obvious way to select one set of constants over another, the possible range of constants for each constituent is defined as the total range over all values for triangular distributions. For the constituents with specific values from remedial investigations, the most likely values are those used in the investigations as illustrated in Table 78. For those constituents without site-specific values, the values from the Oak Ridge RAIS were used (Dolislager 2006). However, no values were provided in the RAIS for the non-organic constituents (e.g., as illustrated in Table 79)[208]; for these constituents, the median values from the NIST Chemistry WebBook (NIST 2005; Sander 1999) were assumed to be the most likely.

Henry's Law constants are used to describe the solubility of gases in water under low concentration conditions and are often available in numerous different sets of units. The basic Henry's Law constant needed for use in the GoldSim model is denoted, K_H, as defined by:

$$K_H \equiv \frac{c_a}{p_g} \quad [33]$$

where c_a is the concentration in the aqueous phase and p_g is the partial pressure in the gas phase (Sander 1999). However, the Henry's Law constants, $K^{cc}_{H,inv}$, in many of the original references were generally provided in units of M/atm. These constants can be converted to the desired units using the following expression (Sander 1999; Tauxe 2004)

$$K_H = \frac{1}{R \times T \times K^{cc}_{H,inv}} \quad [34]$$

Because these are inverse constants, the minima and maxima in Table 78 and Table 79 are interchanged (and the lower quantile value instead of the upper quantile values is selected for the deterministic case).

[208] Tritium can move through the vapor phase. It is assumed that tritium will move as water vapor moves through the system. The Henry's Law constant, K_H, for water can be estimated as $K_H = C_{air}/C_{water} = C_{pore}/\rho_{water}$ where $C_{pore} = P_{water}M_{water}/(RT)$ is the concentration of water vapor in the pore space as a function of temperature, T (and P_{water} is the vapor pressure and M_{water} the molecular weight of water) (Tauxe 2004).

Solid, Porous, and Special Media

Apart from the fluid media (i.e., water and air), a number of solid media play critical roles in the transport and potential exposure of receptors to buried wastes. These media are modeled in the screening risk model using the GoldSim *Solid* element, which requires definition of the following key properties: bulk density, porosity, tortuosity, and solid-liquid partition coefficients for each chemical in the model. For screening purposes[209], partition coefficients, which via a lumped constant (i.e., often referred to as a "K_d") represent the degree to which the chemical adsorbs to the solid phase, are used as the default retention parameter (Sheppard and Thibault 1990) despite the limited applicability of the underlying sorption model to actual environmental conditions (Bethke and Brady 2000; Brady and Bethke 2000). It is assumed that handling partitioning either by using a worst-case K_d for deterministic calculations or a K_d distribution with large uncertainty for stochastic analyses overcomes the use of a sorption model that may be of questionable utility for the spatial and temporal conditions considered in the model.

Generic Solid Media: Sand, Loam, Clay, and Organic Soil

The first four solid media represent major soil types (i.e., sand, loam, clay, and organic soil) whose partition coefficients are taken from one of the definitive compilations of partition coefficients (Sheppard and Thibault 1990). The geometric means and standard deviations for the partition coefficients by soil type are provided in Table 80. Site-specific values will be used when available.

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[209] For the screening analysis, detailed, site-specific information including spatial and temporal variations in soil pH, porewater composition, organic matter content, etc.) as well as the reaction kinetics for each element (Sheppard and Thibault 1990) is unavailable.

Table 80. Summary of K_d values (L kg^{-1}) by soil type (Sheppard and Thibault 1990)

	Sand		Loam		Clay		Organic Soil	
Element	**GMean[a]**	**GSD[b]**	**GMean[a]**	**GSD[b]**	**GMean[a]**	**GSD[b]**	**GMean[a]**	**GSD[b]**
Ac	450	---	1500	---	2400	---	5400	---
Ag	90	1.8	120	1.1	180	*0.4*	15000	*0.9*
Am	1900	2.6	9600	1.4	8400	2.6	112000	1.7
Be	250	---	800	---	1300	---	3000	---
Bi	100	---	450	---	600	---	1500	---
Br	15	---	50	---	75	---	180	---
C	5	*0.8*	20	---	1	---	70	---
Ca	5	---	30	---	50	---	90	---
Cd	80	1.5	40	1.6	560	*0.9*	800	2.3
Ce	500	1.6	8100	1.5	20000	*0.5*	3300	---
Cm	4000	2.4	18000	*0.7*	6000	---	6000	---
Co	60	2.8	1300	1.3	550	1.8	1000	1.5
Cr	70	2.1	30	2.9	1500	---	270	2.7
Cs	280	2.5	4600	1.3	1900	1.6	270	3.6
Fe	220	2.6	800	*0.7*	165	1.6	600	---
Hf	450	---	1500	---	2400	---	5400	---
Ho	250	---	800	---	1300	---	3000	---
I	1	2.2	5	2.0	1	1.5	25	2.0
K	15	---	55	---	75	---	200	---
Mn	50	1.4	750	2.6	180	2.0	150	---
Mo	10	1.1	125	---	90	1.2	25	*0.5*
Nb	160	---	550	---	900	---	2000	---
Ni	400	1.5	300	---	650	*0.7*	1100	*0.9*
Np	5	1.7	25	2.4	55	3.8	1200	*0.4*
P	5	---	25	---	35	---	90	---
Pa	550	---	1800	---	2700	---	6600	---
Pb	270	2.3	16000	1.4	550	---	22000	*0.5*
Pd	55	---	180	---	270	---	670	---
Po	150	1.6	400	1.3	3000	---	7300	---
Pu	550	1.7	1200	1.2	5100	2.1	1900	2.6
Ra	500	3.2	36000	3.1	9100	1.3	2400	---
Rb	55	---	180	---	270	---	670	---
Re	10	---	40	---	60	---	150	---
Ru	55	1.4	1000	---	800	---	56000	*0.3*
Sb	45	---	150	---	250	---	550	---
Se	150	*0.4*	500	---	740	*0.5*	1800	*0.5*
Si	35	---	110	---	180	---	400	---
Sm	245	---	800	---	1300	---	3000	---
Sn	130	---	450	---	670	---	1600	---
Sr	15	1.6	20	1.7	110	2.0	150	1.8
Ta	220	---	900	---	1200	---	3300	---
Tc	0.1	1.8	0.1	1.1	1	*0.1*	1	1.8
Te	125	---	500	---	720	---	1900	---
Th	3200	2.1	3300	---	5800	2.6	89000	4.6
U	35	3.2	15	3.3	1600	2.9	410	2.5
Y	170	---	720	---	1000	---	2600	---
Zn	200	2.6	1300	2.4	2400	1.4	1600	1.6
Zr	600	---	2200	---	3300	---	7300	---
Mean	---	1.9	---	1.8	---	1.6	---	1.7

a. Mean of the natural logarithms of the observed values.

b. Standard deviation of the natural logarithms of the observed values. *Stochastic* elements have a constraint that the geometric standard deviation (GSD) is 1.0001 or greater. An element with GSD less than 1.0001 (in *italics*) is assigned a GSD of 1.0001. A GSD of 2 will be used for those without values.

Other properties of the solid medium are important to predicting the impact of the medium on the fate and transport of contaminants through the system. Three inter-related properties are the particle density, dry bulk density, and porosity of the medium. For example, the Superfund Exposure Assessment Manual (SEAM) indicates that typical values of the particle and dry bulk densities for most mineral materials is 2.65 g/cm^3 and 1-2 g/cm^3, respectively (USEPA 1988). Instead of using these default values, soil data from the UNSODA database (Leij et al. 1996; USEPA 1999) were analyzed to develop specific distributions for the major soil types considered in this research. Because no specific values are provided for soil, the loam results are used for organic soil as well. The results are provided in Table 81.

Table 81. Soil Properties and Distributions from the Data in the UNSODA Database (Leij et al. 1996; USEPA 1999)

	Soil Property	Bulk density, g/cm^3	Particle density, g/cm^3	Porosity, dim'less
Sand	**Bulk density, g/cm^3**	N(1.58, 0.140)[a]	0.450 (0.480)[b]	-0.795
	Particle density, g/cm^3		N(2.66, 0.055)	-0.217
	Porosity, dim'less			N(0.402, 0.056)
Loam	**Bulk density, g/cm^3**	W(1.42, 5.20)	0.797 (0.738)	-0.985
	Particle density, g/cm^3		W(2.64, 30.2)	-0.741
	Porosity, dim'less			LN(-0.634, 0.215)
Clay	**Bulk density, g/cm^3**	N(1.27, 0.203)	0.251 (0.0761)	-0.972
	Particle density, g/cm^3		W2(2.29, 8.609, 0.394)	-0.020
	Porosity, dim'less			LN(-0.730, 0.192)

a. The diagonal elements describe the distributions for the properties. The distributions used are: *Normal* N(mean, standard deviation), *Weibull* W(shape, scale) or W2(minimum, shape, scale), and *Log-Normal* LN(geometric mean, geometric standard deviation).

b. The off-diagonal elements provide the correlations between the property estimates. The two values in the particle density column represent the correlation when all three parameters are available and the correlation in parentheses is that for just the available bulk and particle density values.

Important Parameters: Porosity, Moisture Content, and Tortuosity

Typically, an overall porosity (or one calibrated to flow conditions) is provided for the porous media representing the subsurface conditions for a site. In the performance assessment model developed by Tauxe (2004) that was used as the basis for the screening risk tool, it was indicated that porosity is not easily measured in soils, and thus this important parameter is better calculated from bulk and particle density information, if available. The relationship between the densities and porosity, η, is (Tauxe 2004):

$$\eta = 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{particle}}} \qquad [35]$$

With the porosity of the solid medium, the moisture content and tortuosities are parameters needed to describe fate and transport. Unlike the other soil parameters described thus far, the moisture content is site-specific. A mean and standard deviation of 12% and 4%, respectively, was determined for the Idaho Site Subsurface Disposal Area (SDA) (Varvel and Sondrup 2001). For the Oak Ridge Bear Creek Burial Grounds (BCBG), a value of 22.35% was indicated (SAIC 1996b). Without better information, the same *relative* standard deviation (of 4%) was used to describe both sites. Moisture content is assumed to be lognormally distributed using these site-specific parameters.

Tortuosities in the screening risk model are computed for the gas phase[210]. For the gas phase, the tortuosity, τ, can be predicted from the following simple relationship (Jin and Jury 1996; Millington and Quirk 1961; Tauxe 2004)

[210] It is assumed that advection in the aqueous phase dominates contaminant transport and thus the water phase tortuosities are currently computed but not used in the screening risk model. The basis for computing these parameters is described in the screening risk model.

$$\tau = \frac{\theta_a}{\eta^{2/3}} . \qquad [36]$$

where η is the porosity and θ_a the air content of the soil. The air content is related to the porosity and moisture content of the soil; these quantities are estimated stochastically in the screening model.

Site-Specific Solid Media: Idaho Basalt, Idaho Interbed, and Oak Ridge Loam

In addition to those solid media described in the previous section, site-specific media were defined during the remedial investigations and other studies of the Idaho Site Subsurface Disposal Area (SDA) (Becker et al. 1998; Dicke 1997; Holdren et al. 2006; Holdren et al. 2002; Holdren and Broomfield 2004) and Oak Ridge Bear Creek Valley (Buck et al. 1997; SAIC 1993; 1996b) prototype sites. For the SDA, partition coefficients are needed for both the fractured basalt and sedimentary interbeds. Site-specific values are used for these regions to the extent possible. For the Bear Creek Burial Grounds (BCBG), the textures (i.e., organic soil, loam, and clay) for the subsurface assumed by Buck et al. (1997) were used to determine the proper partition and other coefficients.

Idaho Site Basalt

In the most recent remedial investigation report (Holdren et al. 2006), the partition coefficients for the fractured basalt zones are assumed to be zero, that is, no contaminants sorb on the basalt. In the screening model, this assumption is tested for both prototype sites as illustrated in Chapter VII and Appendix G. Available partition coefficients for basalt are used in the screening risk model to add accuracy to the model[211]. The available coefficients for basalt are provided in Table 82. For those constituents with coefficients available, uniform distributions are used because the ranges of coefficients provided in Table 82 were developed from multiple sources and the "best" value was primarily chosen to be conservative (i.e., low sorption). For those constituents without available coefficients, a value of zero is assumed in the screening risk model.

The estimates of bulk and particle density and porosity will be handled differently for site-specific materials than for the general soil types defined in the previous section. Because the particle density for a soil is easier to measure and likely varies less that the related parameters (e.g., porosity, etc.), a particle density for the basalt is assumed to vary between 2.40 and 3.1 g/cm^3 (Lide 2007) with a most likely value of 2.65 g/cm^3 used for most mineral phases without detailed information available (Freeze and Cherry 1979; USEPA 1988; Yu et al. 1993). Because the porosity of the subsurface regions have been "calibrated" to flow and transport in the subsurface, this parameter will be used to better capture the overall nature of the subsurface regions. Nimmo et al. (2004) indicate that estimates of the effective porosity for the SDA basalt range between 0.05 and 0.25. A most likely porosity value of 0.05 is selected based on SDA calibration results (Magnuson 1995; Magnuson and Sondrup 2006).

[211] The application of partition coefficients is as described except for the case of colloidal transport as described at the end of this appendix.

Table 82. Partition Coefficient (K_d) Estimates for INEEL Materials

	Sediments, K_d (mL/g)			Basalt, K_d (mL/g)		
Element	**Best**[a]	**Best**[b]	**Range**[b]	**Best**[a]	**Best**[b]	**Range**[b]
Ac	225	400	400 - 1000	0	70	70 - 280
Am	225	450	450 - 1100	0	70	70 - 280
Be	---	250	250 - 800	0	12	12 - 40
C	0.4	5	2 - 20	0	0	---
Cd	---	40	7.0 - 962	0	2	0.35 - 48
Cl	0	0	---	0	0	---
Cm	---	400	400 - 1000	0	70	70 - 280
Co	---	1000	50 - 4000	0	11	11 - 54
Cr	---	30	2.2 - 1000	0	1.5	0.11 - 50
Cr(VI)	0.1	0.1	0.1 - 10	0	0	---
Cs	---	1000	589 - 3255	0	39	39 - 44
Eu	---	400	400 - 1000	0	70	70 - 280
Gd	---	400	400 - 1000	0	70	70 - 280
H	---	0	---	0	0	---
Hg	---	176	72 - 1912	0	9.2	9.2 - 87
I	0	0.1	0.02 - 5	0	0	---
Na	---	0	---	0	0	---
Nb	500	500	100 - 1000	0	8	1.3 - 51
Ni	---	300	60 - 2000	0	10	5 - 54
NO_3	0	0	---	0	0	---
Np	23	8	1 - 80	0	8	1.3 - 51
Pa	8	8	1 - 80	0	8	1.3 - 51
Pb	270	270	30 - 1000	0	10	5 - 50
Pu[c]	2500	5100	5100 - 22000	0	100	70 - 130
Ra	575	575	88 - 1890	0	127	127 - 186
Sb	---	7	0.5 - 45	0	0.35	0.025 - 2
Sr	60	60	35 - 186	0	6	1 - 13
Tc	0	0	---	0	0	---
Th	500	500	200 - 3000	0	100	70 - 130
U	15.4	6	3.4 - 9	0	3	0.2 - 5.2
Carbon tetrachloride	0.22	---	---	0	---	---
1,4-Dioxane	6.15E-04	---	---	0	---	---
Dichloromethane (Methylene chloride)	4.40E-03	---	---	0	---	---
Tetrachloroethylene (PCE)	0.182	---	---	0	---	---

a. These partition coefficient estimates taken from the most recent SDA remedial investigation report (Holdren et al. 2006). The estimates for the basalt are assumed identically zero.

b. These partition coefficient estimates were taken from Dicke (1997) and include non-zero estimates for basalt. The "best" K_d value from this report was replaced with the lower quantile (e.g., 5%) value from the uniform distribution with the range provided for consistency in deterministic calculations.

Idaho Site Interbed Material

The interbed media is used to represent the sedimentary interbeds interspersed between the Idaho Site Subsurface Disposal Area (SDA) and the Snake River Plain Aquifer below. Various sets of sediment-water partition coefficients have been defined for the sedimentary interbeds during the SDA remedial investigation (Becker et al. 1998; Dicke 1997; Holdren et al. 2006; Holdren et al. 2002; Holdren and Broomfield 2004). Two of the more definitive sets were provided in Table 82, and these coefficients are used as the basis for predicting the impact of partitioning in the interbed regions. The ranges provided by Dicke (1997) were altered, when needed, to span those values used in the most recent SDA remedial investigation report (Holdren et al. 2006) and a uniform distribution is used for sampling[212]. If a constituent (e.g., carbon tetrachloride) was not described in Dicke (1997), a log-normal distribution is used, centered (geometrically) at the value from Holdren et al. (2006) with a default geometric standard deviation of 2 as was used for the original four major soil types considered.

The other parameters (e.g., particle density, porosity, etc.) needed to define transport through the interbed regions were not sufficiently captured by those for loam (in the previous section) and thus site-specific distributions were added to the model. Log-normal distributions were defined for the particle size, LN(2.63 g/cm^3, 0.08 g/cm^3), and bulk density, LN(1.44 g/cm^3, 0.20 g/cm^3), according to information in Winfield (2005). The resulting porosity estimates span those provided in the most recent SDA remedial investigation (Holdren et al. 2006). The saturated moisture content in the interbed region may also be different than that for the fractured basalt regions. A normal distribution,

[212] Because valence state is not considered in the screening risk model, the range for Cr(VI), which is hazardous, is used for chromium.

N(0.52, 0.081), was used to describe the moisture content in the interbed region (Winfield 2005).

Oak Ridge Loam

Partition coefficients and other important parameters (e.g., particle density, dry bulk density, etc.) were provided above for the general loam soil texture. However, specific partition coefficients were provided for the subsurface regions in the Bear Creek Valley in the CERCLA remedial investigation report (SAIC 1996b). These coefficients either replace or supplement those previously provided for loam in Table 80 (Sheppard and Thibault 1990). The soil-water partitions in the Bear Creek Valley remedial investigation report were provided primarily in the form of ranges. When only a single value is provided (e.g., boron, lithium, etc.), a log-normal distribution will be assumed centered (geometrically) at the given value with the geometric standard deviation from Table 80. When a range of values from Sheppard and Thibault (1990) is provided in the remedial investigation report (SAIC 1996b), the range appears to represent those for the loam category. Instead of using the stated range for these constituents, the pertinent loam distribution from Table 80 is used. Otherwise the range is used as indicated. If no new value or range is given, then the distribution for loam suggested in Table 80 is used as a default. The resulting partition coefficient information is provided in Table 83. The other important properties (e.g., particle density, porosity, etc.) are the same as those for the general loam soil category.

Table 83. Partition Coefficient (K_d) Estimates for Oak Ridge Loam Soil

Element	Range or GMean[a]	GSD[b]	Reference(s)
Ac	1500	---	(Sheppard and Thibault 1990)
Ag	120	1.4	(SAIC 1996b; Sheppard and Thibault 1990)
Am	9600	1.4	(SAIC 1996b; Sheppard and Thibault 1990)
As	3-200	---	(Baes et al. 1984; SAIC 1996b)
B	3	---	(Baes et al. 1984; SAIC 1996b)
Ba	50-60	---	(Baes et al. 1984; SAIC 1996b)
Be	800	---	(SAIC 1996b; Sheppard and Thibault 1990)
Bi	450	---	(Sheppard and Thibault 1990)
Br	50	---	(Sheppard and Thibault 1990)
C	20	---	(Sheppard and Thibault 1990)
Ca	30	---	(Sheppard and Thibault 1990)
Cd	2.9-57.6	---	(SAIC 1996b)
Ce	8100	1.5	(Sheppard and Thibault 1990)
Cm	18000	*0.7*	(Sheppard and Thibault 1990)
Co	1300	1.3	(SAIC 1996b; Sheppard and Thibault 1990)
Cr	30	2.9	(SAIC 1996b; Sheppard and Thibault 1990)
Cs	93.9-10000	---	(Meyer et al. 1987; SAIC 1996b)
Cu	20-100	---	(SAIC 1996b)
Fe	800	*0.7*	(Sheppard and Thibault 1990)
Hf	1500	---	(Sheppard and Thibault 1990)
Hg	10-104	---	(Baes et al. 1984; SAIC 1996b)
Ho	800	---	(Sheppard and Thibault 1990)
I	5	2.0	(Sheppard and Thibault 1990)
K	55	---	(Sheppard and Thibault 1990)
Li	300	---	(Baes et al. 1984; SAIC 1996b)
Mn	750	2.6	(SAIC 1996b; Sheppard and Thibault 1990)
Mo	125	---	(SAIC 1996b; Sheppard and Thibault 1990)
Nb	550	---	(Sheppard and Thibault 1990)
Ni	300	---	(SAIC 1996b; Sheppard and Thibault 1990)
Np	33.2-472	---	(Meyer et al. 1987; SAIC 1996b)
P	25	---	(Sheppard and Thibault 1990)
Pa	1800	---	(Sheppard and Thibault 1990)
Pb	16000	1.4	(SAIC 1996b; Sheppard and Thibault 1990)
Pd	180	---	(Sheppard and Thibault 1990)
Po	400	1.3	(Sheppard and Thibault 1990)
Pu	1200	1.2	(SAIC 1996b; Sheppard and Thibault 1990)
Ra	36000	3.1	(Sheppard and Thibault 1990)
Rb	180	---	(Sheppard and Thibault 1990)

a. The range of values or the mean of the natural logarithms of the observed values.

b. Standard deviation of the natural logarithms of observed values. Stochastic elements have a constraint that the geometric standard deviation (GSD) is 1.0001 or greater. An element with GSD less than 1.0001 (in *italics*) will be assigned a GSD of 1.0001. A GSD of 2 will be used for those without values.

Table 83, Continued

Element	Range or GMean[a]	GSD[b]	Reference(s)
Rb	180	---	(Sheppard and Thibault 1990)
Re	40	---	(Sheppard and Thibault 1990)
Ru	100-1000	---	(Meyer et al. 1987; SAIC 1996b)
Sb	150	---	(SAIC 1996b; Sheppard and Thibault 1990)
Se	500	---	(SAIC 1996b; Sheppard and Thibault 1990)
Si	110	---	(Sheppard and Thibault 1990)
Sm	800	---	(Sheppard and Thibault 1990)
Sn	450	---	(SAIC 1996b; Sheppard and Thibault 1990)
Sr	14.8-64.5	---	(SAIC 1996b)
Ta	900	---	(Sheppard and Thibault 1990)
Tc	0.5-1.3	---	(Meyer et al. 1987; SAIC 1996b)
Te	500	---	(Sheppard and Thibault 1990)
Th	3300	---	(SAIC 1996b; Sheppard and Thibault 1990)
Tl	1500	---	(Baes et al. 1984; SAIC 1996b)
U	2.3-8.6	---	(Meyer et al. 1987; SAIC 1996b)
V	1000	---	(Baes et al. 1984; SAIC 1996b)
Y	720	---	(Sheppard and Thibault 1990)
Zn	1300	2.4	(SAIC 1996b; Sheppard and Thibault 1990)
Zr	2200	---	(SAIC 1996b; Sheppard and Thibault 1990)

a. The range of values or the mean of the natural logarithms of the observed values.

b. Standard deviation of the natural logarithms of observed values. Stochastic elements have a constraint that the geometric standard deviation (GSD) is 1.0001 or greater. An element with GSD less than 1.0001 (in *italics*) will be assigned a GSD of 1.0001. A GSD of 2 will be used for those without values.

Other Special Solid Media: Waste, Gravel, and Colloid

Three additional solid media are used to model contaminant fate and transport in the screening risk tool. The Waste and Gravel media are used to supplement the general and site-specific media described in this appendix. The Colloid medium is used to implement facilitated transport for plutonium in the screening risk tool.

Waste

The Waste solid material allows the surface wash mass release model to be implemented in the screening risk tool as defined in Appendix E. The fundamental properties of the Waste solid material are assumed to be the same as the general Organic Soil material defined above. The screening risk tool provides the ability to independently sample these properties so that the soil and waste properties are different, if desired.

Gravel

An additional specialized solid material, gravel, is needed to complete definition of the surface barrier layers in the GoldSim model. Gravel is used in both the evapotranspiration (ET) and RCRA Subtitle 'C' type caps that are offered in the screening risk tool (Mattson et al. 2004). Without site-specific information, a general gravel solid is defined using available information. The particle density selected for gravel will be that value, 2.65 g/cm^3, used for most mineral phases when detailed information is not available (Freeze and Cherry 1979; USEPA 1988; Yu et al. 1993). The distribution assumed for gravel will be similar to that for the general sand category defined previously. A normal distribution, N(2.65 g/cm^3, 0.055 g/cm^3), is assumed for gravel with the same standard deviation from the sand particle density analysis (provided in Table 81) but not correlated to the bulk density (which is not readily available for gravel).

Because bulk density data are not available, porosity estimates for gravel are used to compute necessary information for the material. The RESRAD data collection manual (Yu et al. 1993) provides a porosity range for gravel of 0.25 to 0.40. A porosity of 0.265 for cobbles (assumed similar to gravel) was provided for the Idaho Site CERCLA Disposal Facility (ICDF) (Crouse 2002). The gravel porosity distribution is assumed triangular over this range with a most likely value of 0.265 and the bulk density and other parameters estimated from this information. The moisture content is assumed to be from the same distribution as defined for organic soil.

Colloid

For some waste sites, facilitated transport of radionuclides via colloids or other media may provide an important mechanism for contaminant movement through the environment. Use of a specially-defined solid medium, denoted Colloid, in the GoldSim model allows modeling of colloidal transport in the screening risk tool. The properties of the Colloid solid medium are defined in this section.

Some fraction of the plutonium buried in the SDA is of a sufficiently small size that it can form colloidal suspensions and thus move more rapidly through the vadose zone than otherwise. Batchellor and Redden (2004) estimated that 3.7% (with an upper bound of 4.9%[213]) of the plutonium originating at the Rocky Flats Plant (RFP) was processed in such a manner (i.e., machined to a sufficiently fine particle size) that it could be suspended as a colloid. Because more than 95% of the plutonium buried in the SDA originated at the RFP, it is assumed that the above fraction applies to all plutonium buried in the SDA.

To implement colloidal transport in the screening risk model, Colloid-Water partition coefficients, K_d, are defined (in the Colloid *Solid* element) for those constituents (e.g., plutonium isotopes) that may be transported through the aqueous phase via advection in colloids. The waste form associated with the entering material is assumed to not impact this colloid transport fraction for screening purposes. The required mass of Colloid is suspended in the various aqueous phases in the waste and other media through which the Colloid (and thus constituents) may then move unretarded.

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[213] It is assumed that the distribution of plutonium in colloids is LN(3.7%, 1.2), which provides an upper-bound value of 4.9% as suggested by Batchellor and Redden (2004).

The mass of colloid, which can vary as a function of time, is estimated using a material balance on Pu-239 for the Accessible and Inaccessible layers (which are modeled as well-mixed *Cell Pathway* elements) for each Waste Area in the model as illustrated in Figure 111. The overall material balance on plutonium can be described by:

$$\begin{aligned}\int_0^t m_{cPu,in}(t)dt &= \int_0^t x_{cPu,in}(t) m_{\Sigma Pu,in}(t)dt \\ &= \int_0^t V_{\Sigma w,out}(t) m_{cPu,out}(t)dt = \int_0^t V_{\Sigma w,out}(t)\left(\frac{m_{cPu,out}(t)}{V_{\Sigma w}}\right)dt\end{aligned} \quad [37]$$

where m is the component mass, M the solid material mass, V is volume, and t is the time in consistent units. If the ratio, $x_{cPu,in}$, of the plutonium suspended in the colloid to the amount entering is constant and a mean component colloid mass out is defined that represents the time integrated value, then the material balance in Equation 37 becomes

$$x_{cPu,in}\int_0^t m_{\Sigma Pu,in}(t)dt = \frac{\overline{m}_{cPu,out}}{V_{\Sigma w}}\int_0^t V_{\Sigma w,out}(t)dt \quad [38]$$

where the total mass of plutonium and total volumetric flow out can be computed using GoldSim elements.

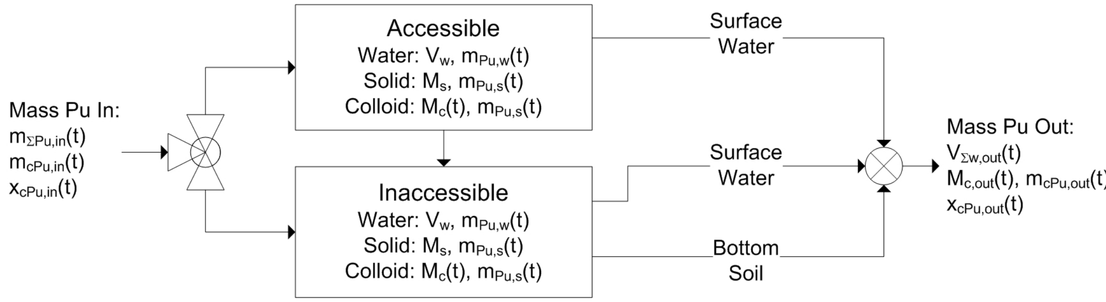

Figure 111. Material Balance to Determine Colloid Mass for Plutonium Transport

The Pu-239 is used as the basis for estimating the colloid mass because this isotope is the primary constituent (by mass) that may undergo facilitated transport and only a single partition coefficient can be defined for all isotopes in a solid medium in GoldSim (GTG 2005a). When examining the relationship between colloidal mass in the Waste Area and the parameters required (especially $K_{d,colloid}$) to define the Colloid solid, either the $K_{d,colloid}$ or Colloid mass in the Waste Areas can be defined and the other parameter then is fixed. It was decided to define a reference $K_{d,colloid}$ value using the plutonium solubility and assuming colloidal plutonium is suspended in EDTA. Note this value is arbitrary and can be defined in different ways. The $K_{d,colloid}$ value is:

$$K_{d,colloid} = \frac{\bar{m}_{cPu,out} / \bar{M}_{c,out}}{\left(m_{AccPu,w} + m_{InaccPu,w}\right) / V_{\Sigma w}} = \frac{\bar{m}_{cPu,out} / \bar{M}_{c,out}}{\bar{C}_{Pu,w}} . \qquad [39]$$

Substitution of the average mass colloidal plutonium into Equation 38 and solving for the Colloid mass provides:

$$\bar{M}_{c,out} = \frac{x_{cPu,in} \int_0^t m_{\Sigma Pu,in}(t)dt}{\bar{C}_{Pu,w} K_{d,colloid} \int_0^t V_{\Sigma w,out}(t)dt} \qquad [40]$$

where the average plutonium concentration can be computed using existing Cell element information. The average Colloid mass is computed using Equation 40 and divided between the Accessible and Inaccessible layers in the Waste Area in the same manner used for the entering source flux.

The important output flux of colloids from the (SDA) Waste Areas is to the fractured vadose zone beneath the burial site. The flux passes through a bottom soil layer that is implemented using a GoldSim *Cell Pathway* element like the Waste Area layers and thus the total Colloid mass computed for the three Waste Layers can be used as the Colloid mass in the bottom soil element. However, once moving through the bottom soil layer, the contaminant fluxes enter the upper vadose zone where Colloids may still be advected with the water moving through the zone.

However, the suspended solids representation in the *Pipe Pathway* elements comprising the fracture representation for the SDA vadose and interbed regions use suspended concentrations and not masses as in the *Cell Pathway* elements. Furthermore, it is very difficult to compute the suspended concentration required to maintain the colloid flux entering from the bottom soil through the vadose zone. To simplify the implementation, it was decided that for cases when colloidal transport is enabled, the partition coefficients for those contaminants (i.e., plutonium isotopes in this case) that may be suspended as colloids would be set to zero[214]. As illustrated in Appendix G, the colloidal transport of plutonium represents the bulk of the plutonium flux from the Waste Areas and thus assuming no retardation in those areas where colloids are transported does not likely impact the results significantly. The idea that the interbed region filters out colloids (Anderson and Becker 2006; Holdren et al. 2006) is tested by merely selecting the original (i.e., non-zero) partition coefficients for the region in question.

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[214] In modeling the vadose zones for the SDA remedial investigations, Idaho Site personnel set the partition coefficients for all contamiants to zero (Anderson and Becker 2006; Holdren et al. 2006).

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APPENDIX D

INVENTORIES AND CONTAMINANTS OF INTEREST FOR THE SUBSURFACE DISPOSAL AREA AND BEAR CREEK BURIAL GROUNDS

The GoldSim model will be capable of modeling the transport of all radioactive and hazardous constituent for the Idaho Site Subsurface Disposal Area (SDA) and Oak Ridge Bear Creek Burial Grounds (BCBG) that may become contaminants of potential concern (COPCs) based on risks to receptors. CERCLA remedial investigations (USEPA 1988) have been completed for both the SDA (Becker et al. 1998; Holdren et al. 2006; Holdren et al. 2002) and BCBG (SAIC 1996a). In these reports, the inventory information compiled for the sites were examined based on projected risks to potential receptors and COPCs were generated.

Because the analysis using the conceptual burial site model (CBSM) developed to screen risks as part of this research can also be used to evaluate the baseline risks of contaminants buried at the sites, it would be inappropriate to base the CBSM development on the COPC lists generated as part of the site remedial investigation process. Instead, the basic inventory information used by both sites for their initial screening analyses to define the COPC lists must be used to define a comprehensive set of constituents to be modeled in the CBSM.

Idaho Site Subsurface Disposal Area (SDA)

The basic inventory information selected for the Idaho Site Subsurface Disposal Area (SDA) is the so-called "historical data task" (HDT) performed by Idaho Site personnel (LMITCO 1995a; b). The HDT determined the best estimates as well as lower and upper bound activities for radionuclides (at the time of disposal) and masses for nonradionuclides for wastes buried in the Idaho Site Radioactive Waste Management Complex (RWMC)[215] for the years 1952-1984 (LMITCO 1995a) and 1984-2003 (LMITCO 1995b). Only low-level wastes have been buried in the SDA since 1970, and because the differences in activities and masses between 1970 and the present (as buried) are likely small relative to corresponding totals, the values estimated for the 1952-1984 period will be primarily used to estimate the inventories for SDA modeling.

Overall Subsurface Disposal Area (SDA) Inventory

The radionuclide inventory information (at time of disposal) (LMITCO 1995a) and the relevant progeny information (Hacker 2001; ICRP 1983; Kocher 1981) for the wastes buried in the SDA for the period 1952-1984 are provided in Table 84; more recent values are provided when available. The bounding inventories roughly correspond to 95% confidence limits about the best inventory estimates. The daughters indicated in Table 84 and their progeny (continued until stable elements form) are included[216] in the GoldSim *species* list to assure all radionuclide risks are accounted for in the modeling. The radionuclide inventory at the time of disposal is used to simplify modeling.

[215] The SDA is the buried waste site contained within the Radioactive Waste Management Complex (RWMC) at the Idaho Site. Only low-level wastes were buried in the SDA after 1970.

[216] The GoldSim Radionuclide Transport (RT) module used to develop the CBSM can handle radioactive decay; however, all pertinent decay information (i.e., half-life, daughters, and stoichiometry) must be added by the modeler. Unfortunately, very long and short half-lives can cause problems in the GoldSim RT solution routines. For radionuclides with very long half-lives, half-lives must be shortened or the radionuclide treated as stable. Very short half-lives also may resulting solution routine problems and require adjustment or using the next daughter in the decay chain.

Table 84. Inventory (activity at time of disposal) of radiological contaminants (listed by atomic number) for the RWMC for the years 1952-1984 (LMITCO 1995a)

Radio-nuclide	Best Estimate (Ci)	Lower Bound (Ci)	Upper Bound (Ci)	First Daughter[a]		Second Daughter[a]	
				Radionuclide	Stoichiometry	Radionuclide	Stoichiometry
H-3[b]	2.67E+06	1.67E+06	4.01E+06	He-3	1		
Be-7	3.50E-01	7.10E-03	2.20E+00	Li-7	1		
Be-10[c]	4.30E+01	2.90E-01	4.39E+02	B-10	1		
C-14[c]	7.31E+02	3.60E+01	1.09E+03	N-14	1		
Na-22	3.00E-01	5.40E-03	2.00E+00	Ne-22	1		
P-32	9.20E-02	1.40E-03	6.10E-01	S-32	1		
S-35	8.80E-02	1.60E-03	5.60E-01	Cl-35	1		
Cl-36[c]	1.66E+00	6.60E-01	2.62E+00	Ar-36	0.981	S-36	0.019
Ca-45	6.70E-04	3.20E-06	4.80E-03	Sc-45	1		
Sc-44	2.50E-02	5.00E-04	1.60E-01	Ca-44	1		
Sc-46	5.30E+01	2.90E-01	3.80E+02	Ti-46	1		
Cr-51	7.30E+05	1.60E+04	4.50E+06	V-51	1		
Mn-53	1.00E-03	2.00E-05	6.30E-03	Cr-53	1		
Mn-54	1.80E+05	3.70E+04	5.40E+05	Cr-54	1		
Mn-56	2.70E+01	1.60E-01	2.00E+02	Fe-56	1		
Fe-55	3.80E+06	2.20E+06	6.00E+06	Mn-55	1		
Fe-59	9.10E+04	2.00E+03	5.60E+05	Co-59	1		
Co-57	4.80E+00	9.60E-02	3.00E+01	Fe-57	1		
Co-58	1.60E+05	4.70E+04	4.00E+05	Fe-58	1		
Co-60[c]	2.80E+06	2.20E+06	7.54E+06	Ni-60	1		
Ni-59	5.10E+03	2.40E+02	2.70E+04	Co-59	1		
Ni-63	7.40E+05	4.70E+05	1.10E+06	Cu-63	1		
Zn-65	3.60E+02	3.80E+00	2.50E+03	Cu-65	1		
Kr-85[c]	1.30E+00	6.20E-03	1.50E+01	Rb-85	1		
Rb-86	7.10E+00	1.10E-01	4.60E+01	Sr-86	1		
Sr-85	2.90E-02	1.50E-04	2.10E-01	Rb-85	1		
Sr-89	4.70E+02	2.00E+01	2.60E+03	Y-89	1		
Sr-90[c]	1.36E+05	3.50E+04	2.43E+05	**Y-90**	1		
Y-88	2.50E-02	5.00E-04	1.60E-01	Sr-88	1		
Y-90	1.90E+04	1.80E+03	8.20E+04	Zr-90	1		
Y-91	5.30E+02	2.20E+01	2.90E+03	Zr-91	1		
Zr-93	4.00E+00	2.40E+00	6.40E+00	**Nb-93m**	1		
Zr-95	7.60E+04	7.00E+04	8.20E+04	**Nb-95**	0.99	**Nb-95m**	0.01
Nb-94[c]	1.46E+02	4.20E+01	2.77E+02	Mo-94	1		
Nb-95	2.40E+03	1.40E+03	3.90E+03	Mo-95	1		
Mo-99	1.00E+00	1.50E-02	6.60E+00	**Tc-99**	0.11	**Tc-99m**	0.89
Tc-99[c]	4.23E+01	9.90E+00	7.59E+01	Ru-99	1		
Ru-103	3.60E+02	1.50E+01	1.90E+03	**Rh-103m**	1		
Ru-106	6.80E+03	5.00E+03	9.00E+03	**Rh-106**	1		
Rh-103m	2.70E+02	9.20E+00	1.50E+03	Rh-103	1		

a. Progeny shown in bold type face are radioactive.

b. Best estimate from SDA WILD report (McKenzie et al. 2005) and bounds from HDT (LMITCO 1995a).

c. Best estimate from SDA RI/BRA report (Holdren et al. 2006) where Table 4-2 from the report is given preference and bounds from HDT (LMITCO 1995a) if not provided.

Table 84, Continued

Radio-nuclide	Best Estimate (Ci)	Lower Bound (Ci)	Upper Bound (Ci)	First Daughter[a]		Second Daughter[a]	
				Radionuclide	Stoichiometry	Radionuclide	Stoichiometry
Rh-106	6.80E+03	5.00E+03	9.00E+03	Pd-106	1		
Ag-110	8.40E-01	4.60E-03	6.10E+00	Cd-110	0.997	Pd-110	0.003
Cd-104	1.50E-07	3.00E-09	9.50E-07	**Ag-104**	1		
Cd-109	4.10E-01	1.10E-02	2.50E+00	**Ag-109m**	1		
Sn-119m	2.70E+04	2.50E+04	3.00E+04	Sn-119	1		
Sb-124	1.80E+03	1.00E+01	1.30E+04	Te-124	1		
Sb-125	1.30E+05	1.10E+05	1.40E+05	Te-125	0.77	**Te-125m**	0.23
I-125	2.90E-02	5.90E-04	1.80E-01	Te-125	1		
I-129[c]	1.88E-01	4.90E-02	1.33E+01	Xe-129	1		
I-131	1.50E+00	8.20E-03	1.10E+01	Xe-131	0.99	**Xe-131m**	0.01
I-133	5.00E-02	2.50E-04	3.60E-01	**Xe-133**	0.97	**Xe-133m**	0.03
Cs-134	2.20E+03	3.70E+02	7.40E+03	Ba-134	0.999997	Xe-134	0.000003
Cs-136	7.70E-01	2.60E-02	4.40E+00	Ba-136	1		
Cs-137[c]	1.68E+05	4.80E+04	3.12E+05	**Ba-137m**	0.95	Ba-137	0.05
Ba-133	5.40E-04	2.80E-06	1.37E-02	Cs-133	1		
Ba-137m	3.40E+00	1.60E-02	2.40E+01	Ba-137	1		
Ba-140	6.60E+02	2.80E+01	3.60E+03	**La-140**	1		
La-140	7.70E+02	3.20E+01	4.20E+03	Ce-140	1		
Ce-141	7.60E+02	3.70E+01	4.00E+03	Pr-141	1		
Ce-144	1.50E+05	2.60E+04	5.20E+05	**Pr-144**	0.9993	**Pr-144m**	0.0007
Pr-143	6.20E+02	2.10E+01	3.60E+03	Nd-143	1		
Pr-144	4.20E+04	3.20E+03	1.90E+05	Nd-144	1		
Pm-147	8.10E+01	9.60E-01	5.50E+02	Sm-147	1		
Eu-152	2.40E+02	2.10E+02	2.60E+02	Sm-152	0.721	Gd-152	0.279
Eu-154	3.00E+03	8.80E+01	1.70E+04	Gd-154	0.9998	Sm-154	0.0002
Eu-155	1.50E+04	7.90E+02	7.60E+04	Gd-155	1		
Er-169	7.60E-03	7.40E-05	5.30E-02	Tm-169	1		
Tm-170	3.40E+00	1.60E-02	2.40E+01	Er-170	1		
Yb-164	7.60E-03	7.40E-05	5.30E-02	**Tm-164**	1		
Hf-181	3.60E-01	3.00E-03	2.60E+00	Ta-181	1		
Ta-182	8.50E+00	3.50E-01	4.60E+01	W-182	1		
Ir-192	5.40E+01	1.40E+00	3.20E+02	Pt-192	0.9513	Os-192	0.0487
Hg-203	1.20E-02	5.80E-05	8.70E-02	Tl-203	1		
Tl-204	6.70E-04	3.20E-06	4.80E-03	Pb-204	0.971	Hg-204	0.029
Pb-210	9.66E-06	1.80E-07	5.99E-05	**Bi-210**	1		
Pb-212	2.00E-05	4.00E-07	1.30E-04	**Bi-212**	1		
Po-210	7.50E+01	1.40E+00	4.80E+02	Pb-206	1		
Rn-222	1.00E-06	2.00E-08	6.30E-06	**Po-218**	1		
Ra-225	2.00E-06	1.50E-06	2.50E-06	**Ac-225**	1		
Ra-226[c]	6.53E+01	4.30E+01	8.72E+01	**Rn-222**	1		
Ra-228[c]	3.66E-05	0.00E+00	6.99E-05	**Ac-228**	1		

a. Progeny shown in bold type face are radioactive.

b. Best estimate from SDA WILD report (McKenzie et al. 2005) and bounds from HDT (LMITCO 1995a).

c. Best estimate from SDA RI/BRA report (Holdren et al. 2006) where Table 4-2 from the report is given preference and bounds from HDT (LMITCO 1995a) if not provided.

Table 84, Continued

Radio-nuclide	Best Estimate (Ci)	Lower Bound (Ci)	Upper Bound (Ci)	First Daughter[a]		Second Daughter[a]	
				Radionuclide	Stoichiometry	Radionuclide	Stoichiometry
Ac-227[c,e]	4.26E-06	0.00E+00	1.16E-05	**Th-227**	1[e]		
Th-228[d]	1.05E+01	0.00E+00	5.09E+01	**Ra-224**	1		
Th-230[c]	5.77E-02	4.05E-02	7.49E-02	**Ra-226**	1		
Th-232[c]	3.51E+00	0.00E+00	7.15E+00	**Ra-228**	1		
Pa-231[c]	8.81E-04	0.00E+00	5.22E-03	**Ac-227**	1		
U-232[c]	1.06E+01	6.80E+00	1.36E+01	**Th-228**	1		
U-233[c]	2.12E+00	1.58E+00	2.66E+00	**Th-229**	1		
U-234[c]	6.39E+01	3.00E+01	1.14E+02	**Th-230**	1		
U-235[c]	4.92E+00	2.70E+00	7.83E+00	**Th-231**	1		
U-236[c]	1.45E+00	5.10E-01	2.39E+00	**Th-232**	1		
U-238[c]	1.48E+02	4.40E+01	2.65E+02	**Th-234**	1		
Np-237[c]	1.41E-01	0.00E+00	2.88E-01	**Pa-233**	1		
Pu-238[c]	1.85E+03	1.32E+03	2.84E+03	**U-234**	1		
Pu-239[c]	6.30E+04	3.95E+04	8.88E+04	**U-235**	1		
Pu-240[c]	1.41E+04	6.53E+03	2.28E+04	**U-236**	1		
Pu-241[b]	3.81E+05	2.76E+05	5.21E+05	**Am-241**	0.9999755	**U-237**	0.0000245
Pu-242[b]	8.58E-01	6.33E-01	1.13E+00	**U-238**	1		
Am-241[c]	2.43E+05	1.78E+05	3.24E+05	**Np-237**	1		
Am-242	7.60E-03	4.00E-05	5.50E-02	**Cm-242**	0.827	**Pu-242**	0.173
Am-243[c]	1.18E-01	7.10E-02	1.65E-01	**Np-239**	1		
Cm-242	9.10E+01	1.20E+01	3.40E+02	**Pu-238**	1		
Cm-244	8.00E+01	4.90E+00	4.00E+02	**Pu-240**	1		
Cf-252	1.00E-02	9.80E-05	6.90E-02	**Cm-248**	0.96908		

a. Progeny shown in bold type face are radioactive.

b. Best estimate from SDA WILD report (McKenzie et al. 2005) and bounds from HDT (LMITCO 1995a).

c. Best estimate from SDA RI/BRA report (Holdren et al. 2006) and bounds from HDT (LMITCO 1995a) if not provided.

d. Two best estimate inventories for Th-228 are provided in Holdren et al. (2006): 10.5 Ci (Table 4-2) and 0.0266 Ci (Table 6-12). The best inventory estimate from Table 4-2 is used with the same relative error as obtained from the values in Table 6-12.

e. The 1% decay of Ac-227 to Fr-223 (11.3 min half-life) is ignored in the modeling because Fr-223 is a short-lived radionuclide without toxicity information and decays (like Th-227) to Ra-223.

Inventories for the nonradiological contaminants originally buried in the SDA are provided in Table 85 (LMITCO 1995a). The bounding inventories roughly correspond to 95% confidence limits about the best estimates. When available, more recent information on the best estimate inventories is substituted for the HDT data and the relative differences from the HDT bounds are used to define the revised bounding inventories when necessary.

Several nonradiological contaminants were also identified in the course of developing the HDT inventory information (represented in Table 85) whose inventories could not be defended based on available information and are not included in the inventory tables; these contaminants are (LMITCO 1995a):

- 1,4-bis(5-phenyloxazol-2-yl)benzene (CAS No. 1806-34-4)
- 3-methylcholanthrene (CAS No. 56-49-5)
- Alcohols
- Benzene (CAS No. 71-43-2)
- Beryllium oxide (CAS No. 1304-56-9)
- Copper (CAS No. 7440-50-8)
- Cyanide
- Dibutylethylcarbutol
- Diisopropylfluorophosphate (CAS No. 55-91-4)
- Ether (CAS No. 60-29-7)
- Lithium hydride (CAS No. 7580-67-8)
- Lithium oxide (CAS No. 12057-24-8)
- Magnesium oxide (CAS No. 1309-48-4)
- Manganese (CAS No. 7439-96-5)
- Mercury (CAS No. 7439-97-6)
- Nitrobenzene (CAS No. 4165-60-0)
- Nitrocellulose
- Organic acids
- Organophosphates
- Polychlorinated biphenyls (PCBs) (CAS No. 1336-36-3)
- Versenes

Table 85. Inventory of nonradiological contaminants (listed alphabetically) buried in the RWMC for the years 1952-1984 (LMITCO 1995a)

CASRN[a]	Chemical	Best Estimate (g)	Lower Bound (g)	Upper Bound (g)	Toxicity/ Reference[b]	Type[c]
71-55-6	1,1,1-Trichloroethane (TCA)	1.1E+08	9.5E+07	1.2E+08	RAIS	NC
76-13-1	1,1,2-trichloro-l,2,2-trifluoroethane	9.1E+06	8.5E+06	9.8E+06	HEAST	NC
123-91-1	1,4-dioxane[d]	2.0E+06	0.0E+00	6.3E+06	IRIS	C
78-93-3	2-butanone or Methyl ethyl ketone (MEK)	3.2E+04	2.5E+04	4.0E+04	IRIS/RAIS	NC
67-64-1	Acetone	1.1E+05	9.8E+04	1.3E+05	IRIS/RAIS	NC
7784-27-2	Aluminum nitrate nonahydrate	1.9E+08	1.5E+08	2.4E+08		
7664-41-7	Ammonia	7.8E+05	2.7E+05	1.8E+06	IRIS/RAIS	NC
120-12-7	Anthracene	2.0E+02	7.0E+01	4.6E+02	IRIS/RAIS	NC
7440-36-0	Antimony	4.5E+02	1.6E+02	1.0E+03	IRIS/RAIS	NC
--	Aqua regia	3.1E+01	3.0E+01	3.2E+01		
1332-21-4	Asbestos	1.2E+06	4.7E+05	2.6E+06	IRIS	C
8032-32-4	Benzine	4.0E+03	3.3E+03	4.8E+03		
7440-41-7	Beryllium	1.5E+07	1.4E+07	1.6E+07	RAIS IRIS	C NC
71-36-3	Butyl alcohol or n-Butanol	9.9E+04	9.0E+04	1.1E+05	IRIS	NC
7440-43-9	Cadmium	1.6E+06	9.2E+05	2.5E+06	RAIS IRIS	C NC
56-23-5	Carbon tetrachloride[d]	7.9E+08	6.2E+08	9.7E+08	IRIS IRIS	C NC
7790-86-5	Cerium chloride	5.1E+05	4.2E+05	6.2E+05		
67-66-3	Chloroform	3.7E+01	3.6E+01	3.7E+01	RAIS IRIS	C NC
7440-47-3	Chromium[e]	2.3E+06	1.6E+06	3.5E+06	RAIS IRIS	C NC
3251-23-8	Copper nitrate (as Nitrates 14797-55-8)	3.3E+02	2.6E+02	4.1E+02		
64-17-5	Ethyl alcohol	2.2E+04	1.8E+04	2.8E+04		
50-00-0	Formaldehyde	1.4E+05	1.3E+05	1.5E+05	RAIS IRIS	C NC
302-01-2	Hydrazine	1.8E+03	1.3E+03	2.3E+03	IRIS	C
7664-39-3	Hydrofluoric acid	7.6E+06	6.0E+06	9.6E+06		
7439-92-1	Lead	5.8E+08	4.9E+08	6.8E+08		
7439-95-4	Magnesium	9.0E+06	7.4E+06	1.1E+07		
7783-40-6	Magnesium fluoride	1.4E+05	1.3E+05	1.4E+05		
7783-34-8	Mercury nitrate monohydrate	8.1E+05	6.3E+05	1.0E+06		
67-56- 1	Methyl alcohol or Methanol	2.2E+05	2.0E+05	2.5E+05	IRIS/RAIS	NC
108-10-1	Methyl isobutyl ketone (MIBK)	8.9E+06	7.0E+06	1.1E+07	IRIS/RAIS	NC
75-09-2	Methylene chloride or Dichloromethane[d]	1.4E+07	1.3E+07	1.6E+07	IRIS HEAST	C NC

a. Chemical Abstract Services (CAS) Registry Number.

b. Risk Assessment Information System (RAIS) (Dolislager 2006), Health Effects Assessment Summary Tables (HEAST) values from RAIS, and Integrated Risk Information System (IRIS) (USEPA 2006).

c. Acronyms indicate non-carcinogen (NC) and carcinogen (C). If blank, then no toxicity data were found.

d. Updated best estimate and bounds from SDA RI/BRA report (Holdren et al. 2006).

e. Best estimate from SDA WILD report (McKenzie et al. 2005) and bounds based on SDA RI/BRA report (Holdren et al. 2006).

Table 85, Continued

CASRN[a]	Chemical	Best Estimate (g)	Lower Bound (g)	Upper Bound (g)	Toxicity/ Reference[b]	Type[c]
7440-02-0	Nickel	2.2E+03	1.0E+03	4.1E+03		
14797-55-8	Nitrates (as Nitrogen)	4.6E+08	1.8E+08	6.4E+08	IRIS	NC
7697-37-2	Nitric acid	5.0E+07	3.9E+07	6.2E+07		
7447-40-7	Potassium chloride	8.0E+07	5.9E+07	1.1E+08		
7778-50-9	Potassium dichromate	2.3E+06	1.7E+06	3.0E+06		
7757-79-1	Potassium nitrate (as Nitrates 14797-55-8)	1.8E+09	1.3E+09	2.4E+09		
7778-77-0	Potassium phosphate	4.0E+07	3.0E+07	5.4E+07		
7778-80-5	Potassium sulfate	8.0E+07	5.9E+07	1.1E+08		
7440-22-4	Silver	5.9E+03	4.7E+03	7.3E+03	IRIS/RAIS	NC
7440-23-5	Sodium	6.8E+04	6.1E+04	7.5E+04		
7647-14-5	Sodium chloride	1.6E+08	1.2E+08	2.1E+08		
143-33-9	Sodium cyanide	9.4E+02	3.2E+02	2.2E+03	IRIS/RAIS	NC
10588-01-9	Sodium dichromate	4.1E+06	3.0E+06	5.4E+06		
1310-73-2	Sodium hydroxide	1.5E+02	5.1E+01	3.4E+02		
7631-99-4	Sodium nitrate (as Nitrates 14797-55-8)	1.2E+09	8.4E+08	1.6E+09		
10101-89-0	Sodium phosphate	8.0E+07	5.9E+07	1.1E+08		
11135-81-2	Sodium potassium alloy (NaK)	1.7E+06	1.2E+06	2.4E+06		
7757-82-6	Sodium sulfate	1.6E+08	1.2E+08	2.1E+08		
7664-93-9	Sulfuric acid	1.2E+05	9.9E+04	1.5E+05		
26140-60-3	Terphenyl	4.5E+05	1.6E+05	1.0E+06		
127-18-4	Tetrachloroethylene (PCE)[d]	9.9E+07	0.0E+00	2.7E+08	RAIS IRIS	C NC
108-88-3	Toluene	1.9E+05	1.3E+05	2.6E+05	IRIS	NC
126-73-8	Tributyl phosphate	1.0E+06	7.8E+05	1.3E+06	RAIS RAIS	C NC
79-01-6	Trichloroethylene [d]	9.0E+07	8.1E+07	1.1E+08	RAIS RAIS	C NC
15625-89-5	Trimethylolpropane-triester	1.2E+06	8.4E+05	1.6E+06		
10102-06-4	Uranyl nitrate (also as Nitrates 14797-55-8)	2.2E+05	1.7E+05	2.8E+05		
1330-20-7	Xylene	8.5E+05	7.2E+05	1.0E+06	IRIS/RAIS	NC
7440-67-7	Zirconium	1.9E+07	1.6E+07	2.3E+07		
--	Zirconium alloys	5.9E+06	4.7E+06	7.3E+06		

a. Chemical Abstract Services (CAS) Registry Number.

b. Risk Assessment Information System (RAIS) (Dolislager 2006), Health Effects Assessment Summary Tables (HEAST) values for chemicals are taken from the RAIS, and Integrated Risk Information System (IRIS) (USEPA 2006) (Dolislager 2006; USEPA 2006).

c. Acronyms indicate non-carcinogen (NC) and carcinogen (C). If blank, then no toxicity data were found.

d. Updated best estimate and bounds from SDA RI/BRA report (Holdren et al. 2006).

Of the unknown contaminants, benzene and beryllium (and its compounds) are either known (for benzene) or probable (for beryllium) human carcinogens with both latent cancer and noncancer effects (Dolislager 2006; USEPA 2006). Computed toxicity values for copper are provided in the RAIS (Dolislager 2006). Cyanide, manganese, mercury, nitrobenzene, and polychlorinated biphenyls (PCBs) also have (noncarcinogen) toxicity values available and may need consideration during risk analysis of the SDA buried wastes (Dolislager 2006; USEPA 2006). The inventory values estimated for these "unknown" quantities are provided in Table 86 (LMITCO 1995a). For benzene (that has no best inventory estimate) or the other chemicals in Table 86 with best estimates of "None", one-half of the upper bound values are used for the best estimates. For the "unknown" contaminants, the unknown lower bounds are replaced with zeros. Because the maximum nitrobenzene that might have been buried in the SDA is a trace (LMITCO 1995a), this contaminant is not modeled.

The constituents that must be included in the GoldSim model to represent the Idaho Site SDA include the radionuclides in Table 84 (and their progeny through the relevant decay chains to stable isotopes[217]) and the nonradionuclide contaminants in Table 85 and Table 86 (excluding nitrobenzene). EDTA (assumed to have been buried in the Series 744 Sludge (Bates 1993)) is included in the constituents list because it may increase actinide mobility in the subsurface[218]. The organic constituents may undergo degradation in the subsurface to products that are more toxic; therefore, the appropriate degradation products may require modeling. Because the degradation in the subsurface can be highly uncertain (Holdren et al. 2006), this determination is made after defining

[217] The stable isotopes do not require modeling unless the element represented is toxic.

[218] EDTA is not modeled in the most recent SDA remedial investigation study because monitoring of the vadose zone beneath the SDA does not indicate enhanced actinide mobility (Holdren et al. 2006). Instead the possible impact of facilitated transport is modeled based on actinide properties (e.g., particle size, available mass, etc.) and not the availability of complexants. Both conceptual models are investigated in Chapter VII to determine if the phenomenon just has not yet been observed.

the inventory estimates for the Bear Creek Burial Grounds (BCBG), which contain large volumes of organic contaminants known to have degraded in the surrounding environment (SAIC 1996a; b).

Table 86. Inventory of "unknown" nonradiological contaminants (listed alphabetically) buried in the RWMC for the years 1952-1984 (LMITCO 1995a)

CASRN[a]	Chemical	Best Estimate (g)	Lower Bound (g)	Upper Bound (g)	Toxicity/ Reference[b]	Type[c]
71-43-2	Benzene	--	--	1.2E+05	IRIS IRIS	C NC
1304-56-9	Beryllium and Beryllium oxide[d]	1.5E+07	--	8.0E+06	IRIS IRIS	C NC
7440-50-8	Copper	1.1E+02	--	4.5E+04	RAIS	NC
57-12-5	Cyanide	9.4E+02	--	2.9E+03	IRIS/RAIS	NC
7439-96-5	Manganese	None	--	1.0E+04	IRIS/RAIS	NC
7439-97-6	Mercury	4.7E+05	--	1.2E+06	IRIS/RAIS	NC
4165-60-0	Nitrobenzene	None	--	Trace	IRIS/RAIS	NC
1336-36-3	Polychlorinated biphenyls (PCBs)	None	--	2.4E+03	IRIS/RAIS	NC
60-00-4	Versenes (EDTA)[e]	None	--	7.1E+07[e]	Actinide mobility	--

a. Chemical Abstract Services (CAS) Registry Number.

b. Risk Assessment Information System (RAIS) (Dolislager 2006), Health Effects Assessment Summary Tables (HEAST) values for chemicals are taken from the RAIS, and Integrated Risk Information System (IRIS) (USEPA 2006).

c. Acronyms indicate non-carcinogen (NC) and carcinogen (C). If blank, then no toxicity data were found.

d. The beryllium oxide was combined with beryllium; the equivalent beryllium quantities are reported in this table and Table 85.

e. This chemical is assumed to be ethylenediaminetetraacetic acid (EDTA), a chelating agent which, although not known to be toxic can, under the appropriate conditions, enhance actinide mobility. The complexants buried in the SDA were originally adsorbed into a Portland cement mixture and included in the Series 744 Sludge from the Rocky Flats Plant (RFP). A total of 1,287 gal of versenes (EDTA) was thought to have been buried in SDA Pit 9 (Bates 1993). Approximately 2,700 drums of the Series 744 Sludge were estimated to have been buried in the SDA. If each drum were full of EDTA (and all EDTA was originally in these drums), the total mass would be two orders of magnitude lower than the estimate given in the table. The distribution for EDTA is based on these assumptions instead of the bounding value given in this table.

Waste Area Definition for the Subsurface Disposal Area (SDA)

The total inventory information for the wastes that were buried in the Idaho Site Subsurface Disposal Area (SDA) is described in the previous section and Table 84 through Table 86. Although this information is very useful when initially examining potential risks related to the buried wastes, the total inventory omits critical information needed to ascertain the spatial and temporal natures of the risks presented by the buried wastes in the site. These critical pieces of missing information include containment (i.e., whether the wastes were buried in drums or boxes), waste form, and original location in which the contaminants in Table 84 through Table 86 were buried.

Apart from the presence of water or other motive force for contaminant release, containment (restricted here to drums or boxes) and waste form are likely the most important features controlling contaminant release to and thus potential transport in the environment. For example, contained wastes will not be exposed to infiltrating water unless the container has first been compromised. However, even contaminants in loose wastes may be slow to release if they are in a durable waste form (e.g., cement, glass, etc.). These considerations may be very important because at times slower releases can result in higher exposures if institutional controls (ICs) are assumed to limit access to contaminated media. If all contaminants are assumed to be "loose" to simplify modeling, then the predicted peak contaminant concentrations may arrive at times when no receptor is assumed present (e.g., during IC periods). Instead a more accurate representation of containment and waste form may result in lower maximum concentrations in exposure media but at times when receptors are assumed to be present, and thus, at higher risk.

Information describing contaminant concentrations specific to containment, waste form, and waste generator is provided in the Idaho CERCLA Administrative Record and Information Repository[219] describing Idaho Site environmental cleanup. Information is provided in recent Idaho Site SDA remedial investigation reports concerning the containment and waste form (related to contaminant release) for selected Rocky Flats Plant (RFP) and other SDA waste streams (Anderson and Becker 2006; Holdren et al. 2006). Containment and waste form information is provided for 26 radionuclides (i.e., ^{14}C, ^{36}Cl, ^{90}Sr, ^{94}Nb, ^{99}Tc, ^{129}I, ^{137}Cs ^{210}Pb, $^{226,228}Ra$, ^{227}Ac, $^{229,230,232}Th$, ^{231}Pa, $^{233,234,235,236,238}U$, ^{237}Np, $^{238,239,240}Pu$, and $^{241,243}Am$) and 7 nonradionuclides (i.e., nitrate, chromium, carbon tetrachloride, 1,4-dioxane, methylene chloride, tetrachloroethylene, and trichloroethylene). The information for non-RFP waste streams is summarized in Table 87 for contaminants that are either contained (in drums or boxes) or have a release mechanism other than surface wash (i.e., the partitioning of the contaminant between waste and aqueous phases).

Other release mechanisms include dissolution of the waste matrix or diffusion of the contaminant though the waste matrix (Anderson and Becker 2006). The manners in which the three release mechanisms are modeled in GoldSim are described in Appendix E. Anderson and Becker (2006) indicate that Ac-227 is contained only in the TAN-607-6RN waste stream; however, containment is assumed for all pertinent waste streams (e.g., INTEC-MOD-9H (contained in drums), TRA-670-1N (release by dissolution), etc.). The containment assumption is tested in Chapter VII. The corresponding information for the RFP wastes streams is provided in Table 88.

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[219] The Idaho Site Administrative Record and Information Repository, available at http://ar.inel.gov/ (accessed March 13, 2008), provides public access to information on Idaho Site environmental cleanup.

Table 87. Radiological Source-Release Information for Selected Non-RFP Contaminants in the Subsurface Disposal Area (SDA) (Anderson and Becker 2006)

Waste Stream (Ci)	Contam-inant(s)	% in Stream[a]	Description	Release Mechanism[b]	Drums (%)	Boxes (%)
ANL-785-1	C-14	1.0	Subassembly waste	Dissolution—activated metal	N/C[b]	N/C
ANL-MOD-1H	C-14 Nb-94 Tc-99	2.2 1.9 16.3	Irradiated subassembly	Dissolution—activated metal	9	91[d]
ANL-MOD-1R	C-14 Nb-94 Tc-99	2.1 1.8 14.8	Irradiated subassembly	Dissolution—activated metal	N/C	N/C
ANL-MOD-2H	Cs-137 Np-237 Sr-90 Tc-99 U-236	2.9 2.7 2.6 1.4 1.3	Irradiated & unirradiated fuel	Dissolution—fuel-like elements	7	93[d]
ANL-MOD-3H	Cs-137 Np-237 Sr-90 Tc-99 U-236	2.5 2.4 2.3 1.2 1.1	Dissolved fuel and other	Surface wash	6	94[d]
ANL-MOD-4H	Np-237 U-234	3.1 1.4	Bulk-actinide waste	Surface wash	25	75[d]
ANL-MOD-5H	Cs-137 I-129 Np-237 Sr-90 Tc-99 U-234 U-236	8.3 1.9 7.9 7.4 4.0 1.3 3.7	General plant waste	Surface wash	6	94[d]
ARA-602-3H	Sr-90	1.2	Hot Cell waste	Surface wash	1	99[d]
ARA-616-1H	Sr-90	1.6	Scrap metal	Surface wash	1	99[d]
ARA-626-1H	U-233	28.4	Some fuel scraps	Surface wash	2	98[d]
INTEC-MOD-2H	Cs-137 I-129 Sr-90 Tc-99	27.9 9.6 31.3 15.8	Vycor glass	Dissolution—glass	N/C	N/C
INTEC-MOD-3H	U-235 U-236	19.3 4.1	Mockup fuel specimens	Surface wash	2	98[d]
INTEC-MOD-6H	Tc-99	1.9	CPP-603 resins	Surface wash—resin-controlled	N/C	N/C

a. Represents the percentage of the radiological inventories presented in Table 84.

b. Release mechanisms include surface wash (by partitioning into infiltrating water), diffusion through a waste matrix (to the surface where surface wash is involved), and dissolution (or materials encasing radionuclides). It is assumed that the release mechanism applies to all elements in the waste.

c. N/C – not contained.

d. This column includes containers other than drums including all types of boxes.

Table 87, Continued

Waste Stream (Ci)	Contam-inant(s)	% in Stream[a]	Description	Release Mechanism[b]	Drums (%)	Boxes (%)
INTEC-MOD-9H	Cs-137 I-129 Np-237 Pu-238 Sr-90 Tc-99 Th-228	4.8 1.4 1.9 1.6 5.9 3.8 1.3	General plant waste	Surface wash	2	98[d]
LLW-metal	C-14 Cl-36 Nb-94	9.8 32.5 1.9	Activated metal	Dissolution—activated metals	N/C	N/C
LLW-resins	C-14 I-129 Tc-99	1.1 24.8 4.8	2000 to 2009 resins	Surface wash—resin-controlled	N/C	N/C
NRF-MOD-1H	Cs-137 I-129 Sr-90 Tc-99	6.3 2.1 4.6 3.5	Shippingport fuel material	Dissolution—fuel-like elements	N/C	N/C
NRF-MOD-6H	C-14 Cl-36 Nb-94	5.2 9.5 3.5	Core structural materials	Dissolution—activated metals	17	83[d]
NRF-MOD-6R	Cl-36	2.7	Core structural materials	Dissolution—activated metals	N/C[c]	N/C
NRF-MOD-9H	C-14	2.3	Sludge and resins	Surface wash—resin-controlled	18	82[d]
NRF-MOD-10H	I-129 Nb-94 Tc-99	2.5 16.5 2.8	ECF wastes	Surface wash	7	93[d]
OFF-AEF-1H	Ra-226	10.2	Scrap metal	Surface wash	91	9[d]
OFF-ATI-1H	Cs-137 U-234 U-235	13.3 5.7 2.3	Irradiated fuel	Surface wash	36	64[d]
OFF-CSM-1H	U-234 U-235	2.0 1.6	Magnesium fluoride slag	Surface wash	100	0
OFF-DPG-1H	Ra-226	5.1	Animal and lab waste	Surface wash	92	8[d]
OFF-GDA-1H	U-235	1.4	Fuel fabrication items	Surface wash	48	52[d]
OFF-HEW-1H	Ra-226	1.5	Ra-contaminated lab waste	Surface wash	100	0
OFF-ISC-1H	Ra-226	15.3	Magnesium-thorium scrap	Surface wash	75	25[d]
OFF-LRL-2H	Pu-240	3.1	Concrete, bricks, & asphalt	Surface wash	100	0
OFF-USN-1H	Ra-226	66.4	Animal carcasses, lab items	Surface wash	12	88[d]
PBF-620-1	I-129	1.0	Ion exchange resins	Surface wash	N/C	N/C
SMC-628-1	U-233	1.1	Various waste types	Surface wash	46	54[d]

a. Represents the percentage of the radiological inventories presented in Table 84.

b. Release mechanisms include surface wash (by partitioning into infiltrating water), diffusion through a waste matrix (to the surface where surface wash is involved), and dissolution (or materials encasing radionuclides). It is assumed that the release mechanism applies to all elements in the waste.

c. N/C – not contained.

d. This column includes containers other than drums including all types of boxes.

Table 87, Continued

Waste Stream (Ci)	Contam-inant(s)	% in Stream[a]	Description	Release Mechanism[b]	Drums (%)	Boxes (%)
SMC-628-2	U-233 U-236 U-238	14.2 3.0 1.5	Unsolidified slag	Surface wash	11	89[d]
SMC-990-1	U-233	1.3	Metals, glass, & gravel	Surface wash	66	34[d]
TAN-607-6RN	Ac-227 Sr-90	1.7 1.2	General plant waste	Surface wash	3	97[d]
TRA-603-1N	I-129 Tc-99	44.6 8.0	Resins	Surface wash—resin-controlled	N/C	N/C
TRA-603-4N	C-14 Nb-94 Tc-99	46.0 45.5	Core components	Dissolution—activated metals	13	87[d]
TRA-603-9N	Cs-137 Nb-94 Np-237 Pu-238 Sr-90 Tc-99 U-232 U-233 U-235 U-236	3.8 1.0 8.9 1.2 4.5 2.2 79.0 28.4 9.9 2.3	Fuel materials	Dissolution—fuel-like elements	8	92[d]
TRA-632-2N	C-14 Cs-137 I-129 Nb-94 Np-237 Pu-238 Sr-90 Tc-99 U-236	7.8 9.8 2.3 9.5 24.9 3.2 12.7 6.2 6.3	Hot Cell waste	Surface wash	24	76[d]
TRA-670-1N	C-14 Cl-36	12.7 53.3	Beryllium waste	Dissolution—beryllium blocks	N/C	N/C

a. Represents the percentage of the radiological inventories presented in Table 84.

b. Release mechanisms include surface wash (by partitioning into infiltrating water), diffusion through a waste matrix (to the surface where surface wash is involved), and dissolution (or materials encasing radionuclides). It is assumed that the release mechanism applies to all elements in the waste.

c. N/C – not contained.

d. This column includes containers other than drums including all types of boxes.

Table 88. Source-Release Information for Selected RFP Contaminants in the Subsurface Disposal Area (SDA) (Anderson and Becker 2006)

Waste Stream	Contaminants	% in Stream	Description[a]	Release Mechanism[b]	Drums (%)	Boxes (%)
RFO-DOW-2H	Pu-238 Pu-239 Pu-240	0.3 0.3 0.3	Cemented Series 744 sludge	Surface wash Surface wash Surface wash	Not given (100)	Not given (0)
RFO-DOW-3H	Am-241 U-238 Pu-238 Pu-239 Pu-240 Methylene Chloride	77.8 18.8 11.0 11.6 11.3 51.2	Uncemented Series 741/742 sludges	Surface wash Surface wash Surface wash Surface wash Surface wash Diffusion	99.8	0.2
RFO-DOW-4H	Am-241 Pu-238 Pu-239 Pu-240 1,4-Dioxane Methylene Chloride	13.4 4.8 5.1 5.0 7.8 20.3	Combustibles (Type I)	Surface wash Surface wash Surface wash Surface wash Diffusion Diffusion	70	30
RFO-DOW-6H	Am-241 Pu-238 Pu-239 Pu-240 Methylene Chloride	0.9 17.6 18.6 18.0 0.9	Filters (Type III)	Surface wash Surface wash Surface wash Surface wash Diffusion	0	100
RFO-DOW-7H	Pu-239 Pu-240	4.6 4.5	Glass (Type II)	Surface wash Surface wash	Not given (0)	Not given (0)
RFO-DOW-9H	Pu-238 Pu-239 Pu-240 Methylene Chloride	13.8 14.5 14.3 18.3	Line-generated waste	Surface wash Surface wash Surface wash Diffusion	55	45
RFO-DOW-11H	Pu-238 Pu-239 Pu-240	24.7 26.0 25.4	Graphite molds, crucibles, and scarfings	Surface wash Surface wash Surface wash	Not given (0)	Not given (100)
RFO-DOW-12H	Am-241 Pu-238 Pu-239 Pu-240 Methylene Chloride	2.6 16.5 17.5 17.1 9.3	Dirt, concrete, ash, & soot (Type I and IV)	Surface wash Surface wash Surface wash Surface wash Diffusion	81	19
RFO-DOW-15H	Pu-238 Pu-239 Pu-240 Carbon Tetrachloride 1,4-Dioxane Tetrachloroethylene Trichloroethylene	0.2 0.3 0.2 99.5 88.2 100.0 99.6	Series 743 sludge (organic)	Surface wash Surface wash Surface wash Diffusion Diffusion Diffusion Diffusion	100	0
RFO-DOW-16H	U-234 U-235 U-236 U-238	22.7 22.0 62.4 51.3	Depleted uranium	Surface wash Surface wash Surface wash Surface wash	100	0
RFO-DOW-17H	Pu-238 Pu-239 Pu-240 Nitrate Chromium	0.01 0.01 0.002 37.5 21.4	Series 745 nitrate salt	Surface wash Surface wash Surface wash Surface wash Surface wash	100	0
RFO-DOW-18H	U-234 U-235 U-236	33.7 15.1 5.6	Enriched uranium	Surface wash Surface wash Surface wash	Not given (100)	Not given (0)
RFO-DOW-19H	U-233	25.5	U-233 stream	Surface wash	100	0
PDA-RFO-1A	U-234 U-235 U-238 Nitrate Chromium	7.3 6.6 16.8 51.6 78.6	Roaster oxides Roaster oxides Roaster oxides Series 745 nitrate salt Series 745 nitrate salt	Surface wash Surface wash Surface wash Surface wash Surface wash	100 100 100 54.8 54.8	0 0 0 45.2 45.2

a. Descriptions for the RFP waste streams vary by report (Holdren et al. 2006; Holdren et al. 2002; LMITCO 1995a; McKenzie et al. 2005). Best guesses for the major RFP streams are made.

b. Release mechanisms include surface wash (by partitioning into infiltrating water), diffusion (to surface where surface wash is involved), and dissolution (or materials encasing radionuclides).

Because containment can play such an important part in controlling the release of contaminants into the environment, the missing containment information in Table 88, which represents significant proportions of plutonium and uranium contaminants, is estimated to reflect the nature of the contaminant release in the burial site. For the Series 744 sludge (RFO-DOW-2H), the wastes are assumed to be drummed like the other RFP Series 74x sludges. This assumption is also made for the graphite (RFO-DOW-11H) and glass (RFO-DOW-7H) waste streams; this assumption is reinforced by an analysis of the drum versus box data in the Idaho Site inventory database for the SDA (LMITCO 1995a)[220]. The enriched uranium wastes (RFO-DOW-18H), like those for the depleted uranium stream, are also assumed to have been placed in drums for burial. These assumptions are represented by the values in parentheses in Table 88.

Containment (in drums or boxes) and waste form likely play a significant role in controlling contaminant release from buried wastes. An alternative way to represent the information in Table 87 and Table 88 is by using the relative percentages among containment and waste form (indicated by release mechanism) for selected contaminants. This information, obtained from the most recent Idaho Site SDA remedial investigation studies (Anderson and Becker 2006; Holdren et al. 2006), is presented in Table 89. The diffusion release mechanism had to be approximated in the GoldSim simulation software as illustrated in Appendix E.

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[220] The volumes of the Rocky Flats Plant (RFP) waste streams (i.e., RFP-DOW-1 through -14) buried before 1970 are not known (LMITCO 1995a) and are estimated from other information. The total annual volumes of all waste streams shipped from the RFP are available, and the estimates of the relative annual fractions and numbers of drums and boxes used to contain the wastes for each of the 14 streams can be made using post-1970 stored RFP wastes (LMITCO 1995a). This analysis indicates that very few boxes were associated with the Series 744 sludge, graphite, or glass streams.

From the information in Table 89, the releases for many buried contaminants (e.g., C-14, Sr-90, Nb-94, Tc-99, Cs-137, Np-237, Pu-238, etc.) can be very complicated involving both contained and uncontained wastes with multiple release mechanisms. Many contaminants (e.g., Ac-227, I-129, Np-237, Pa-231, Pb-210, Ra-228, Th-228, etc.) also are neither mostly contained in drums[221] nor in a waste matrix that delays release to the environment. For those contaminants that are neither contained nor in a waste matrix, retrieval of the wastes might be impossible if the contaminants have already migrated through the environment. This temporal aspect of the potential exposure risks must be considered when developing remedial options for buried wastes.

As illustrated in Table 89, information concerning containment and waste form is available for many contaminants deemed by Idaho Site personnel to be *high-risk*. However, information concerning where wastes were originally buried in the SDA, that is needed to ascertain if selected *high-risk* wastes can be targeted for separate retrieval, is not publicly available[222]. Disposal locations are available for selected radioactive and hazardous contaminants of concern identified by Idaho Site personnel during the remedial investigation process (Holdren et al. 2006). For the Idaho Site remedial investigation, the SDA was conceptually divided into 18 different "source areas" based on disposal location and waste form. General information for the source areas is provided in Table 90. For convenience, the definition of waste areas for analysis of the risks associated with the SDA will begin using these source area designations.

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[221] Boxes that are buried in the ground are assumed to fail immediately and provide no waste containment (Anderson and Becker 2006; Holdren et al. 2006).

[222] According to the most recent SDA remedial investigation report (Holdren et al. 2006), waste stream versus disposal location information is available in the Waste Information and Location Database (WILD) (McKenzie et al. 2005). However, the contaminant versus disposal location information cannot be generated from information provided in McKenzie et al. (2005). Access to the WILD database, which is limited to site personnel, would be required to generate the necessary information.

Table 89. Inventory (Percentages) by Containment and Waste Form for Selected SDA Contaminants

	Drums					Boxes					No Containment					
	Metal	Fuel	Resin	Glass	Surface	Metal	Fuel	Resin	Glass	Surface	Metal	Be	Fuel	Resin	Glass	Surface
Ac-227[a]	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	19.8	0.0	17.3	0.0	0.0	1.1	61.3
Am-241[a]	0.0	0.0	0.0	0.0	94.2	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Am-243[a]	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	20.8	0.0	66.8	0.0	0.0	0.0	12.0
C-14[b]	7.1	0.0	0.4	0.0	1.9	46.3	0.0	1.9	0.0	5.9	17.9	12.7	0.0	1.1	0.0	4.9
Cl-36[b]	1.6	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	37.2	53.3	0.0	0.0	0.0	0.0
Cs-137[a]	0.0	0.5	0.0	0.0	8.4	0.0	6.6	0.0	0.0	32.8	0.0	0.0	6.7	0.0	29.8	15.1
I-129[c,h]	0.0	0.0	0.0	0.0	**0.9**	0.0	0.0	0.0	0.0	**7.2**	0.0	0.0	9.2	70.4	9.6	**2.7**
Nb-94[a]	6.9	0.1	0.0	0.0	3.5	45.6	1.0	0.0	0.0	23.3	3.8	0.0	0.0	8.3	0.0	7.5
Np-237[a]	0.0	1.0	0.0	0.0	8.0	0.0	11.6	0.0	0.0	35.5	0.0	0.0	2.0	0.0	0.0	41.8
Pa-231[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Pb-210[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Pu-238[d]	0.0	0.1	0.0	0.0	61.3	0.0	1.1	0.0	0.0	35.8	0.0	0.0	0.0	0.0	0.0	1.8
Pu-239[e]	0.0	0.0	0.0	0.0	68.4	0.0	1.6	0.0	0.0	29.9	0.0	0.0	0.0	0.0	0.0	0.0
Pu-240[a]	0.0	0.0	0.0	0.0	70.5	0.0	0.0	0.0	0.0	29.5	0.0	0.0	0.0	0.0	0.0	0.0
Ra-226[a]	0.0	0.0	0.0	0.0	35.5	0.0	0.0	0.0	0.0	64.5	0.0	0.0	0.0	0.0	0.0	0.0
Ra-228[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Sr-90[f]	0.0	0.5	0.0	0.0	3.8	0.0	6.5	0.0	0.0	28.4	0.0	0.0	4.6	0.0	31.2	24.9
Tc-99[a,h]	1.5	0.3	0.0	0.0	**2.1**	15.4	3.5	0.0	0.0	**16.6**	15.3	0.0	3.7	13.3	16.4	**11.9**
Th-228[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	98.7
U-232[a]	0.0	6.3	0.0	0.0	0.0	0.0	72.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.9
U-233[a]	0.0	2.3	0.0	0.0	29.3	0.0	26.4	0.0	0.0	41.9	0.0	0.0	0.0	0.0	0.0	0.0
U-234[g]	0.0	0.0	0.0	0.0	68.1	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	26.1
U-235[e]	0.0	0.0	0.0	0.0	68.1	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	26.1

a. Miscellaneous wastes are composed of various waste types—contaminant distributed over all available waste forms.
b. Miscellaneous wastes are mostly activated metals—added to uncontained activated metal form.
c. Miscellaneous wastes are mostly fuel-like elements—added to uncontained fuel-like waste form.
d. Miscellaneous wastes are mostly debris (assumed to be INTEC-MOD-9H).
e. Miscellaneous wastes are mostly fuel-like (assumed to be TRA-603-9N like Pu-238 contains).
f. Miscellaneous wastes are mostly debris (assumed to be ARA-602-1H in stream).
g. Assume no containment.
h. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

Table 89, Continued

	Drums					Boxes					None					
	Metal	**Fuel**	**Resin**	**Glass**	**Surface**	**Metal**	**Fuel**	**Resin**	**Glass**	**Surface**	**Metal**	**Be**	**Fuel**	**Resin**	**Glass**	**Surface**
U-236[a]	0.0	0.4	0.0	0.0	70.1	0.0	7.6	0.0	0.0	16.1	0.0	0.0	0.0	0.0	0.0	5.8
U-238[g]	0.0	0.0	0.0	0.0	87.1	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	11.6
Carbon tetrachloride[a]	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,4-Dioxane[a]	0.0	0.0	0.0	0.0	95.7	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0
Methylene chloride[a]	0.0	0.0	0.0	0.0	82.9	0.0	0.0	0.0	0.0	17.1	0.0	0.0	0.0	0.0	0.0	0.0
Tetrachloroethylene[a]	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichloroethylene[a]	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate[a,h]	0.0	0.0	0.0	0.0	**65.8**	0.0	0.0	0.0	0.0	**23.3**	0.0	0.0	0.0	0.0	0.0	**10.9**
Chromium[a]	0.0	0.0	0.0	0.0	64.5	0.0	0.0	0.0	0.0	35.5	0.0	0.0	0.0	0.0	0.0	0.0

a. Miscellaneous wastes are composed of various waste types—contaminant distributed over all available waste forms.
b. Miscellaneous wastes are mostly activated metals—added to uncontained activated metal form.
c. Miscellaneous wastes are mostly fuel-like elements—added to uncontained fuel-like waste form.
d. Miscellaneous wastes are mostly debris (assumed to be INTEC-MOD-9H).
e. Miscellaneous wastes are mostly fuel-like (assumed to be TRA-603-9N like Pu-238 contains).
f. Miscellaneous wastes are mostly debris (assumed to be ARA-602-1H in stream).
g. Assume no containment.
h. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

Table 90. General Characteristics for the 18 Source Areas Defined for the Idaho Site Subsurface Disposal Area (SDA) (Holdren et al. 2006)

Source Area	**Denotation**	**Average Depth (m)**	**Surface Area (m^2)**	**Average Vol. (m^3)**	**Total Activity (%)[a]**	**Total Mass (%)[b]**
Trenches 1-10	T1-10	3.60	17,419	6.27E+04	6.21[c]	0.05
Acid Pit	Acid Pit	1.43	2,903	4.15E+03	0.00	3.67
Pits 1-2 & Trenches 11-15	P1-2 & T11-15	2.99	26,129	7.81E+04	29.35[c]	0.20
Trenches 16-41	T16-41	2.38	7,258	1.73E+04	3.02	0.00
Pit 3	Pit 3	1.25	5,806	7.26E+03	1.81[c]	0.01
Pit 4	Pit 4	3.90	11,613	4.53E+04	19.37[c]	29.15
Pit 5	Pit 5	2.65	10,161	2.69E+04	9.74[c]	0.42
Trenches 42-58	T42-58	2.19	27,581	6.04E+04	3.25	0.00
Pit 6	Pit 6	5.46	4,355	2.38E+04	4.64[c]	23.54
Pit 8	Pit 8	2.50	4,355	1.09E+04	0.00	0.00
Pits 7&9	Pits 7&9	2.01	5,806	1.17E+04	3.96[c]	9.15
Pits 10-12	Pits 10-12	3.69	13,064	4.82E+04	17.21[c]	16.31
Pit 13	Pit 13	3.66	1,452	5.31E+03	0.09	0.00
Pad A	Pad A	0.49	4,355	---[d]	0.03	17.49[d]
Pits 14-16	Pits 14-16	1.43	11,613	1.66E+04	0.20	0.00
Soil Vault Rows	SVRs	3.38	15,968	5.40E+04	1.10	0.00
LLW Pits 17-20	Pits 17-20	7.47	13,064	9.76E+04	0.01	0.00
Projected Pits 17-20	LLW proj	7.50	10,161	7.62E+04	0.00	0.00
Totals and averages	---	3.43[e]	188,708	6.46E+05	100.00[c]	---

a. Percent total activity is based on the 24 radionuclides considered in SDA modeling (Holdren et al. 2006) as listed in Table 91.

b. Percent total mass is based on the seven nonradionuclides used in SDA modeling (Holdren et al. 2006) and listed in Table 91.

c. Activity primarily derived (> 90%) from plutonium and americium isotopes (and not fission products).

d. Pad A is above ground and does not require excavation *per se*. Furthermore, installing a cap on the SDA requires removal of Pad A and thus it does not need consideration when judging relative risks of remedial actions. Nonradionuclide contaminant mass is almost exclusively nitrate removed from other SDA burial sites (e.g., Pits 11 and 12) during test retrieval actions (Holdren et al. 2006). From a conceptual standpoint, the contaminants that were removed to in Pad A will be considered in their original locations, when the information is available.

e. The average depth is equal to the total average volume divided by the total surface area.

For the 18 source areas defined by Holdren et al. (2006)[223], activities and masses are provided for 24 radionuclides[224] and seven nonradionuclide contaminants for the

[223] Source areas were originally defined by Anderson and Becker (2006).

[224] The activities and source areas for C-14 are developed on a different (i.e., temporal) basis than that for the 24 radionuclides shown. To simplify modeling (and because one cannot go back in time, for example, to retrieve pre-1960 buried wastes), C-14 will be treated like the other radionuclides.

various waste streams and forms (e.g., metal, fuel, resin, glass, etc.) known to have been buried in the SDA and of potential consequence in terms of risk. Table 91 provides a summary of the percentages of radionuclide activities and nonradionuclide masses by source area (aggregated by waste form) modeled in the SDA remedial investigations (Anderson and Becker 2006; Holdren et al. 2006)[225]. The majority of the radionuclide activities and nonradionuclide masses were originally buried in a relatively small number of pits and trenches in the SDA. This fact might, depending on the amount and extent of contaminant migration since burial, make retrieval of *high-risk* wastes from a few of these burial sites the best solution in terms of both worker risks and long-term health risks to the surrounding public.

The rank-ordering of total activities for the source areas with greater than 1% of the total activity (for the 24 radionuclides considered) is:

Pit 1&2+Trenches 11-15 > Pit 4 > Pit 10-12 > Pit 5 > Trenches 1-10 > Pit 6 > Pits 7&9 > Trenches 42-48 > Trenches 16-41 > Pit 3 > Soil Vault Rows

The corresponding rank-ordering for nonradionuclide masses (with greater than 1% of the total mass) is (excluding Pad A where material was relocated from Pits 11 and 12):

Pit 4 > Pit 6 > Pits 10-12 > Pits 7&9 > Acid Pit

Therefore, remedial priorities would differ for the SDA buried waste based upon whether radionuclide or nonradionuclide hazards (and the corresponding non-cancer impacts) are given preference.

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[225] The source areas for C-14 were different than those in Table 91 (Holdren et al. 2006) and the inventory will be analyzed when developing the final waste area inventories for modeling purposes.

Table 91. Inventory (Percentages) by Waste Area for Selected SDA Contaminants

	T1–10	Acid Pit	P1-2 & T11–15	T16–41	P3	P4	P5	T42–58	P6	P8	P7 & 9	P10–12	P13	Pad A	P14–16	SVRs	P17–20	LLW_ proj
Ac-227	9.1	0.0	0.6	13.0	0.0	0.0	0.0	26.8	0.0	0.0	0.0	0.2	0.8	0.0	16.5	9.2	23.8	0.0
Am-241	8.6	0.0	31.7	0.2	0.9	21.2	11.9	0.0	4.9	0.0	4.2	16.4	0.0	0.0	0.0	0.0	0.0	0.0
Am-243	9.7	0.0	0.6	3.9	0.0	0.0	0.0	50.6	0.0	0.0	0.0	0.2	0.9	0.0	10.9	20.7	0.9	1.6
C-14[a]	3.2	0.0	0.0	40.2	0.0	0.0	0.0	35.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	16.5	0.0
Cl-36[b]	0.0	0.0	0.0	3.0	0.0	0.0	0.0	45.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	18.3	0.0	32.8
I-129[b]	0.7	0.0	0.0	15.5	0.0	0.0	0.0	28.2	0.0	0.0	0.0	0.2	1.9	0.0	13.6	2.4	10.8	26.6
Nb-94	1.9	0.0	0.1	53.0	0.0	0.0	0.0	12.1	0.0	0.0	0.0	2.1	0.0	0.0	0.5	26.3	0.7	3.4
Np-237	1.6	0.0	0.1	35.1	0.0	0.0	0.1	16.6	0.0	0.0	0.0	0.7	1.0	0.0	6.0	15.6	7.0	16.1
Pa-231	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	99.6	0.0
Pb-210	0.0	1.9	0.1	0.9	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.2	0.0	2.5	1.3	91.3	0.0
Pu-238	2.0	0.0	29.0	4.9	4.9	18.7	6.1	2.0	4.9	0.0	4.2	19.8	0.2	0.0	1.0	2.1	0.1	0.0
Pu-239[c]	1.0	0.0	31.1	0.1	5.2	20.4	6.6	0.6	5.4	0.0	4.6	24.6	0.0	0.0	0.0	0.1	0.0	0.0
Pu-240[c]	1.0	0.0	32.0	0.1	5.1	20.4	6.5	0.3	5.4	0.0	4.6	24.4	0.0	0.0	0.0	0.0	0.0	0.0
Ra-226	0.0	0.0	37.2	57.8	0.0	4.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.3
Ra-228	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	29.3	70.3
Sr-90	0.7	0.0	3.8	35.9	0.0	0.0	0.1	39.4	0.0	0.0	0.0	3.1	1.1	0.0	2.4	13.4	0.0	0.0
Tc-99[b]	2.0	0.0	0.1	14.4	0.0	0.0	0.0	29.0	0.0	0.0	0.0	0.4	0.9	0.0	6.8	39.2	2.3	4.9
Th-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.5	91.6	0.0
Th-230	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	31.0	0.1	0.0	23.2	45.4
Th-232	0.0	0.0	30.8	26.7	0.0	6.5	0.0	29.9	0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.3	0.7	0.8
U-233	0.0	0.0	0.0	26.0	0.2	0.0	21.7	30.6	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.8	0.8
U-234	9.7	0.1	18.8	12.6	1.1	6.2	7.7	5.2	6.9	0.0	3.1	11.0	0.2	6.7	3.0	1.2	5.8	0.7
U-235	20.7	0.0	14.8	9.0	1.5	6.0	6.7	2.0	4.5	0.0	0.8	6.9	0.3	6.1	12.3	0.8	6.6	0.8
U-236	24.3	0.0	10.5	9.5	0.3	9.9	10.8	6.9	4.3	0.0	1.3	9.9	0.4	1.0	1.1	4.7	4.1	1.2
U-238	4.1	0.1	11.0	1.8	0.4	17.7	13.5	1.7	8.6	0.0	1.0	16.2	0.0	14.9	1.3	0.0	2.7	5.0

a. The C-14 inventory was not provided in Holdren et al. (2006) for the 18 source areas. Best guesses were made for the inventories in the 18 source areas based on Figure 5-3 in Holdren et al. (2006) and original burial information in the ABRA (Holdren et al. 2002) . Any C-14 wastes buried in Pit 15 are omitted due to lack of knowledge.

b. The activities for only these three radionuclides were given by waste form and area in Holdren et al. (2006). A single method will be used to generate the activities by waste area and form and the results will be verified for these three. Therefore, the activities have been summed for these three like the others in this table.

c. The Pu-239 and Pu-240 activities were split by colloidal fraction and waste are a in Holdren et al. (2006)–and not by waste form. The colloidal fractions will be computed elsewhere and thus the total values by waste area are presented here.

Table 91, Continued

	T1–10	Acid Pit	P1-2 & T11–15	T16–41	P3	P4	P5	T42–58	P6	P8	P7 & 9	P10–12	P13	Pad A	P14–16	SVRs	P17–20	LLW_ proj
Carbon tetrachloride	0.0	0.0	0.0	0.0	0.0	44.3	0.4	0.0	30.0	0.0	13.1	12.2	0.0	0.0	0.0	0.0	0.0	0.0
1,4-Dioxane	0.2	0.0	0.9	0.0	0.1	19.7	0.7	0.1	13.0	0.0	57.0	7.5	0.0	0.0	0.8	0.0	0.0	0.0
Methylene chloride	5.0	0.0	18.6	0.1	0.7	22.7	11.4	0.0	8.2	0.0	7.0	26.3	0.0	0.0	0.0	0.0	0.0	0.0
Tetrachloroethylene	0.0	0.0	0.0	0.0	0.0	43.9	0.5	0.0	29.5	0.0	12.8	13.3	0.0	0.0	0.0	0.0	0.0	0.0
Trichloroethylene	0.0	0.0	0.0	0.1	0.0	43.8	0.5	0.1	29.3	0.0	12.7	13.3	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	1.5	23.9	0.0	52.1	0.0	0.0	0.0	0.0
Chromium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	0.0	0.9	13.7	0.0	79.0	0.0	0.0	0.0	0.0

The time to effect also plays a significant role in selection and sequence of remedial actions. For example, if hazardous volatile organic compounds were of primary concern because of their mobility in the environment, then their cleanup might take priority in early remedial actions (as is the case for the SDA (USDOE-ID 2004c)). However, if the majority of the volatile organic compounds have already migrated from their original disposal sites by the time remedial actions can begin, then excavating the area where the organic compounds were originally buried (but are no longer) impacts exposure and risk little in return for what could be a large additional worker risk.

Another example is based on the rank-ordering of radionuclides according to uncontained and unimmobilized activities[226] (greater than 10 Ci as buried in the SDA):

Sr-90 > Cs-137 >> C-14 > Pu-238 > Nb-94 > U-234 > Tc-99 >
Th-228 > U-238 > U-232

From Holdren et al. (2006), these contaminants are primarily located in soil vault rows and trenches, which would be the focus of retrieval of wastes contaminated with Sr-90 and Cs-137[227]. If, on the other hand, remedial action is prioritized on long-term exposure risks to the general public from radionuclides, then excavation of the handful of the SDA pits mentioned previously would likely reduce long-term exposure risks dramatically (assuming the radionuclides have limited release and mobility). Two source areas (i.e., Pit 4 and Pits 10-12) contain significant quantities of both the initial radionuclide and

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[226] Because there is containment neither in a drum nor waste matrix, these contaminants might be most likely to migrate through the environment. This, as in previous rank-orderings, omits the relative toxicities of the various contaminants considered.

[227] Because of the relatively short half-life (approximately 30 years) for Sr-90 and Cs-137, these large activities are likely offset by relatively rapid decay. As long as institutional control can be maintained at the SDA, these risks are likely manageable using *in situ* techniques.

nonradionuclide disposals. These source areas are, therefore, excellent candidates for targeted retrieval[228].

The best approach to select areas that are the best candidates for targeted retrieval would be to partition the total radionuclide and nonradionuclide inventories in Table 84 and Table 85 by waste form (as was done in Table 89) and waste area (or source area in Idaho Site parlance as was done in Table 91). It is assumed that the wastes in an area are mixed to the point that the whole area must be excavated to assure retrieval of the targeted wastes. Using the information in Table 90 as a guide, the impacts on exposure risks could be modeled for the targeted retrieval of each waste area (with significant source inventory). The impact on risk from retrieval of obvious combinations of waste areas would then be modeled to identify the optimal targeted retrieval area (or set of waste areas) based upon incremental costs and risks.

However, the first step in any evaluation of the impact of targeting remedial actions on SDA buried waste involves partitioning the contaminant inventories (e.g., Table 84 and Table 85) among the various waste forms (Table 89) and waste areas (Table 91) describing the SDA buried wastes. As indicated earlier, information that relates waste stream and form and thus contaminants to original disposal locations in the SDA is not publicly accessible except for a few selected contaminants. A number of assumptions must be made to divide the total inventory into the appropriate waste areas and forms. As additional information is obtained, the inventory partitioning can be improved along with the corresponding exposure and risk estimates.

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[228] Historically, wastes have been retrieved from the following Pits: 1, 2, 5, 10, 11, and 12 as well as Pad A and Trenches 1, 5, 7, 8, 9, and 10. Major retrieval projects have been completed on Pit 9 and Pit 4 (Holdren et al. 2006; USDOE-ID 2004a; b).

Because of the lack of information needed to partition the total waste inventory among waste forms and areas, a set of basic assumptions will be made to partition the contaminants in a way that makes their use meaningful. The information in Table 90 for both radionuclides and chemicals of interest and the fact that these same primary risk drivers are from the Rocky Flats Plant (RFP) wastes (Holdren et al. 2006) suggests that it is reasonable (and likely safe in terms of potential exposure risks) to focus retrieval efforts on wastes generated at the Rocky Flats Plant[229]. There has been an on-going legal battle concerning whether "all" RPF transuranic wastes should be retrieved from the Radioactive Waste Management Complex (of which the SDA is part) or just those wastes stored aboveground since 1970. Therefore, RFP wastes are the appropriate focus for retrieval from both risk and legislative perspectives.

Assumptions Needed to Define the SDA Waste Area Inventories

A number of assumptions are made to use the available information to generate the necessary partitioned inventories for modeling. The initial assumption is that the SDA can be divided into two waste areas: one the target of potential retrieval activities and the other to be only managed in-place. Because of the independent manner in which the GoldSim simulation software manages solubility, partitioning, release, etc., this assumption will not impact the results when compared to including all the source areas in

[229] Wastes from generators other than the Rocky Flats Plant (RFP) that cannot be partitioned among waste forms and generators based on available information will be considered loose. If the focus on RFP wastes for retrieval is found unwarranted (i.e., they are shown to not be the primary risk drivers for the SDA), this fact will become immediately apparent during the simulation studies. Any other *high-risk* wastes will then be the focus of future study.

the model individually[230]. This inclusion would unnecessarily add to the complexity of the model and the likelihood of programming errors. The contaminants for the 18 source areas defined by Idaho Site personnel (Holdren et al. 2006) are apportioned between the two hypothetical waste areas for modeling purposes.

Another assumption is that any containers or contaminants within containers are completely mixed throughout the area (or container and/or waste forms). Because no specific information is available on how contaminants are temporally or spatially distributed throughout the waste stream, form, or burial site, contaminants will be assumed to be completely mixed through the waste (or, if contained, in the drum or box or, if in a matrix, throughout the matrix). The impact of this assumption on resulting exposure and risk estimates is evaluated in Chapter VII by comparison to the results of a test case where no containment is assumed for the buried wastes. Furthermore, the waste area is implemented as a "box model" as described in Chapter V and Chapter VI meaning that any contaminants released into the waste area "box" are immediately and completely mixed throughout the volume.

The final assumption that is used to define inventories for SDA exposure modeling is that the many types of wastes buried in the SDA can be adequately represented by a few types based on their primary contaminants. This assumption simplifies implementation and is appropriate because representing each individual waste stream (with the necessary release and transport interconnections and resulting reduction in model efficiency) would likely not result in a significant increase in accuracy when considering the large uncertainties in the model (e.g., inventory, parameter, model, etc.)

[230] For example, when modeling contaminant release for the SDA remedial investigation, the source areas were handled independently and their results summed for inclusion in the transport model (Anderson and Becker 2006).

and their magnitudes. In general, the waste streams represented in the model are: loose wastes, boxed wastes, drummed RFP volatile organic compound (VOC) wastes, and non-VOC drummed wastes. The waste forms (i.e., glass, resin, etc.) within these streams are maintained for modeling purposes.

Volatile organic compound (VOC) wastes are distinguished from non-VOC wastes by their relative contribution of VOCs (excluding methylene chloride) to radionuclides in the overall waste stream. The primary source of VOC wastes is the RFP Series 743 sludge, which was originally drummed. The high-nitrate and chromium waste stream (i.e., RFP Series 745 sludge which was also drummed) is included in the VOC waste stream because the Series 745 sludge contributes little in the way of radionuclides, and the potential risk impacts (i.e., primarily noncarcinogenic) are similar to those for the VOCs. Holdren et al. (2006) indicate that the Series 743 and 745 sludges were originally drummed and the release mechanism is surface wash. Thus the VOC waste stream (in drums) can be obtained by multiplying the drum fractions obtained using the percentages in Table 89 by the percentages in Table 92.

Table 92. Percentages of Drummed Wastes that are VOC Wastes[a]

Contaminant	Percentage		Contaminant	Percentage
Pu-238	0.395		Methylene chloride	0.0
Pu-239	0.374		Tetrachloroethylene	100.0
Pu-240	0.349		Trichloroethylene	100.0
Carbon tetrachloride	100.0		Nitrate	100.0[b]
1,4-Dioxane	94.2		Chromium	100.0

a. All contaminants that are not shown are identically zero in the VOC drummed wastes.
b. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

The non-VOC drummed wastes are assumed to be the complement of those obtained for VOC wastes using the percentages in Table 92. Non-VOC wastes could be further distinguished by whether uranium isotopes or other radionuclides were the primary contaminant of interest. However, in the initial modeling effort, all the non-VOC drummed wastes (for the 24 radionuclides and 7 nonradionuclides from the most recent remedial investigation study (Holdren et al. 2006)) will be grouped together for both convenience and the fact that their potential risk impacts would be similar. Furthermore, because the variations in concentration among the drums and media are not available, the impact from combining and mixing the wastes on a container/waste stream basis cannot be determined except on a gross level. Comparison to the results from the test case where no containment is assumed for any wastes in Chapter VII sheds as much light on this issue as possible for the screening analysis performed in this research.

Therefore, the various streams describing the wastes buried in the SDA and the contaminants of primary interest are partitioned among four categories (i.e., VOC drums, non-VOC drums, boxed, and loose wastes) using the information provided in this appendix. However, container failure has also been shown to be a function of whether the drums were stacked or dumped in the burial site (Anderson and Becker 2006). For the current model implementation, loose and boxed wastes will both have all contaminants available for transport upon burial or, in other words, buried boxes (unless known to be lined with polyethylene) are assumed to fail immediately upon burial.

The presence of a polyethylene liner in a container appears to drive the failure rate and thus source term for the model (Anderson and Becker 2006); however, none of the boxes were identified as being lined (and this assumption will be maintained in modeling). The VOC drums fail at the slowest rate (compared to stacked or dumped non-VOC drums) likely because of the presence of a polyethylene liner. Stacked drums fail at a slower rate than dumped drums. RFP boxed and drummed wastes were stacked in the SDA pits until November 1963 (Holdren et al. 2006). Holdren et al. (2006) indicate that Pits 1-3 were in operation during this period. The contaminants in the two source areas containing these three SDA pits will be treated as if they were originally contained in stacked drums[231]. The necessary container failure distribution information for the resulting SDA waste types is provided in Table 93.

Table 93. Container Failure Distributions and Parameters used for SDA Waste Types (Anderson and Becker 2006)

Container	Failure Distribution	Initial Failure Rate (%)	Time to Fail (yr)		Assumptions
			Mean	Std. Dev.	
Loose or boxed—unlined	N/A[a]	100.0	N/A	N/A	Immediate failure
Drums—stacked	Normal[b]	0.0	34.1	14.6	Stacked drums do not fail from the burial process
Drums—dumped	Normal[b]	28.5	11.7	5.0	Dumped drums fail more quickly than stacked drums
Drums or boxes—lined	Normal[b,c]	30.0 0.0	45.0 200.0	22.5 50.0	The presence of a liner controls failure and these fail least quickly

a. Not applicable.

b. Failures following normal distributions were used in Anderson and Becker (2006). Because a Gaussian failure distribution is unavailable in GoldSim, a Weibull distribution is used with a shape coefficient of 3.3, which provides a normal failure distribution.

c. Two distributions were provided in Anderson and Becker (2006) for use in the SDA remedial investigation. The VOC drums are assumed to be lined and measured environmental contamination suggests that lined drums fail at a much slower rate than originally assumed (Holdren et al. 2006). Both distributions will be evaluated in this research.

[231] Partitioning contaminants based on stacked versus unstacked drums is perfomed by summing the contribution for each contaminant in the *Trenches 11-15 & Pit 1-2* and *Pit 3* source areas in Table 91 for the stacked drums—the unstacked drum component being the complement.

Therefore, the type of container (and if it was lined with polyethylene) and the manner in which the container was buried have a significant impact on the failure rate and contaminant flux into the burial site. In the simplified screening risk tool, only drummed wastes are assumed to retard the flux of contaminants to the burial site. Furthermore, the numbers of drums failing may have a profound impact on the contaminant flux. The numbers of drums by waste area and type are provided in Table 94. The numbers of drums are not considered stochastic; uncertainties are incorporated into the corresponding failure rates.

Table 94. Approximate SDA Drum Allocation

	VOC[a]	**Total non-VOC**[b]	**Stacked non-VOC**[b]	**Dumped non-VOC**[b]
Waste Area 01	9,740	60,000	18,000	42,000
Waste Area 02	49	40,000	12,000	28,000
Total	9,789	100,000	30,000	70,000

a. The numbers and locations of volatile organic drums (VOC) from the Rocky Flats Plant (RFP) are described in Holdren et al. (2006).

b. No specific information on the numbers and locations of other RFP drums was found. Using available SDA information (Holdren et al. 2006; LMITCO 1995a), separate analyses based on waste stream versus data of burial and waste stream versus burial location indicated that a total of (approximately) 100,000 RFP drums were buried, approximately 30% of the drums were buried before 1964 (and assumed stacked), and approximately 60% of the drums were buried in Waste Area 01 (for targeted retrieval).

SDA Waste Area Inventory Information for Modeling

Selection of the waste areas that may be targeted for retrieval is based on various decision elements and/or their combinations including minimizing long-term exposure risk to the general public, regulatory mandate, or minimizing worker risks. Two initial cases are evaluated based on the two most likely decision bases: regulatory mandate and risk. The result of the on-going legal battle concerning which transuranic wastes must be retrieved from the SDA may require removal of all RPF TRU wastes. Using the Pu-239 isotope as an indicator[232], RFP wastes were buried in all 18 source areas (Holdren et al. 2002). Small quantities of Pu-239 are contained in each source area represented in Table 91 although some areas (i.e., Acid Pit, Pit 8, Pit 13, Pad A, Pits 17-20, and LLW_proj) have concentrations that are less than 0.05% and are rounded to zero in the table.

If the decision is to remove RFP TRU *wastes* instead of all RFP TRU *contamination*, then the areas (i.e., Trenches 16-41, Soil Vault Rows, etc.) containing small amounts of RFP contaminants would likely be excluded. However, for the maximum retrieval case, all 18 source areas are considered in play. The relative percentages of contaminants by container and form for this maximum retrieval case are provided in Table 95. All other contaminants were assumed to have been buried loose and subject to the surface wash mechanism; these assumptions maximize the impact of risks at the shortest possible times to effect. Test cases are run in Appendix G to test the impact of institutional controls on the resulting risks.

Very little contamination (including plutonium isotopes and VOCs) was buried in the stacked VOC drums (i.e., before November 1963). Significant quantities were buried in the other containers (i.e., drums and boxes) or as loose wastes. On a waste form basis, only loose wastes and a handful of contaminants including Ac-227, Am-243, C-14, and Cl-36 are impacted by the beryllium block wastes. The impacts on the exposure for all other contaminants from container and waste forms must be considered in modeling.

[232] Holdren et al. (2006) indicate that the only source of Pu-239 in the SDA is various Rocky Flats Plant (RFP) waste streams. This analysis ignores the possibility that only TRU wastes (defined specifically using concentrations and half-lives) from the RFP may require retrieval and instead focuses on where RFP wastes were originally buried in the SDA.

Table 95. Inventory (%) by Containment and Waste Form for SDA Contaminants for the Maximum Retrieval Case

	Stacked, VOC Drums					Stacked, Non-VOC Drums					Unstacked, VOC Drums					
	Metal	Fuel	Resin	Glass	Surface	Metal	Fuel	Resin	Glass	Surface	Metal	Be	Fuel	Resin	Glass	Surface
Ac-227	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Am-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0
Am-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl-36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
I-129[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nb-94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Np-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pa-231	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-238	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	20.7	0.0	0.0	0.0	0.0	0.0	0.2
Pu-239	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	24.7	0.0	0.0	0.0	0.0	0.0	0.2
Pu-240	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	26.1	0.0	0.0	0.0	0.0	0.0	0.2
Ra-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0	0.0	0.0	0.0	0.0	0.0
Ra-228	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Tc-99[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th-228	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th-232	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U-232	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U-233	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U-234	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6	0.0	0.0	0.0	0.0	0.0	0.0
U-235	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0

a. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

Table 95, Continued

	Stacked, VOC Drums					Stacked, Non-VOC Drums					Unstacked, VOC Drums					
	Metal	**Fuel**	**Resin**	**Glass**	**Surface**	**Metal**	**Fuel**	**Resin**	**Glass**	**Surface**	**Metal**	**Be**	**Fuel**	**Resin**	**Glass**	**Surface**
U-236	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0
U-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.9	0.0	0.0	0.0	0.0	0.0	0.0
Carbon tetrachloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
1,4-Dioxane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	89.3
Methylene chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0
Tetrachloroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Trichloroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Nitrate[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**65.8**
Chromium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.5

a. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

Table 95, Continued

	Unstacked, Non-VOC Drums					Boxes					No Containment (Loose)					
	Metal	Fuel	Resin	Glass	Surface	Metal	Fuel	Resin	Glass	Surface	Metal	Be	Fuel	Resin	Glass	Surface
Ac-227	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	19.8	0.0	17.3	0.0	0.0	1.1	61.3
Am-241	0.0	0.0	0.0	0.0	63.5	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Am-243	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	20.9	0.0	66.8	0.0	0.0	0.0	12.0
C-14	7.1	0.0	0.4	0.0	1.9	46.3	0.0	1.9	0.0	5.9	17.9	12.7	0.0	1.1	0.0	4.9
Cl-36	1.6	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	37.2	53.3	0.0	0.0	0.0	0.0
Cs-137	0.0	0.5	0.0	0.0	8.1	0.0	6.6	0.0	0.0	32.8	0.0	0.0	6.7	0.0	29.8	15.1
I-129[c]	0.0	0.0	0.0	0.0	**0.9**	0.0	0.0	0.0	0.0	**7.2**	0.0	0.0	9.2	70.4	9.6	**2.7**
Nb-94	6.9	0.1	0.0	0.0	3.5	45.6	1.0	0.0	0.0	23.3	3.8	0.0	0.0	8.3	0.0	7.5
Np-237	0.0	1.0	0.0	0.0	8.0	0.0	11.6	0.0	0.0	35.5	0.0	0.0	2.0	0.0	0.0	41.8
Pa-231	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Pb-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Pu-238	0.0	0.1	0.0	0.0	40.3	0.0	1.1	0.0	0.0	35.8	0.0	0.0	0.0	0.0	0.0	1.8
Pu-239	0.0	0.0	0.0	0.0	43.4	0.0	1.7	0.0	0.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0
Pu-240	0.0	0.0	0.0	0.0	44.2	0.0	0.0	0.0	0.0	29.5	0.0	0.0	0.0	0.0	0.0	0.0
Ra-226	0.0	0.0	0.0	0.0	22.3	0.0	0.0	0.0	0.0	64.5	0.0	0.0	0.0	0.0	0.0	0.0
Ra-228	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Sr-90	0.0	0.5	0.0	0.0	3.7	0.0	6.5	0.0	0.0	28.4	0.0	0.0	4.6	0.0	31.2	24.9
Tc-99[a]	1.5	0.3	0.0	0.0	**2.1**	15.4	3.5	0.0	0.0	**16.6**	15.3	0.0	3.7	13.3	16.4	**11.9**
Th-228	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	98.7
Th-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Th-232	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U-232	0.0	4.4	0.0	0.0	0.0	0.0	72.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.9
U-233	0.0	2.3	0.0	0.0	29.3	0.0	26.4	0.0	0.0	41.9	0.0	0.0	0.0	0.0	0.0	0.0
U-234	0.0	0.0	0.0	0.0	54.5	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	26.1
U-235	0.0	1.5	0.0	0.0	39.5	0.0	20.3	0.0	0.0	21.1	0.0	0.0	0.0	0.0	0.0	9.6

a. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

Table 95, Continued

	Unstacked, Non-VOC Drums					Boxes					No Containment (Loose)					
	Metal	Fuel	Resin	Glass	Surface	Metal	Fuel	Resin	Glass	Surface	Metal	Be	Fuel	Resin	Glass	Surface
U-236	0.0	0.3	0.0	0.0	62.6	0.0	7.6	0.0	0.0	16.1	0.0	0.0	0.0	0.0	0.0	5.8
U-238	0.0	0.0	0.0	0.0	77.1	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	11.6
Carbon tetrachloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,4-Dioxane	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0
Methylene chloride	0.0	0.0	0.0	0.0	66.8	0.0	0.0	0.0	0.0	17.2	0.0	0.0	0.0	0.0	0.0	0.0
Tetrachloroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichloroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**23.3**	0.0	0.0	0.0	0.0	0.0	**10.9**
Chromium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.5	0.0	0.0	0.0	0.0	0.0	0.0

a. Holdren et al. (2006) assumed the partition coefficient for the surface wash mechanism was zero for this contaminant.

The information in Table 95 represents the case when all contaminants in the SDA must be retrieved (due to regulatory fiat). A hopefully more realistic case can be made to target only *high-risk* wastes buried in the SDA. As indicated above, the best approach to select the best candidate areas for targeted retrieval would be to partition the total radionuclide and nonradionuclide inventories in Table 84 and Table 85 by waste area, container, and form. Using the information in Table 90 as a guide, the impacts on exposure risks can be modeled for the targeted retrieval of each waste area (with significant source inventory). The impact on risk from retrieval of obvious combinations of waste areas would then be modeled to identify the optimal targeted retrieval area (or set of waste areas) based upon incremental costs and risks.

To illustrate the potential benefits of targeting retrieval actions to the highest risk wastes, a set of candidate waste areas is defined based on the author's judgment concerning not only those waste areas representing the highest potential exposure risks but also some idea of the more standard industrial risks. Exposure risks are included in the selection using the information presented in Table 90 and by treating both radionuclide and nonradionuclide risks. This idea suggests that the following waste areas would be the best candidates for retrieval (in no implied order):

Trenches 1-10, Pits 1-2 & Trenches 11-15, Pit 4, 5, 6, Pits 7&9, and Pits 10-12[233]

However, because there are very small amounts of volatile organic compounds in Trenches 1-10 and Pit 5 and the SDA will eventually be capped (reducing the impetus for environmental transport), these two areas are excluded from targeted retrieval. Finally,

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[233] The contaminant inventory in Pad A is assumed to be located in the Pits 10-12 waste area because the Pad A wastes were relocated from these pits and the modeling inventory is based upon the wastes as they were originally buried.

because Pit 1 was originally used in 1957 for burial of large bulky items (Holdren et al. 2006), which are difficult to retrieve, the waste area including Pit 1 is also excluded from targeted retrieval. These exclusions result in the following targeted retrieval area:

Pit 4, Pit 6, Pits 7&9, and Pits 10-12 (including Pad A)

This targeted retrieval area constitutes approximately 20% of the total buried waste volume[234] and approximately one-half of the radionuclide activity and almost all the nonradionuclide mass. The three areas (i.e., Trenches 1-10, Pits 1-2 & Trenches 11-15, and Pit 5) excluded from the targeted retrieval comprises approximately the other half of the radionuclide activity for the radionuclides considered in the SDA remedial investigation modeling (Holdren et al. 2006). The information analogous to that in Table 95 for the two waste areas defined for the SDA is provided in the model. There are no stacked drums in the targeted retrieval area defined above. This provides the information necessary to model the exposure risks for the contaminants buried in the SDA.

Oak Ridge Bear Creek Burial Grounds (BCBG)

The Bear Creek Burial Grounds (BCBG) are located within the Beak Creek Valley, an area contained in the Department of Energy (DOE) Oak Ridge Reservation approximately 20 miles northwest of Knoxville, Tennessee (SAIC 1996a). The valley is over 10 miles long and runs from the eastern end of the Oak Ridge Y-12 Plant to the Clinch River. There are multiple individual waste units within the valley containing

[234] When divided between the retrieval and non-retrieval areas, the waste volumes are $1.29x10^5$ m^3 and $5.17x10^5$ m^3 and the waste areas are $3.48x10^4$ m^2 and $1.54x10^5$ m^2 for the retrieval and non-retrieval areas, respectively. These dimensions translate into waste area depths of 3.70 m and 3.36 m for the retrieval and non-retrieval areas, respectively.

various types of hazardous and radioactive wastes derived primarily from Y-12 Plant operations. Groundwater has been contaminated throughout at least the eastern 3 miles of the valley, including commingled plumes from various contaminant sources.

Hazardous and radioactive wastes produced during operation of the Y-12 facility were disposed of at various sites in the Bear Creek Valley. Large volumes of solid hazardous and radioactive wastes (particularly contaminated with uranium) were buried in trenches located at the BCBG. Hazardous liquids are known to have been disposed of at various locations including the BCBG. Soils, groundwater, and surface water at each of these sites including the BCBG are known to be contaminated (SAIC 1996a).

At the BCBG, solid and liquid wastes were disposed of in a series of unlined trenches. Uranium dominates the wastes disposed with a total estimated mass of $18.6x10^6$ kg (SAIC 1996b). Liquid waste disposal has also resulted in volatile organic compound (VOC) contamination in groundwater that may have reached depths over 600 ft. Contaminants in the BCBG include VOCs and metals in groundwater and VOCs, metals, and radionuclides in surface water, soils, waste materials, and leachates. Organic contamination of environmental media tends to be more widespread than inorganic and radionuclide contamination.

The primary contaminants detected in environmental media at the BCBG include (SAIC 1996a):

- *Groundwater*: boron; tetrachloroethylene (PCE); trichloroethene (TCE); 1,1,1-trichloroethane (1,1,1-TCA); and 1,2-dichloroethylene (1,2-DCE)
- *Surface water*: beryllium; 1,1,2-trichloroethane (1,1,2-TCA); 1,1-dichloroethylene (1,1-DCE); 1,2-dichloroethane (1,2-DCA); vinyl chloride; 1,1-DCA; 1,1,1-TCA; chloroethane; and uranium isotopes
- *Soils surrounding waste areas:* arsenic, vanadium, polychlorinated biphenyls (PCBs), acetone, and toluene

- *Wastes*: uranium, beryllium, PCBs, TCE, and PCE

Contaminant concentrations in BCBG groundwater exceed applicable or relevant and appropriate requirements (ARARs) for inorganic and organic chemicals in drinking water (SAIC 1996a).

As of 1996, groundwater and surface water contamination had been dominated by VOCs with three major groundwater plumes identified (SAIC 1996a):

- Burial Ground A (BG-A) plume is dominated by PCE, TCE, and 1,2-DCE, and includes DNAPL;
- Walk-in Pits (WIP) plume is dominated by PCE; and
- Plume at the North Tributaries 8 (NT-8) catchment is dominated by 1,2-DCE, with lesser concentrations of vinyl chloride.

Radiological contamination is virtually absent from groundwater wells in the BCBG, but uranium had been consistently detected in surface water (SAIC 1996a). Leachate collection in the North Tributaries (NT) catchments, which drain the BCBG, significantly reduced the concentration of radiological and other contaminants in surface water. However, radiological contamination occurs in soils in the NT-8 floodplain may be related to past disposal of contaminated sediments derived from other BCBG areas.

General BCBG Inventory Information

The primary wastes disposed of in the BCBG were uranium and uranium-contaminated materials although other wastes were disposed of including hazardous liquids, which were often poured into standpipes in the burial ground. Many types of hazards are associated with the wastes including exposure to radiological and hazardous contaminants; however, the very natures of the wastes present very real physical hazards as well. Incompatible materials presenting explosive hazards were mixed together throughout the BCBG, and there is a history of uncontrolled and, at times, pyrophoric and explosive events (SAIC 1996a). The waste forms also drive the physical hazards associated with potential handling of the buried wastes. One important waste form is the metallic uranium saw fines and tailings, which can undergo rapid oxidation causing fires. Therefore, not only the identification of the contaminants, but, like the inventory analysis for the SDA, the waste forms associated with the contaminants must be identified.

The BCBG can be divided into 15 waste or source areas. Descriptions for the areas are provided in Table 96 including best available information for uranium, the most prevalent and important contaminant from a risk perspective. The waste form information for the uranium contamination and the identities of other, selected potential contaminants of interest are provided. Other than the waste form information, the next most important pieces of information for predicting exposure risks from the BCBG are the hydrological settings for the various source areas; water movement through the waste areas is likely the most important driver for contaminant transport through the environment.

As illustrated in Table 96, many of the BCBG waste areas have been capped as part of RCRA closure actions (SAIC 1996a) even if some of the areas are seasonally or perennially inundated by groundwater. Therefore, the capping of these areas may have little, if any, impact on contaminant transport because the water interacting with the wastes does not come from percolating that would be diverted by a surface barrier. On the other hand, contaminant migration from BG A-17, which is subject to bathtubbing, is likely reduced by capping. These ideas are considered when developing the set of source areas for potential excavation and capping remedial actions.

Table 96. General Characteristics of Bear Creek Burial Grounds Source Areas

Source Area	Volume (m^3)	Uranium (%)[a]	Uranium (kg)	Uranium Form	Other Contaminants[b]	Hydrologic Setting[c]
A-South	46,807	5.00	9.30E+05[d]	Debris & solids[e]	Be, TCA, PCE, TCE, Benzene, MEK, PCBs	Capped/uncapped perennially inundated
A-North	65,824	5.00	9.30E+05[d]	Debris & solids[e]	Li, Th(-232),Be, Tc(-99), PCBs	Capped/uncapped inundated intermittently during storm
A-16	33,640	0.15	2.79E+04	Debris	None provided	Uncapped dry
A-17	51,989	0.25	4.65E+04	Debris	None provided	Uncapped bathtubbing
A-18	25,995	0.10	1.86E+04	Debris	Th(-232)	Uncapped dry
B	11,062	33.00	6.14E+06	Metallic chips	Th(-232), PCBs	Capped dry
C-East	8,827	1.35	2.51E+05	Debris & chips	Li, Be, Th(-232)	Capped/uncapped perennially inundated
C-West	23,013	3.65	6.79E+05	Debris & chips	Li, Th(-232), Be, Tc(-99)	Capped/uncapped inundated during wet season
D-East	8,158	18.00	3.35E+06	Metallic chips	None provided	Capped/uncapped inundated during wet season
D-South	65	0.15	2.79E+04	Metallic chips	None provided	Capped/uncapped inundated during wet season[c]
D-West	841	1.85	3.44E+05	Metallic chips	None provided	Capped/uncapped inundated during wet season[c]
E	2,688	6.50	1.21E+06	Metallic blocks	None provided	Capped/uncapped inundated intermittently during storm
J	4,035	10.00	1.86E+06	Metallic chips	None provided	Capped/uncapped inundated intermittently during storm
Walk-In North	16,364	9.00	1.67E+06	Metallic fines	Many including Acetone, As, Cr, Benzene, Carbon tetrachloride, DDT, Ethers, Pb, Th(-232)	Capped dry
Walk-In South	10,468	6.00	1.12E+06	Metallic fines	Mixed acids, Cr, Hg	Capped dry
Total	309,777	100.00	1.86E+07	Various	Not applicable	Various

a. The total uranium mass was estimated based on the Y-12 Plant Kardex Blanket File disposal records, which provided a per-year estimate of 620,000 kg/yr for 30 years (SAIC 1996b). The original percentages have been reconciled to remove rounding errors. Natural isotopic ratios are assumed.

b. Isotopes assumed for contaminants are placed in parentheses (SAIC 1996b). Because of the large number of contaminants, only selected contaminants are provided for Walk-In North.

c. The hydrologic settings for the source areas are from Figure 3.36 (SAIC 1996a). The settings for BG D-South and D-West are not provided; these settings are assumed to be the same as that for D-East.

d. BG A-North and A-South contain 2,000 and 1,800 kg of uranium in waste oil and mop water, respectively (SAIC 1996b). The remaining uranium is contained in contaminated debris.

e. The solids are particles contained in either waste oil or mop water poured into the site.

Overall Bear Creek Burial Ground (BCBG) Inventory

A number of assumptions are required to generate the inventory information for the Bear Creek Burial Grounds (BCBG) that is needed to estimate both exposure and physical or industrial risks associated with remedial activities. The first set of assumptions is summarized in Table 96 and concern estimating the amounts of the most abundant contaminant in the BCBG, uranium[235]. An analysis of the uranium input to the BCBG was performed as input to the remedial investigation process, which resulted in a per-year estimate of 620,000 kg/yr for 30 years (or 18.6 x 10^6 kg U total) where other estimates ranged from 17.3-19.3 x 10^6 kg U total (SAIC 1996b). This variation in the total uranium buried in the BCBG of less than 10% appears difficult to justify considering the estimates were obtained from more than 100,000 reports representing a 30-year period (SAIC 1996b).

However, not only the inventory matters; how the inventory is divided among the waste areas and forms dictates the relative impacts of contaminants from the various areas. Because of a lack of information, the relative percentages of uranium among the sites provided in Table 96 will be considered more accurate than the overall inventory estimate. The overall inventory will then dictate the amounts of uranium in each waste area for modeling purposes based on the relative percentages. The manner in which variation in the inventory information is defined will be described after the best inventory information has been provided for the waste areas.

[235] Uranium is by far the contaminant with the largest inventory in the BCBG; however, the magnitude of the inventory does not necessarily translate directly to risks. Uranium is considered the *highest-risk* driver because uranium has migrated into the environment surrounding the BCBG and pyrophoric forms of uranium have been buried in the BCBG. Thus uranium is thus important from both an exposure and physical risk perspective.

Wastes were buried in the BCBG in a number of forms including contaminated debris, waste oil, mop water, liquids, solids, and metallic fines, chips, and blocks. For waste forms like contaminated debris, metallic forms, solids, and liquids, reasonable inventory estimates are available in the most recent remedial investigation report (i.e., Tables A.13 through A.27 in SAIC (1996b)) and summarized for uranium in Table 96 based on historical records. However, based on results of environmental monitoring (i.e., Table 3.12 in SAIC (1996b)), numerous contaminants not represented in the major waste streams described in SAIC (1996b) have been released and migrated into the surrounding soil, groundwater, and surface water. From available information, these contaminants appear to have been contained in the very large volumes of waste oils and mop water disposed of in the BCBG via standpipes that were inserted into BG-A North and South (SAIC 1996b). The estimates of the compositions for the wastes oil and mop waters that will be used to estimate inventories are provided in Table 97. Solvents buried in the Walk-In Pits were packaged in drums, boxes, and buckets (USDOE-ORO 1993).

Liquid solvent wastes were originally burned in an open tank east of BG-A; however, between 1970 and 1981, approximately 100,000 gallons (375 m^3) of solvent wastes (e.g., TCA, PCE, TCE, benzene, toluene, etc.) were poured onto rock piles and into waste-filled trenches in BG-A (SAIC 1993; 1996b). These contaminants have migrated outside the original burial site. There is also evidence that the organic solvent wastes have degraded in the surrounding environment, including to products (e.g., vinyl chloride) that may more dangerous than the original solvent disposed of in the site (SAIC 1996a). Therefore, both radioactive decay and organic degradation products must also be considered in modeling the potential exposure effects of the BCBG wastes.

Table 97. Spectrographic Analyses of Selected Y-12 Plant Oily Wastes (SAIC 1993)

	Waste Oil (ppm)				Mop Water (ppm)			
Element	**Analysis**	**Low**[a]	**Best**[b]	**High**[c]	**Analysis**	**Low**[a]	**Best**[b]	**High**[c]
Ag	<0.01	0	0.005	0.05	<0.2	0	0.1	1
Al	2	1	2	4	10	5	10	20
Au	---	---	---	---	<0.8	0	0.4	4
B	0.2	0.1	0.2	0.4	10	5	10	20
Ba	0.4	0.2	0.4	0.8	0.8	0.4	0.8	1.6
Be	12	6	12	24	0.04	0.02	0.04	0.08
Bi	---	---	---	---	0.4	0.2	0.4	0.8
Ca	25	12.5	25	50	200	100	200	400
Cd	0.2	0.1	0.2	0.4	<2.	0	1	10
Co	<0.2	0	0.1	1	<0.2	0	0.1	1
Cr	2	1	2	4	2	1	2	4
Cs	---	---	---	---	<20	0	10	100
Cu	0.5	0.25	0.5	1	3	1.5	3	6
Fe	9	4.5	9	18	70	35	70	140
Ge	---	---	---	---	---	---	---	---
Hf	---	---	---	---	<0.8	0	0.4	4
K	50	25	50	100	800	400	800	1600
Li	4.5	2.25	4.5	9	2	1	2	4
Mg	4.5	2.25	4.5	9	20	10	20	40
Mn	0.5	0.25	0.5	1	0.8	0.4	0.8	1.6
Mo	0.01	0.005	0.01	0.02	2	1	2	4
Na	>200	200	400	800	800	400	800	1600
Nb	---	---	---	---	3	1.5	3	6
Ni	<0.04	0	0.02	0.2	0.8	0.4	0.8	1.6
P	<1.	0	0.5	5	<40	0	20	200
Pb	0.4	0.2	0.4	0.8	3	1.5	3	6
Pd	---	---	---	---	---	---	---	---
Rb	---	---	---	---	<60	0	30	300
Sb	---	---	---	---	<2.	0	1	10
Si	4.5	2.25	4.5	9	50	25	50	100
Sn	<0.01	0	0.005	0.05	<0.2	0	0.1	1
Ta	---	---	---	---	60	30	60	120
Th	---	---	---	---	<2.	0	1	10
Ti	0.2	0.1	0.2	0.4	2	1	2	4
U	60	30	60	120	80	40	80	160
V	<0.01	0	0.005	0.05	0.2	0.1	0.2	0.4
W	<0.1	0	0.05	0.5	6	3	6	12
Zn	2	1	2	4	<3.	0	1.5	15
Zr	1.5	0.75	1.5	3	2	1	2	4

a. For analytes designated '<', the low value is defined to be zero. For those analytes designated '>', the low value is the value provided. For all others, the low value is one-half the value given.

b. For analytes designated '<', the best value is defined to be one-half of the value given. For analytes designated '>', the best value is twice the value provided. For others, the best value is the value given.

c. For analytes designated '<', the high value is defined to be ten times the best. For all other analytes, the high value is twice the best.

Assumptions Needed to Define the BCBG Waste Area Inventories

Because the total inventory information is not provided for the BCBG, the inventory information will be constructed for the source areas first and then the inventories for the two waste areas for modeling will be assembled. The initial assumption made is that only the contaminants described in the remedial investigation and supporting documentation are needed to estimate exposure effects from the waste buried in the BCBG. Inventory estimates are not available for contaminants including asbestos[236] and many solvents[237]. However, despite these omissions, the contaminants that are modeled represent those (or their products) that have migrated into the areas surrounding the BCBG.

The primary motive force for contaminant migration from the buried waste sites is water either percolating from the surface or from groundwater moving through the site either perennially or periodically associated with storm or seasonal events (SAIC 1996a). Therefore, the waste areas for possible excavation are defined based on the movement of water through the source areas. Capping these areas (especially those perennially inundated with groundwater) will likely have little impact on the migration of contaminants from the site[238].

The BCBG source areas that are either periodically or perennially inundated with groundwater or impacted by shallow runoff (and bathtubbing) that directly impacts groundwater are (SAIC 1996a):

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[236] Asbestos was not recognized as a hazardous substance until the mid-1970s, and thus records were not kept concerning its disposal in the BCBG.

[237] Almost 60% of the solvents poured into BG-A between 1970 and 1981 are classified as "miscellaneous" (SAIC 1993); it is assumed that these solvents are not hazardous for modeling purposes.

[238] Much of the Bear Creek Burial Ground (BCBG) site has been capped under RCRA closures (SAIC 1996a; USDOE-ORO 1993).

- *Bathtubbing*: BG A-17
- *Intermittently inundated during storm events*: BG-A North and BG-E and J
- *Inundated during wet season*: BG-C West and BG-D East (assuming South and West)
- *Inundated perennially*: BG-A South and BG-C East

Therefore, two-thirds of the BCBG source areas (including two with very large volumes of organic solvents and contaminants) are likely candidates for retrieval. The remaining one-third of the areas are not good candidates either due to the likely effectiveness of a surface barrier or the extremely dangerous nature of the wastes including explosive and pyrophoric materials. Surface barriers have been installed at three of these BCBG areas (i.e., BG-B, Walk-In Pits North and South) as part of RCRA closures (SAIC 1996a).

It would appear unwise to remove the caps and excavate the wastes in these areas based on the information available. However, it may be appropriate to remove the caps for the *high-risk* source areas, especially if the caps are likely ineffective due to groundwater inundation. Whether or not a cap is already in-place for a BCBG source area does not factor into the decision to target it for retrieval; however, the impact on worker risks associated with the additional effort to remove an existing surface barrier is included in the model.

Two sets of waste areas are defined for modeling the impacts of waste retrieval activities on life-cycle risks: the maximum retrieval case and the targeted retrieval case. As indicated above, one-third of the source areas should not be considered for retrieval, which leaves the ten areas potentially impacted by groundwater (or shallow surface runoff) inundation. It is assumed that a combination of a surface barrier and modest groundwater collection and/or containment wall could be used successfully to maintain the four source areas (i.e., BG A-17, BG-A North and BG-E,J) that are impacted by bathtubbing or intermittent groundwater inundation (during storm events). The remaining six areas constitute the targeted retrieval waste area. Because these source areas also contain highly reactive and pyrophoric materials (i.e., metallic uranium chips), an excavation and retrieval process must be developed (e.g., using a contained, nitrogen-blanketed system) to prevent oxygen from reacting with the wastes upon excavation, retrieval, and handling.

All metallic saw fines that are also pyrophoric were buried in the Walk-In Pits and thus are not candidates for retrieval. It is also assumed that the solvents and organics buried in the Walk-In Pits were contained in 55-gal drums (USDOE-ORO 1993). All other wastes are assumed to be loose based on available information. For the waste form analysis, the wastes buried in the BCBG are translated into the categories used for the SDA inventory analysis. Uranium, thorium, and beryllium contaminants in metallic forms (i.e., saw fines, chips, or blocks) are assumed to be analogous to the fuel-like waste form defined for SDA modeling; contamination in other forms (i.e., debris or solid particles in oil or water) is assumed to undergo surface wash. All other BCBG contaminants in all other waste forms (i.e., sludge, liquid, solids, debris, etc.) are assumed to undergo surface wash.

BCBG Waste Area Inventory Information for Modeling

Based on the assumptions provided in the previous section, the waste area inventories needed for modeling are defined. Three sets of inventories will be defined based upon their inclusion or exclusion in targeted retrieval actions:

- *Set 1: Not included in any retrieval actions*: BG-B, Walk-In Pits North and South, BG A-16 and BG A-18
- *Set 2: Always targeted for retrieval actions (Targeted Retrieval case)*: BG-C East and West and BG-D East, South, and West, and BG-A South
- *Set 3: Targeted only during Maximum Retrieval case*: BG A-17, BG-A North and BG-E and BG-J

These sets of inventories can then be combined to derive the appropriate source information for modeling the impacts of targeted retrieval activities for the BCBG wastes. Also, because the primary focus of this research is the impact on relative risks for the various remedial actions (and the Walk-In Pits and BG A-16 and A-18 are included in all cases), accuracy in the inventory estimates for these source areas is less significant to the risk comparison, and thus minimal effort can be expended to define these inventories.

The first set of inventories includes those areas not involved in any retrieval scenario (i.e., denoted *Set 1* above). Based on the information provided in the most recent remedial investigation report for the Bear Creek Valley (SAIC 1996a; b), the best inventory for *Set 1* can be defined as illustrated in Table 98 and includes wastes from BG A-16 and -18, BG B, and Walk-In Pits North and South[239]. The most diverse (including organics, acids, reactive explosive chemicals, waste oils, etc.) and likely difficult-to-handle wastes (including reactive, pyrophoric, and explosive materials in addition to hazardous wastes) are those in the Walk-In Pits although other areas in *Set 1* also may contain significant amounts of pyrophoric uranium and thorium. There is no evidence that PCA was buried in BCBG and thus the reported inventory for trichloroethane is split between 1,1,1- trichloroethane and 1,1,2-trichloroethane (which also may account for the 1,2-dichloroethane found in the environment (SAIC 1996a; b)). Fortunately these *high-*

[239] The number of drums in which wastes are buried is not available; therefore, the value from Table 94 for the dumped, non-VOC drums is used. The same failure rate is also used for the BCBG drums.

risk areas are not likely to be impacted from groundwater inundation and can be capped to limit further contaminant migration.

Diverse wastes from both an exposure and physical hazard sense were also buried in the source areas contained in BCBG *Set 2*. The diversity in contaminants for *Set 2* primarily comes from the BG A-South source area, which included liquid solvent, gasoline, waste oil, and mop water disposals via pouring into standpipes as well as uranium-contaminated debris. However, the primary physical hazard involves potential excavation, retrieval, and handling of pyrophoric uranium from the other source areas that are included in *Set 2*.

The wastes and hazards are similar for the source areas defining BCBG *Set 3*. The primary diversity in buried wastes comes from BG-A North, but the primary physical hazards would involve excavation and retrieval of the waste buried in the other *Set 3* source areas that contain large amounts of pyrophoric uranium. From the information provided in the most recent remedial investigation reports (SAIC 1996a; b), the wastes in the source areas comprising both BCBG *Set 2* and *Set 3* are likely uncontained or "loose". The best inventory information for the *Set 2* and *Set 3* source areas on a waste form basis is provided in Table 99[240].

[240] The dimensions of the BCBG waste areas are also needed. From the information in Table 96, the waste area volumes for *Set 1*, *2*, and *3* are 97,500 m^3, 87,700 m^3, and 124,500 m^3, respectively. Because waste depths are not provided on an area-specific basis, an average depth of 6 m is used.

Table 98. Best Inventory by Waste Form[a] for BCBG *Set 1* Source Areas

	Drums (kg)		No Containment (kg)		
Contaminant[b]	**Fuel-like**	**Surface Wash[c]**	**Fuel-like**	**Surface Wash**	**Total**
Ag		9.00E-06			9.00E-06
Al		3.60E-03		7.00E+00	7.00E+00
As				1.00E-01	1.00E-01
B		3.60E-04			3.60E-04
Ba		7.20E-04			7.20E-04
Be		2.16E-02		6.10E+02	6.10E+02
Br		2.30E+01			2.30E+01
Cd		3.60E-04			3.60E-04
Co(-60)		1.80E-04			1.80E-04
Cr		1.00E+02		7.00E+02	8.00E+02
Cu		9.00E-04			9.00E-04
Fe		1.62E-02			1.62E-02
Hg				3.10E+01	3.10E+01
Mn		9.00E-04			9.00E-04
Mo		1.80E-05			1.80E-05
Ni		3.60E-05		1.20E+02	1.20E+02
Pb		7.20E-04		1.40E+02	1.40E+02
Sb		0.00E+00			0.00E+00
Sn		9.00E-06			9.00E-06
Th(-232)		0.00E+00	2.24E+04		2.24E+04
Ti		3.60E-04			3.60E-04
U (total)		1.08E-01	8.93E+06	4.80E+04	8.98E+06
U(-238)		1.07E-01	8.87E+06	4.77E+04	8.91E+06
U(-235)		7.68E-04	6.35E+04	3.41E+02	6.38E+04
U(-234)		5.83E-06	4.82E+02	2.59E+00	4.85E+02
U(-236)		6.48E-07	5.36E+01	2.88E-01	5.39E+01
V		9.00E-06			9.00E-06
Zn		3.60E-03			3.60E-03
Benzene		3.00E+03			3.00E+03
PCBs		4.00E+01			4.00E+01
Ammonia				1.10E+01	1.10E+01
Benzidine		7.30E+02			7.30E+02
Chloroform		2.50E-01			2.50E-01
(Sodium) Cyanide		4.80E-01			4.80E-01
DDT		1.10E+02			1.10E+02
Epoxys		2.20E+03			2.20E+03
Ether		1.40E+01			1.40E+01
Formaldehyde		1.00E+01			1.00E+01
Hydrazine		2.20E+00			2.20E+00
Mercuric Chloride				4.00E+02	4.00E+02
Phenol		1.10E+03			1.10E+03
1,1,(1,2)-Trichloroethane		1.80E+02			1.80E+02

a. Metallic waste forms for uranium and thorium are assumed to be analogous to the fuel-like forms defined for SDA modeling. Contaminants in other forms are assumed to undergo surface wash.

b. The contaminants considered were restricted to those that either have toxicity information (Dolislager 2006; USEPA 2006) or present potential physical hazards. Assumed radioactive isotope identity is provided in parentheses. Isotopic abundances for naturally-occurring uranium are used (Miles and Sieben 1994).

c. The 1,800 kg of waste oils in Walk-In Pit North were assumed to be the waste oil described in Table 97 contained in drums (like other liquids placed into this area).

Table 99. Best Inventory Estimates for the BCBG *Set 2* and *Set 3* (All Uncontained)

	Set 2 kilograms (No Containment)			Set 3 kilograms (No Containment)		
Contaminant[b]	**Fuel-like**	**Surface Wash[c]**	**Total**	**Fuel-like**	**Surface Wash**	**Total**
Ag		2.21E+00	2.21E+00		2.19E+00	2.19E+00
Al		2.30E+02	2.30E+02		2.22E+02	2.22E+02
B		2.19E+02	2.19E+02		2.18E+02	2.18E+02
Ba		1.99E+01	1.99E+01		1.83E+01	1.83E+01
Be	4.60E+04	2.57E+03	4.86E+04		5.36E+01	5.36E+01
Cd		2.30E+01	2.30E+01		2.22E+01	2.22E+01
Co(-60)		2.79E+00	2.79E+00		2.39E+00	2.39E+00
Cr		5.59E+01	5.59E+01		4.78E+01	4.78E+01
Cu		2.18E+02	2.18E+02		2.18E+02	2.18E+02
Fe		1.58E+03	1.58E+03		1.54E+03	1.54E+03
Mn		2.05E+01	2.05E+01		1.85E+01	1.85E+01
Mo		4.36E+01	4.36E+01		4.36E+01	4.36E+01
Ni		1.75E+01	1.75E+01		1.75E+01	1.75E+01
Pb		6.78E+01	6.78E+01		6.62E+01	6.62E+01
Sb		2.18E+01	2.18E+01		2.18E+01	2.18E+01
Sn		2.21E+00	2.21E+00		2.19E+00	2.19E+00
Tc(-99)		5.00E-01	5.00E-01		1.30E-01	1.30E-01
Th(-232)	1.12E+05	4.86E+04	1.60E+05		3.02E+02	3.02E+02
Ti		4.48E+01	4.48E+01		4.40E+01	4.40E+01
U (total)	4.21E+06	1.09E+06	5.30E+06	3.07E+06	9.76E+05	4.05E+06
U(-238)	4.18E+06	1.09E+06	5.26E+06	3.05E+06	9.69E+05	9.69E+05
U(-235)	2.99E+04	7.77E+03	3.77E+04	2.18E+04	6.94E+03	6.94E+03
U(-234)	2.27E+02	5.90E+01	2.86E+02	1.66E+02	5.27E+01	5.27E+01
U(-236)	2.52E+01	6.56E+00	3.18E+01	1.84E+01	5.85E+00	5.85E+00
V		4.39E+00	4.39E+00		4.37E+00	4.37E+00
Zn		4.50E+01	4.50E+01		3.69E+01	3.69E+01
Asbestos					2.60E+05	2.60E+05
Cyclohexane		2.28E+01	2.28E+01			
Ethylbenzene		4.59E+02	4.59E+02			
n-Hexane		5.33E+02	5.33E+02			
MEK		3.90E+03	3.90E+03			
Methanol		2.40E+04	2.40E+04			
Naphthalene		8.27E+01	8.27E+01			
PCBs		1.40E+03	1.40E+03		1.10E+05	1.10E+05
PCE		5.60E+04	5.60E+04			
TCA		6.00E+04	6.00E+04			
TCE		5.30E+03	5.30E+03			
Toluene		3.50E+03	3.50E+03			
1,2,4-Trimethyl-benzene		5.64E+02	5.64E+02			
Varsol		5.90E+04	5.90E+04			
m-Xylene		8.04E+02	8.04E+02			
o-Xylene		5.04E+02	5.04E+02			
p-Xylene		3.35E+02	3.35E+02			
Xylenes (total)		1.64E+03	1.64E+03			

a. Metallic waste forms for uranium and thorium are assumed to be analogous to the fuel-like forms defined for SDA modeling. Contaminants in other forms are assumed to undergo surface wash.

b. The contaminants considered were restricted to those that either have toxicity information (Dolislager 2006; USEPA 2006) or present potential physical hazards. Assumed isotope identity is provided in parentheses. Isotopic abundances for naturally-occurring uranium are used for conversion (Miles and Sieben 1994).

c. The 57,000 kg of fuel-water poured into BG A-South was assumed to be a 50-50 mixture with the fuel assumed to be gasoline (ATSDR 1999; SAIC 1996b).

The final issue concerning the inventories for the BCBG concerns how to manage variation for modeling purposes. In general, the inventories provided for BG A-South (i.e., *Set 2*) were arbitrarily doubled to account for all years of potential disposal in this area (SAIC 1996b). A similar method (i.e., doubling) was used by the author to develop ranges for the inventories resulting from waste oil and mop water disposals as illustrated in Table 97. Other inventory information is based on per-year estimates multiplied by the time the disposal area was in service. For lack of better information, the doubling principal from the BCBG remedial investigation is followed: upper inventory values will be twice the best from Table 98 and Table 99 and the lower inventory values will be one-half the best value for each. For modeling purposes, these values will be treated as upper and lower 95% confidence limits about the centroid. The high and low inventories are included in the model.

Defining the Constituents of Interest for Prototype Site Exposure Modeling

A great many constituents are needed to model potential exposures for the Idaho Site Subsurface Disposal Area (SDA) and Oak Ridge Bear Creek Burial Grounds (BCBG). The minimum set of constituents of potential interest can be gathered from the various tables defined in this appendix describing the inventories for the constituents that may present risk to potentially exposed receptors. The minimum set of constituents of interest must include the radionuclides in Table 84 and the nonradionuclides in Table 85 and Table 86 with toxicity information and non-trace inventories. For the radionuclides in Table 84, their progeny must be included down to stable isotopes. The stable isotopes must only be included in the minimum constituent set if they present toxic hazards.

The decay chain information was collected from a number of sources (BNL-NNDC 2007; Eckerman 2003a; Hacker 2001; ICRP 1983; Kocher 1981). Most of the radioactive isotopes that require modeling are represented by four decay chain sequences: thorium (Figure 112), neptunium (Figure 112), uranium (Figure 113), and actinium (Figure 113). Other progeny are determined from recent datasets (BNL-NNDC 2007; Eckerman 2003b). Some progeny (e.g., At-128, At-215, Tl-210, etc. in Figure 113) are produced in such small quantities as to be negligible. Other radionuclides possess half-lives that are so long or short to cause problems with the GoldSim solution routines. These problematic radionuclides were discovered by trial-and-error and their half-lives replaced by values that did not result in either inaccurate results or solution errors[241]. Stable isotopes may be included in the constituent list to close the material balance to the extent possible.

Any radionuclides buried in the BCBG (as described in Table 98 and Table 99) that were not already members of the constituent list corresponding to the SDA inventory would also need to be included; however, no such constituents were identified in the BCBG wastes. The additions to the constituent list result from the solvents and other nonradionuclides buried in the BCBG. The nonradionuclide constituents corresponding to the SDA buried waste were identified in Table 85 and Table 86; only those contaminants with known or pending toxicity information are included in the GoldSim model constituent list. The nonradionuclide constituents with known or pending toxicity information corresponding to the BCBG wastes are found in Table 98 and Table 99.

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[241] These issues and their "work-arounds" are described in detail in the GoldSim model included with the media accompanying this dissertation.

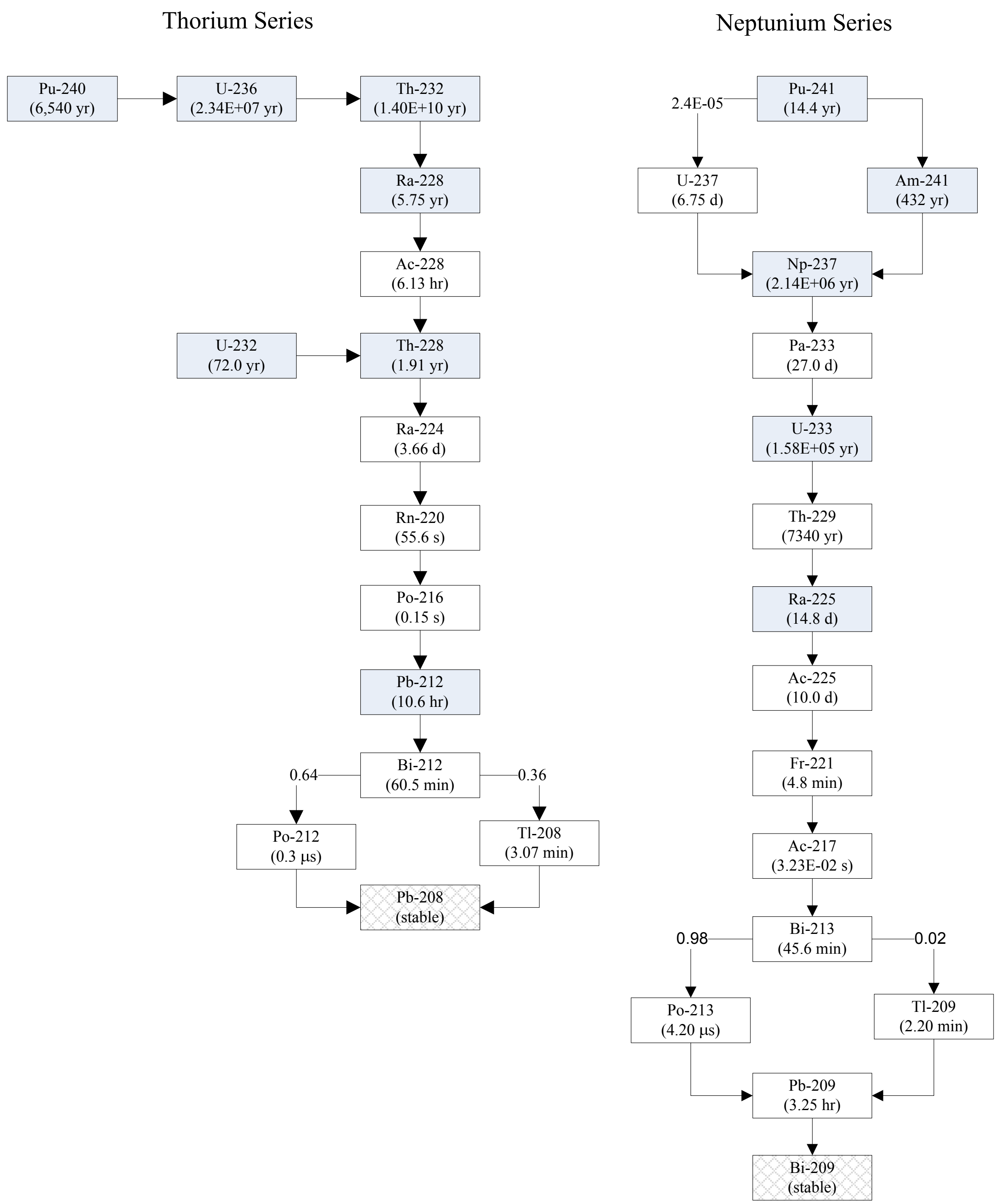

Figure 112. Decay chains for the thorium and neptunium series (BNL-NNDC 2007; Holdren et al. 2006) (where half-lives are provided in parentheses, anthropogenic predecessors from weapons production and reactor operations are shown to the left and contaminants included in site inventories are shown on a white background).

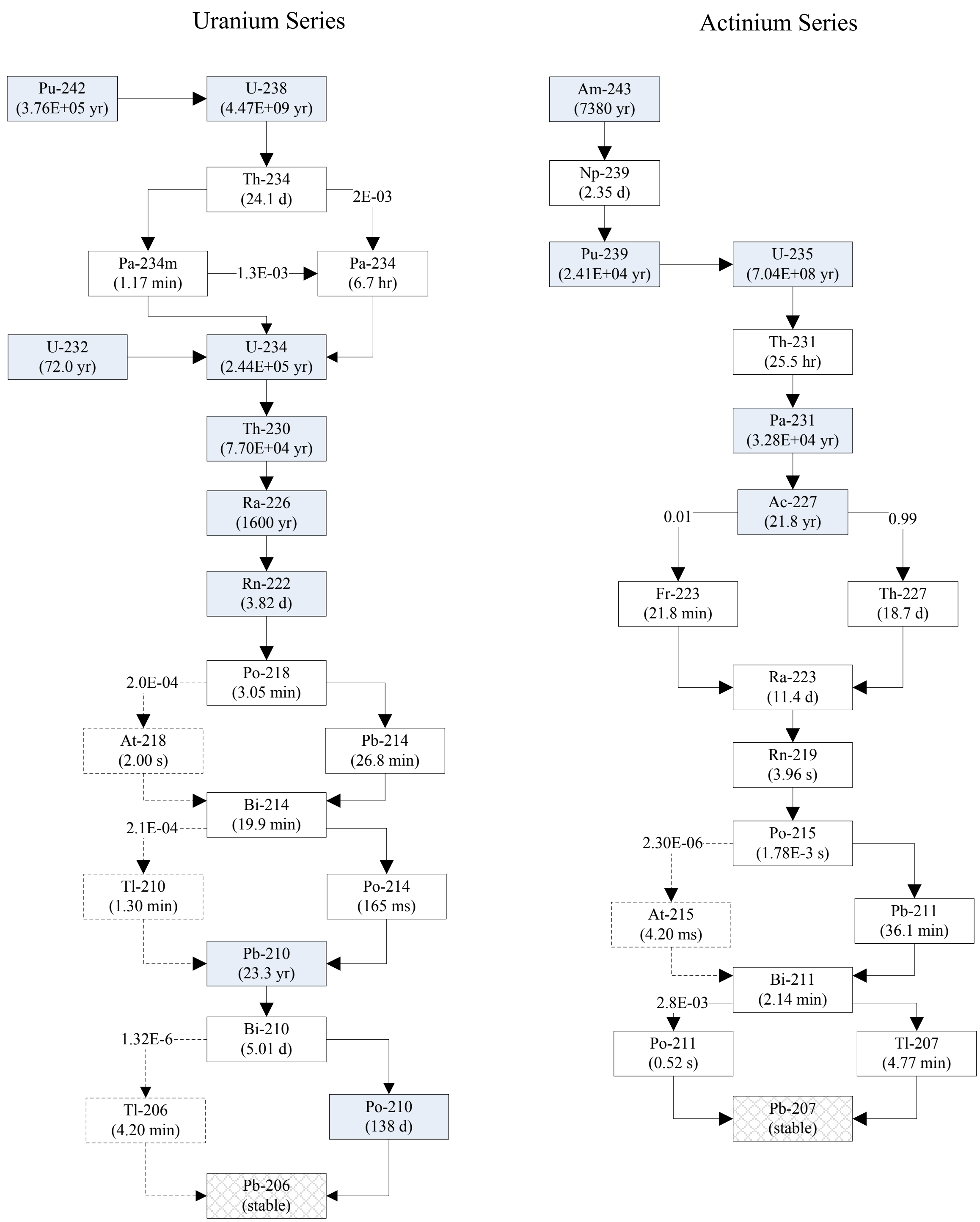

Figure 113. Decay chains for the uranium and actinium series (BNL-NNDC 2007; Holdren et al. 2006) (where half-lives are provided in parentheses, anthropogenic predecessors from weapons production and reactor operations are shown to the left, contaminants included in site inventories are shown on a white background, and those radionuclides produced in negligible quantities with very short half-lives are illustrated with dashed lines).

Degradation products for organic solvents have been found in media around the SDA (Holdren et al. 2006) and BCBG (SAIC 1996a) and, because some of these products may be more toxic than their parents, the ability to represent these constituents in the GoldSim exposure model is warranted[242]. Unlike the decay of radionuclides, the degradation of solvents in the media surrounding a buried waste site is very complicated and heterogeneous. However, the decision was made to implement degradation using the first-order decay mechanism built into the GoldSim model. For this research, a single set of progeny is defined for each organic solvent that might undergo decay and, unlike radioactive decay, a range of possible decay rates (or half-lives) will be defined and degradation in the environment handled stochastically. Both radioactive decay and solvent degradation can be turned off to allow comparisons to be made and transport and exposure results to be more easily verified. Tests are described in Appendix G illustrating the impacts of both radioactive decay and degradation on the exposure and risk results.

The radioactive constituents (and necessary progeny) list used for modeling exposure risks for the SDA and BCBG buried wastes is provided in Table 100. The elements needed to represent chemical hazards are also included in the constituent list in Table 100. Naturally-occurring isotopic ratios are not used to generate the constituents for the (nonradioactive) toxic elements. If a stable isotope is already available as a daughter product, then this isotope is used even if not the most abundant isotope. This assignment will have no impact on the resulting toxicity calculation. The most abundant, stable isotope is used otherwise.

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[242] Despite the presence of degradation products in the vadose zone beneath the SDA, the decision was made to not model the degradation products in the SDA remedial investigation "because of uncertainty about the rate and mechanism" for carbon tetrachloride (Holdren et al. 2006). An interesting comparison might be the uncertainty in the degradation information compared to the uncertainty in K_d values over the 1,000 years modeling period for the SDA.

Table 100. Minimum Set of Radioactive Isotopes for GoldSim Modeling

ID	Isotope	Atomic Weight[a]	Half-Life (yr)[a]	Rad	Daughter1	Stoich1	Daughter2	Stoich2	Reason for Inclusion[b]		
									SDA	BCBG	Progeny
H3	Y	3.01702	1.23E+01	Y	He3	1			r		
He3	Y	4.002602	9.00E+09	N							r
Li7	Y	6.941	9.00E+09	N							r
Be7	Y	9.012182	1.46E-01	Y	Li7	1			r		
Be9	Y	9.012182	9.00E+09	N					t,c		
Be10	Y	9.012182	1.51E+06	Y	B10	1			r		
B10	Y	10.811	9.00E+09	N						t	r
C14	Y	12.0107	5.70E+03	Y	N14	1			r		
N14	Y	14.0067	9.00E+09	N							r
Ne22	Y	20.1797	9.00E+09	N							r
Na22	Y	22.98976928	2.60E+00	Y	Ne22	1			r		
Al27	Y	26.9815386	9.00E+09	N						t	
P32	Y	30.973762	3.91E-02	Y	S32	1			r		
S32	Y	32.065	9.00E+09	N							r
S35	Y	32.065	2.40E-01	Y	Cl35	1			r		
S36	Y	32.065	9.00E+09	N							r
Cl35	Y	35.453	9.00E+09	N							r
Cl36	Y	35.453	3.01E+05	Y	Ar36	0.981	S36	0.019	r		
Ar36	Y	39.948	9.00E+09	N							r
Ca44	Y	40.078	9.00E+09	N							r
Ca45	Y	40.078	4.46E-01	Y	Sc45	1			r		
Sc44	Y	44.955912	4.53E-04	Y	Ca44	1			r		
Sc45	Y	44.955912	9.00E+09	N							r
Sc46	Y	44.955912	2.30E-01	Y	Ti46	1			r		
Ti46	Y	47.867	9.00E+09	N						t	r
V51	Y	50.9415	9.00E+09	N						t	r
Cr51	Y	51.9961	7.59E-02	Y	V51	1			r		
Cr53	Y	51.9961	9.00E+09	N					t,c	t,c,p	r
Cr54	Y	51.9961	9.00E+09	N							r
Mn53	Y	54.938045	3.74E+06	Y	Cr53	1			r		
Mn54	Y	54.938045	8.55E-01	Y	Cr54	1			r		
Mn55	Y	54.938045	9.00E+09	N					t	t	r
Mn56	Y	54.938045	2.94E-04	Y	Fe56	1			r		
Fe55	Y	55.845	2.74E+00	Y	Mn55	1			r		
Fe56	Y	55.845	9.00E+09	N						t	r
Fe57	Y	55.845	9.00E+09	N							r
Fe58	Y	55.845	9.00E+09	N							r
Fe59	Y	55.845	1.22E-01	Y	Co59	1			r		
Co57	Y	58.933195	7.44E-01	Y	Fe57	1			r		
Co58	Y	58.933195	1.94E-01	Y	Fe58	1			r		
Co59	Y	58.933195	9.00E+09	N							r
Co60	Y	58.933195	5.27E+00	Y	Ni60	1			r	r	
Ni59	Y	58.6934	7.60E+04	Y	Co59	1			r		
Ni60	Y	58.6934	9.00E+09	N						t	r
Ni63	Y	58.6934	1.00E+02	Y	Cu63	1			r		
Cu63	Y	63.546	9.00E+09	N					t	t	r
Cu65	Y	63.546	9.00E+09	N							r
Zn64	Y	65.409	9.00E+09	N						t	
Zn65	Y	65.409	6.68E-01	Y	Cu65	1			r		

a. Atomic weights and half-lives ($t_{½}$) primarily taken from the RAIS database (Dolislager 2006). In GoldSim, half-lives are converted to decay rates using $\ln(2)/t_{½}$. Stable elements are given a half-life of 9×10^9 years.

b. The possible reasons for inclusion in the radioactive constituent list are either inclusion in the SDA or BCBG inventory or progeny of these elements. The type of hazards is also represented: radioactive (r), toxic (t), carcinogenic (c), or physical hazard (p).

Table 100, Continued

ID	Isotope	Atomic Weight[a]	Half-Life (yr)[a]	Rad	Daughter1	Stoich1	Daughter2	Stoich2	Reason for Inclusion[b]		
									SDA	BCBG	Progeny
As75	Y	74.9216	9.00E+09	N						t	
Br79	Y	79.904	9.00E+09	N						t	
Kr85	Y	83.798	1.07E+01	Y	Rb85	1			r		
Rb85	Y	85.4678	9.00E+09	N							r
Rb86	Y	85.4678	5.11E-02	Y	Sr86	1			r		
Sr85	Y	87.62	1.78E-01	Y	Rb85	1			r		
Sr86	Y	87.62	9.00E+09	N							r
Sr88	Y	87.62	9.00E+09	N							r
Sr89	Y	87.62	1.39E-01	Y	Y89	1			r		
Sr90	Y	87.62	2.89E+01	Y	**Y90**	1			r		
Y88	Y	88.90585	2.92E-01	Y	Sr88	1			r		
Y89	Y	88.90585	9.00E+09	N							r
Y90	Y	88.90585	7.31E-03	Y	Zr90	1			r		r
Y91	Y	88.90585	1.60E-01	Y	Zr91	1			r		
Zr90	Y	91.224	9.00E+09	N							r
Zr91	Y	91.224	9.00E+09	N							r
Zr93	Y	91.224	1.53E+06	Y	**Nb93m**	1			r		
Zr95	Y	91.224	1.75E-01	Y	**Nb95**	0.99	**Nb95m**	0.01	r		
Nb93	Y	92.90638	9.00E+09	N							r
Nb93m	Y	92.90638	1.61E+01	Y	**Nb93**	1					r
Nb94	Y	92.90638	2.03E+04	Y	Mo94	1			r		
Nb95	Y	92.90638	9.59E-02	Y	Mo95	1			r		r
Nb95m	Y	92.90638	9.89E-03	Y	**Nb95**	1					r
Mo94	Y	95.94	9.00E+09	N							r
Mo95	Y	95.94	9.00E+09	N							r
Mo98	Y	95.94	9.00E+09	N						t	
Mo99	Y	95.94	7.53E-03	Y	**Tc99**	0.11	**Tc99m**	0.89	r		
Tc99	Y	98	2.11E+05	Y	Ru99	1			r	r	r
Tc99m	Y	98	6.87E-04	Y	**Tc99**	1					r
Ru99	Y	101.07	9.00E+09	N							r
Ru103	Y	101.07	1.08E-01	Y	**Rh103m**	1			r		
Ru106	Y	101.07	1.02E+00	Y	**Rh106**	1			r		
Rh103	Y	102.9055	9.00E+09	N							r
Rh103m	Y	102.9055	1.07E-04	Y	Rh103	1			r		r
Rh106	Y	102.9055	9.45E-07	Y	Pd106	1			r		r
Pd104	Y	106.42	9.00E+09	N							r
Pd106	Y	106.42	9.00E+09	N							r
Pd110	Y	106.42	9.00E+09	N							r
Ag104	Y	107.8682	1.32E-04	Y	Pd104	1					r
Ag109	Y	107.8682	9.00E+09	N					t	t	r
Ag109m	Y	107.8682	1.26E-06	Y	Ag109	1					r
Ag110	Y	107.8682	7.80E-07	Y	Cd110	0.997	Pd110	0.003	r		
Cd104	Y	112.411	1.10E-04	Y	**Ag104**	1			r		
Cd109	Y	112.411	1.26E+00	Y	**Ag109m**	1			r		
Cd110	Y	112.411	9.00E+09	N					t,c	t,c	r
Sn119	Y	118.71	9.00E+09	N						t	r
Sn119m	Y	118.71	8.03E-01	Y	Sn119	1			r		
Sb121	Y	121.76	9.00E+09	N					t	t	
Sb124	Y	121.76	1.65E-01	Y	Te124	1			r		

a. Atomic weights and half-lives ($t_{½}$) primarily taken from the RAIS database (Dolislager 2006). In GoldSim, half-lives are converted to decay rates using $\ln(2)/t_{½}$. Stable elements are given a half-life of 9×10^9 years.

b. The possible reasons for inclusion in the radioactive constituent list are either inclusion in the SDA or BCBG inventory or progeny of these elements. The type of hazards is also represented: radioactive (r), toxic (t), carcinogenic (c), or physical hazard (p).

Table 100, Continued

ID	Isotope	Atomic Weight[a]	Half-Life (yr)[a]	Rad	Daughter1	Stoich1	Daughter2	Stoich2	Reason for Inclusion[b] SDA	BCBG	Progeny
Sb125	Y	121.76	2.76E+00	Y	Te125	0.77	**Te125m**	0.23	r		
Te124	Y	127.6	9.00E+09	N							r
Te125	Y	127.6	9.00E+09	N							r
Te125m	Y	127.6	1.57E-01	Y	Te125	1					r
I125	Y	126.90447	1.63E-01	Y	Te125	1			r		
I129	Y	126.90447	1.57E+07	Y	Xe129	1			r		
I131	Y	126.90447	2.20E-02	Y	Xe131	0.99	**Xe131m**	0.01	r		
I133	Y	126.90447	2.37E-03	Y	**Xe133**	0.97	**Xe133m**	0.03	r		
Xe129	Y	131.293	9.00E+09	N							r
Xe131	Y	131.293	9.00E+09	N							r
Xe131m	Y	131.293	3.27E-02	Y							r
Xe133	Y	131.293	1.44E-02	Y	Cs133	1					r
Xe133m	Y	131.293	6.00E-03	Y	**Xe133**	1					r
Xe134	Y	131.293	5.80E+22	N							r
Cs133	Y	132.9054519	9.00E+09	N							r
Cs134	Y	132.9054519	2.07E+00	Y	Ba134	0.999997	Xe134	0.000003	r		
Cs136	Y	132.9054519	3.57E-02	Y	Ba136	1			r		
Cs137	Y	132.9054519	3.00E+01	Y	**Ba137m**	0.95	Ba137	0.05	r		
Ba133	Y	137.327	1.05E+01	Y	Cs133	1			r		
Ba134	Y	137.327	9.00E+09	N					r		
Ba136	Y	137.327	9.00E+09	N					r		
Ba137	Y	137.327	9.00E+09	N					r	t	
Ba137m	Y	137.327	4.86E-06	Y	Ba137	1			r		
Ba140	Y	137.327	3.49E-02	Y	**La140**	1			r		
La140	Y	138.90547	4.60E-03	Y	Ce140	1			r		r
Ce140	Y	140.116	9.00E+09	N							r
Ce141	Y	140.116	8.91E-02	Y	Pr141	1			r		
Ce144	Y	140.116	7.81E-01	Y	**Pr144**	0.9993	**Pr144m**	0.0007	r		
Pr141	Y	140.90765	9.00E+09	N							r
Pr143	Y	140.90765	3.72E-02	Y	Nd143	1			r		
Pr144	Y	140.90765	3.29E-05	Y	Nd144	1			r		r
Pr144m	Y	140.90765	1.37E-05	Y	**Pr144**	0.9993	Nd144	0.0007			r
Nd143	Y	144.242	9.00E+09	N							r
Nd144	Y	144.242	2.29E+15	N							r
Pm147	Y	145	2.62E+00	Y	Sm147	1			r		
Sm147	Y	150.36	1.06E+11	N							r
Sm152	Y	150.36	9.00E+09	N							r
Sm154	Y	150.36	9.00E+09	N							r
Eu152	Y	151.964	1.35E+01	Y	Sm152	0.721	Gd152	0.279	r		
Eu154	Y	151.964	8.59E+00	Y	Gd154	0.9998	Sm154	0.0002	r		
Eu155	Y	151.964	4.75E+00	Y	Gd155	1			r		
Gd152	Y	157.25	1.08E+14	N							r
Gd154	Y	157.25	9.00E+09	N							r
Gd155	Y	157.25	9.00E+09	N							r
Er164	Y	167.259	9.00E+09	N							r
Er169	Y	167.259	2.57E-02	Y	Tm169	1			r		
Er170	Y	167.259	9.00E+09	N							r
Tm164	Y	168.93421	3.81E-06	Y	Er164	1					r
Tm169	Y	168.93421	9.00E+09	N							r

a. Atomic weights and half-lives ($t_{½}$) primarily taken from the RAIS database (Dolislager 2006). In GoldSim, half-lives are converted to decay rates using $\ln(2)/t_{½}$. Stable elements are given a half-life of 9×10^9 years.

b. The possible reasons for inclusion in the radioactive constituent list are either inclusion in the SDA or BCBG inventory or progeny of these elements. The type of hazards is also represented: radioactive (r), toxic (t), carcinogenic (c), or physical hazard (p).

Table 100, Continued

ID	Isotope	Atomic Weight[a]	Half-Life (yr)[a]	Rad	Daughter1	Stoich1	Daughter2	Stoich2	Reason for Inclusion[b]		
									SDA	BCBG	Progeny
Tm170	Y	168.93421	3.52E-01	Y	Er170	1			r		
Yb164	Y	173.04	1.44E-04	Y	**Tm164**	1			r		
Hf181	Y	178.49	1.16E-01	Y	Ta181	1			r		
Ta181	Y	180.94788	9.00E+09	N							r
Ta182	Y	180.94788	3.14E-01	Y	W182	1			r		
W182	Y	183.84	8.30E+18	N							r
Os192	Y	190.23	9.00E+09	N							r
Ir192	Y	192.217	2.02E-01	Y	Pt192	0.9513	Os192	0.0487	r		
Pt192	Y	195.084	9.00E+09	N							r
Hg203	Y	200.59	1.28E-01	Y	Tl203	1			r		
Hg204	Y	200.59	9.00E+09	N					t	t	r
Tl203	Y	204.3833	9.00E+09	N							r
Tl204	Y	204.3833	3.78E+00	Y	Pb204	0.971	Hg204	0.029	r		
Tl207	Y	204.3833	9.08E-06	Y	Pb207	1					r
Tl208	Y	204.3833	5.81E-06	Y	Pb208	1					r
Tl209	Y	204.3833	4.11E-06	Y	**Pb209**	1					r
Tl210	Y	204.3833	2.47E-06	Y	**Pb210**	1					r
Pb204	Y	207.2	1.40E+17	N							r
Pb206	Y	207.2	9.00E+09	N							r
Pb207	Y	207.2	9.00E+09	N							r
Pb208	Y	207.2	9.00E+09	N					bk	bk	r
Pb209	Y	207.2	3.71E-04	Y	Bi209	1					r
Pb210	Y	207.2	2.02E+01	Y	**Bi210**	1			r		
Pb211	Y	207.2	6.87E-05	Y	**Bi211**	1					r
Pb212	Y	207.2	1.21E-03	Y	**Bi212**	1			r		
Pb214	Y	207.2	5.10E-05	Y	**Bi214**	1					r
Bi209	Y	208.9804	9.00E+09	N							r
Bi210	Y	208.9804	1.37E-02	Y	**Po210**	1					r
Bi211	Y	208.9804	4.07E-06	Y	**Tl207**	0.99724	**Po211**	0.00276			r
Bi212	Y	208.9804	1.15E-04	Y	**Po212**	0.6406	**Tl208**	0.3594			r
Bi213	Y	208.9804	8.67E-05	Y	**Po213**	0.9791	**Tl209**	0.0209			r
Bi214	Y	208.9804	3.79E-05	Y	**Po214**	0.99979	**Tl210**	0.00021			r
Po210	Y	209	3.79E-01	Y	Pb206	1			r		r
Po211	Y	209	6.36E-09	Y	Pb207	1					r
Po212	Y	209	9.48E-12	Y	Pb208	1					r
Po213	Y	209	1.16E-13	Y	**Pb209**	1					r
Po214	Y	209	5.21E-12	Y	**Pb210**	1					r
Po215	Y	209	5.65E-11	Y	**Pb211**	1					r
Po216	Y	209	4.60E-09	Y	**Pb212**	1					r
Po218	Y	209	5.89E-06	Y	**Pb214**	0.9998	**At218**	0.0002			r
At217	Y	210	1.02E-09	Y	**Bi213**	0.99993					r
At218	Y	210	1.57E-08	Y	**Bi214**	0.999					r
Rn219	Y	222	1.26E-07	Y	**Po215**	1					r
Rn220	Y	222	1.76E-06	Y	**Po216**	1					r
Rn222	Y	222	1.05E-02	Y	**Po218**	1			r		r
Fr221	Y	223	9.32E-06	Y	**At217**	1					r
Fr223	Y	223	4.19E-05	Y	**Ra223**	0.99994					r
Ra223	Y	226	3.13E-02	Y	**Rn219**	1					r
Ra224	Y	226	9.95E-03	Y	**Rn220**	1					r

a. Atomic weights and half-lives ($t_{½}$) primarily taken from the RAIS database (Dolislager 2006). In GoldSim, half-lives are converted to decay rates using $\ln(2)/t_{½}$. Stable elements are given a half-life of $9x10^9$ years.

b. The possible reasons for inclusion in the radioactive constituent list are either inclusion in the SDA or BCBG inventory or progeny of these elements. The type of hazards is also represented: radioactive (r), toxic (t), carcinogenic (c), or physical hazard (p).

Table 100, Continued

ID	Isotope	Atomic Weight[a]	Half-Life (yr)[a]	Rad	Daughter1	Stoich1	Daughter2	Stoich2	Reason for Inclusion[b]		
									SDA	BCBG	Progeny
Ra225	Y	226	4.08E-02	Y	**Ac225**	1			r		r
Ra226	Y	226	1.60E+03	Y	**Rn222**	1			r		r
Ra228	Y	226	5.75E+00	Y	**Ac228**	1			r		r
Ac225	Y	227	2.74E-02	Y	**Fr221**	1					r
Ac227	Y	227	2.18E+01	Y	**Th227**	0.9862	**Fr223**	0.0138	r		r
Ac228	Y	227	7.02E-04	Y	**Th228**	1					r
Th227	Y	232.03806	5.12E-02	Y	**Ra223**	1					r
Th228	Y	232.03806	1.91E+00	Y	**Ra224**	1			r		r
Th229	Y	232.03806	7.34E+03	Y	**Ra225**	1					r
Th230	Y	232.03806	7.54E+04	Y	**Ra226**	1			r		r
Th231	Y	232.03806	2.91E-03	Y	**Pa231**	1					r
Th232	Y	232.03806	1.41E+10	Y	**Ra228**	1			r	r	r
Th234	Y	232.03806	6.60E-02	Y	**Pa234m**	1					r
Pa231	Y	231.03588	3.28E+04	Y	**Ac227**	1			r		r
Pa233	Y	231.03588	7.39E-02	Y	**U233**	1					r
Pa234	Y	231.03588	7.65E-04	Y	**U234**	1					r
Pa234m	Y	231.03588	2.23E-06	Y	**U234**	0.9984	**Pa234**	0.0016			r
U232	Y	238.02891	6.89E+01	Y	**Th228**	1			r		r
U233	Y	238.02891	1.59E+05	Y	**Th229**	1			r		r
U234	Y	238.02891	2.46E+05	Y	**Th230**	1			r	r	r
U235	Y	238.02891	7.04E+08	Y	**Th231**	1			r	r	r
U236	Y	238.02891	2.34E+07	Y	**Th232**	1			r	r	r
U237	Y	238.02891	1.85E-02	Y	**Np237**	1					r
U238	Y	238.02891	4.47E+09	Y	**Th234**	1			r	r	r
U240	Y	238.02891	1.61E-03	Y	**Np240m**	1					r
Np237	Y	237	2.14E+06	Y	**Pa233**	1			r		r
Np239	Y	237	6.45E-03	Y	**Pu239**	1					r
Np240m	Y	237	1.18E-04	Y	**Pu240**	1					r
Pu238	Y	244	8.77E+01	Y	**U234**	1			r		r
Pu239	Y	244	2.41E+04	Y	**U235**	1			r		r
Pu240	Y	244	6.56E+03	Y	**U236**	1			r		r
Pu241	Y	244	1.43E+01	Y	**Am241**	0.9999755	**U237**	0.0000245	r		
Pu242	Y	244	3.75E+05	Y	**U238**	1			r		r
Pu244	Y	244	8.00E+07	Y	**U240**	0.99879					r
Am241	Y	243	4.33E+02	Y	**Np237**	1			r		r
Am242	Y	243	1.83E-03	Y	**Cm242**	0.827	**Pu242**	0.173	r		
Am243	Y	243	7.37E+03	Y	**Np239**	1			r		
Cm242	Y	247	4.46E-01	Y	**Pu238**	1			r		r
Cm244	Y	247	1.81E+01	Y	**Pu240**	1			r		
Cm248	Y	247	3.48E+05	Y	**Pu244**	0.9161					r
Cf252	Y	251	2.65E+00	Y	**Cm248**	0.96908			r		

a. Atomic weights and half-lives ($t_{1/2}$) primarily taken from the RAIS database (Dolislager 2006). In GoldSim, half-lives are converted to decay rates using $\ln(2)/t_{1/2}$. Stable elements are given a half-life of 9×10^9 years.

b. The possible reasons for inclusion in the radioactive constituent list are either inclusion in the SDA or BCBG inventory or progeny of these elements. The type of hazards is also represented: radioactive (r), toxic (t), carcinogenic (c), or physical hazard (p).

As indicated in Table 100, modeling exposures to radionuclides from the SDA buried wastes may be complex. On the other hand, modeling the volatile organic and other nonradioactive constituents is complex for both the SDA and BCBG. There are indications at both sites that degradation products have been formed (Holdren et al. 2006; SAIC 1996a). Based upon available information, it is assumed that degradation primarily proceeds anaerobically for both sites; however, abiotic and aerobic pathways are included[243] if there is any indication that the products may be present in the subsurface (Holdren et al. 2006; SAIC 1996a). The pathways assumed for the primary organic solvents buried in the SDA and BCBG are provided in Figure 114.

The minimum constituent list for modeling the nonradioactive compounds is provided in Table 101. The known degradation products (or daughters) with toxicity information for the nonradioactive compounds originally buried in the SDA and BCBG are also provided in Table 101 (Lawrence 2006)[244]. The stochiometries for the progeny are not provided in the table because they, unlike their radioactive counterparts in Table 100, are not intrinsic properties, but instead depend upon the nature of the pathways and conditions under which degradation is occurring and thus may vary over time. The decision was made to define degradation product stoichiometries stochastically to represent the impact of variation in stoichiometry on exposure and risk in a manner easiest to implement in GoldSim.

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[243] From a review of the available information, no degradation products from known aerobic pathways are indicated (Holdren et al. 2006; SAIC 1996a). Therefore, only the degradation products from known anaerobic and abiotic pathways are included in the exposure model (Lawrence 2006).

[244] The progeny that are *italicized* in Table 101 are not included in the minimum constituent list because they do not have toxicity information and were only included to illustrate that these progeny must be accounted for when the contaminant degrades. In the GoldSim model, this may result in the unit-sum constraint not being maintained for the stoichiometries for the constituents included in the model.

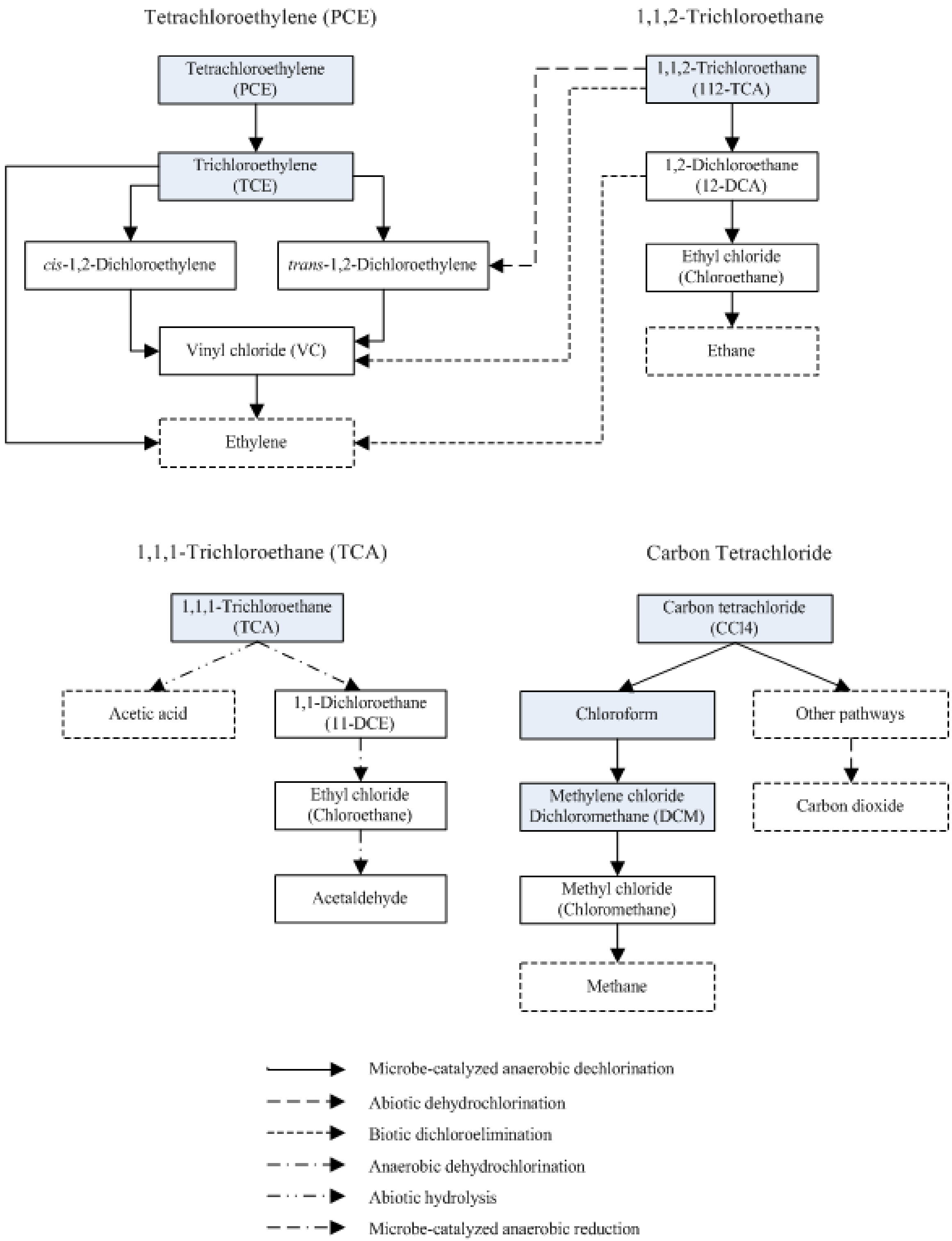

Figure 114. Degradation pathways for the primary volatile organic compounds (VOCs) originally buried in the SDA and BCBG (modified from Lawrence (2006)). Boxes with shaded backgrounds indicate inventories are available and dotted boxes indicate the chemical does not have toxicity information.

Table 101. Minimum Set of Nonradioactive Constituents for GoldSim Modeling

Chemical	Atomic Weight[a]	Progeny[b]			Reason for Inclusion[c]		
					SDA	BCBG	Progeny
Acetaldehyde	44.05						d
Acetone	58.08				t		
Ammonia	17.03				t	t	
Anthracene	178.24				t		
Asbestos	100				c	c	
Benzene	78.11	Phenol			c,t	c,t	
Benzidine	184.24					t	
Butanol, N-	74.12				t		
Carbon Tetrachloride (CCl4)	153.82	Chloroform	*Other pathways*		c,t		
Chloroethane (Ethyl chloride)	64.52	Acetaldehyde					d
Chloroform	119.38	DCM			c,t	t	d
Chloromethane	50.49						d
Dichloroethylene, 1,2-cis-	96.94	Vinyl Chloride					d
Dichloroethylene, 1,2-trans-	96.94	Vinyl Chloride					d
Cyclohexane	84.16					t	
Dichloromethane (DCM)	84.93	Chloromethane			c,t		
DDT	354.49					c,t	
Dichloroethane, 1,1-	98.96	Chloroethane					d
Dichloroethane, 1,2-	98.96	Chloroethane	*Ethylene*				d
Dioxane, 1,4-	88.11				c		
Epoxys	100					p	
Ether	100					p	
Ethylbenzene	106.17					c,t	
Formaldehyde	30.03				c,t	c,t	
Freon113[c]	187.38				t		
Hexane, N-	86.18					t	
HgCl2 (Mercuric Chloride)	271.5					t	
Hydrazine	32.05				c	c	
Methyl Ethyl Ketone (MEK)	72.11				t	t	
Methanol	32.04				t	t	
Methyl isobutyl ketone (MIBK)	100.16				t		
NaCN (Sodium cyanide)	49.01				t	t	
Naphthalene	128.18					t	
Nitrate (NO3)	62				t		
PCBs (high risk)	291.99				t	t	
PCE (Tetrachloroethylene)	165.83	TCE			c,t	c,t	
Phenol	94.11					t	d
Tributyl phosphate (TBP)	266.32				c,t		
Trichloroethane, 1,1,1- (TCA)	133.41	Dichloroethane, 1,1-	*Acetic acid*		t	t	
Trichloroethylene (TCE)	131.39	Dichloroethylene, 1,2-cis-	Dichloroethylene, 1,2-trans-	*Ethylene*	c,t	c,t	
Toluene	92.14				t	t	
Trichloroethane, 1,1,2-	133.41	Dichloroethane, 1,2-	Dichloroethylene, 1,2-trans-	Vinyl Chloride			d
Trimethylbenzene, 1,2,4-	120.2					t	
Vinyl Chloride	62.5	*Ethylene*					d
Xylene, Mixture	106.17				t	t	

a. Formula weights primarily taken from the RAIS database (Dolislager 2006). Any chemical that does not have a formula weight or is a mixture of many compounds was assigned a value of 100 g/mol. Degradation rates for organic compounds are described later in this appendix.
b. Only those progeny are shown with toxicity information unless required (in *italics*) to illustrate multiple progeny.
c. The possible reasons for inclusion in the nonradioactive constituent list are either inclusion in the SDA or BCBG inventory or progeny of these elements. The type of hazards is also represented: radioactive (r), toxic (t), carcinogenic (c), or physical hazard (p).
d. Freon 113 is also known as 1,1,2-Trichloro-1,2,2-trifluoroethane.

The following rules are used to define stoichiometries for the degradation products in Table 101. The first rule is that there is a unit-sum constraint on the products, which dictates the corollary that the stoichiometry is unity for a contaminant with a single daughter. Examples are chloromethane and chloroform. The second rule is that, for lack of better information, progeny are assumed equally likely (which is needed for the point-value case). A simple way to implement this rule is to generate *n* stochastic values from a unit uniform distribution, U[0,1], and then normalize the *n* samples by their sum. This also provides the correct stoichiometry when there is a single daughter.

None of the chemicals in Table 101 are isotopes or radioactive. Unlike the constant, first-order decay of the radionuclides in Table 100, degradation of the organic solvents and other compounds in Table 101 is a much more complicated process. Under specific conditions, organic compounds often degrade at a particular rate based on the presence and activity of appropriate microbes and environmental conditions (Lawrence 2006). However, as conditions change so does the rate of degradation. Unlike radioactive decay, there is no intrinsic rate of degradation.

Because of the difficulty in characterizing the various environmental media through which the organic contaminants will migrate, the degradation process is handled stochastically using the first-order decay mechanism built into the GoldSim model (for radioactive decay). The degradation rate is assumed to be adequately described for screening purposes using a stochastic first-order model (producing progeny with stochastic stoichiometries). Available ranges and summary statistics for the first-order degradation rates for many of the contaminants in Table 101 are provided in Table 102. For lack of better information, available anaerobic rates for aqueous conditions are used for both the SDA and BCBG (Howard et al. 1991); the corresponding aerobic rates are provided for comparison purposes or if aerobic pathways are later identified for either the SDA or BCBG conditions. When available, anaerobic degradation rates from field and *in situ* studies are preferred (Suarez and Rifai 1999). When only a range of values are provided, it is assumed that all rates are equally likely and a uniform distribution is used. When summary statistics (i.e., arithmetic mean and standard deviation) are provided, the distribution is assumed lognormal. For the point-value case, the mean (or 50^{th}-percentile) value of the degradation rate is assumed. To evaluate the impact of organic degradation on exposure and risk, the results are compared to those from a test case in which organic degradation is not allowed as illustrated in Appendix G.

Table 100 and Table 101 define a minimum set of 237 isotopes and 45 nonradioactive compounds, respectively, that should be modeled to predict the potential exposure risks to receptors impacted from the SDA and BCBG buried wastes. Inventories and other basic information describing these constituents are provided in this appendix and the GoldSim model. The other information required form modeling (especially the transport properties) will be provided in other appendices to this dissertation and the GoldSim model with appropriate references.

Table 102. First-order Degradation Rates for Selected Organic Compounds (day^{-1})

	Aerobic (Soil)[a]		Anaerobic			
			Aqueous[a]		Field/In Situ[b]	
Chemical	Low	High	Low	High	Mean	Std. Dev.
Acetone	0.099	0.69	0.025	0.17	---	---
Anthracene	0.0015	0.014	0.00038	0.0035	---	---
Benzene	0.043	0.14	0.0010	0.0062	0.03	0.06
Benzidine	0.087	0.35	0.022	0.087	---	---
Carbon Tetrachloride (CCl4)	0.0019	0.0039	0.025	0.17	0.141	0.174
Chloroform	0.0039	0.025	0.025	0.099	---	---
Chloroethane (Ethyl chloride)	0.025	0.099	0.0062	0.025	---	---
Chloromethane (Methyl chloride)	0.025	0.099	0.0062	0.025	---	---
DDT	0.00012	0.00095	0.0069	0.043	---	---
Dichloroethane, 1,1-	0.0045	0.022	0.0011	0.005	0.002	0.003
Dichloroethane, 1,2-	0.0039	0.0069	0.0010	0.0017	0.002	0.003
Dichloroethylene, *cis*-1,2-	0.0039	0.025	0.0010	0.0062	0.002	0.031
Dichloroethylene, *trans*-1,2-	0.0039	0.025	0.0010	0.0062	0.003	0.001
Dioxane, 1,4-	0.0039	0.025	0.0010	0.0062	---	---
Ethylbenzene	0.069	0.23	0.0030	0.0039	0.218	1.057
Formaldehyde	0.099	0.69	0.025	0.17	---	---
Hydrazine	0.099	0.69	0.025	0.17	---	---
Methanol	0.099	0.69	0.14	0.69	---	---
Methyl Ethyl Ketone (MEK)	0.099	0.69	0.025	0.17	---	---
Methyl isobutyl ketone (MIBK)	0.099	0.69	0.025	0.085	---	---
Methylene chloride (DCM)	0.025	0.099	0.0062	0.025	---	---
Naphthalene	0.014	0.042	0.0027	0.028	---	---
Phenol	0.069	0.69	0.025	0.087	---	---
Tetrachloroethylene (PCE)	0.0019	0.0039	0.00042	0.0071	0.01	0.022
Toluene	0.032	0.17	0.0033	0.012	0.237	0.733
Trichloroethane, 1,1,1- (TCA)	0.0025	0.0050	0.00063	0.0012	0.029	0.039
Trichloroethane, 1,1,2-	0.0019	0.0051	0.00047	0.0010	---	---
Vinyl chloride	0.0039	0.025	0.0010	0.0062	0.153	0.228
Trichloroethylene (TCE)	0.0019	0.0039	0.00043	0.0071	0.003	0.005
Xylene, Mixture[c]	0.025	0.099	0.0019	0.0039	0.021	0.026

a. Degradation rates converted from half-lives provided in Howard et al. (1991). A uniform distribution is assumed over the range provided as there is no reason to assume certain parts (e.g., the middle) of the distribution are more likely than others.

b. Degradation rate summary statistics for selected compounds are provided in Suarez (1999). A lognormal distribution is assumed using the arithmetic mean and standard deviation provided.

c. Summary statistics based upon an assumed equal split of the *m*-, *o*-, and *p*- isomers of xylene.

Uncertainties in Defining the Inventory for Modeling

Inventories provide the most fundamental information required to determine if the radionuclides and chemicals originally buried pose unacceptable risks to receptors—both workers and the general public. If neither the contaminant nor one of its parent compounds were buried at the site, then there is no risk from the contaminant. However, lack of knowledge may also be problematic if, for example, no records were kept concerning the disposals. That is why the as-buried inventory information was reconciled to the point possible with measurement information for the media surrounding the buried waste sites studied for this research. This approach cannot prevent all such errors of omission[245], but it can reduce them to the point possible with available information.

The Idaho Site SDA and Oak Ridge BCBG are highly complex sites in which thousands of shipments of waste were buried over many decades. The wastes contained hundreds of contaminants of potential interest, contained and loose, in diverse waste forms. Because of the nature of the disposal at both sites, thousands of records were examined during the on-going remedial investigation process for each site to identify contaminants and estimate inventories. However, it is not deemed appropriate to begin with the results of the existing remedial investigations for the sites. The original inventory information used to generate the contaminants of potential concern for the sites must be used as the basis for the modeling here because 1) the approach in this research is different because it incorporates probabilistic analyses and 2) the contaminants that may be unimportant from a classical exposure analysis may be important from an integrated exposure and physical hazard perspective.

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[245] Unknown or unrecorded contaminants may have been released or have migrated at such slow rates that their presence may go unnoticed for a long time. Furthermore, the contaminant may not be expected and thus not analyzed for or the analytical method not sufficiently sensitive to detect the contaminant.

Furthermore, identifying contaminants of potential interest from a risk perspective and estimating their total inventories is insufficient for the analysis performed in this research. To successfully predict the release and impact of retrieval on the risks associated with the buried wastes, the inventories must be partitioned as follows:

- *Source area*—this helps dictate whether certain high-risk wastes can be targeted for retrieval,
- *Containment*—for example, were the wastes buried loose or in a drum or box, did the drum or box have a liner, and was the drum stacker or dumped, and
- *Waste form*—was the contaminant associated with a matrix (e.g., grout, glass, etc.) that might slow its release into the waste site.

The manners in which these release mechanisms are implemented in the GoldSim for exposure and risk model are presented in Appendix E. The remedial investigation reports and supporting information was invaluable in partitioning the available inventories according to area, containment, and waste form.

After an exhaustive analysis of the available information, the best that could be extracted were lower, best, and upper inventories partitioned by area, containment, and form for selected contaminants thought by the DOE site personnel to be the primary exposure risk drivers. Ranges for the partitioning were not apparent from the available information nor were they deemed necessary for the screening analysis performed in this research. The release and transport parameters used in the GoldSim model tend to be constant, independent values selected from often large ranges of values. Therefore, the added complexity of managing the inventory stochastically (and dealing with the complexity added by the unit-sum constraints) does not add sufficient value for the screening risk assessment model.

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APPENDIX E

IMPLEMENTING THE SURFACE WASH, DISSOLUTION, AND DIFFUSION RELEASE MECHANISMS IN GOLDSIM

The GoldSim model is capable of modeling the transport of the radioactive and hazardous species for the Idaho Site Subsurface Disposal Area (SDA) and Oak Ridge Bear Creek Burial Grounds (BCBG) that may become contaminants of potential concern based on predicted risks to receptors. CERCLA remedial investigations (USEPA 1988) have been completed for both the Idaho Site SDA (Becker et al. 1998; Holdren et al. 2006; Holdren et al. 2002) and Oak Ridge BCBG (SAIC 1996). In these reports, the inventory information compiled for the sites were examined based on projected risks to potential receptors and lists of contaminants of potential concern (COPC) were generated.

Apart from the movement of water through the burial site, the two primary factors affecting contaminant release and the potential for migration are whether or not the contaminant is contained in a drum or box and/or is immobilized in a waste matrix that would limit interaction of the waste with water or retard the release of contaminants into the surrounding water. This appendix deals with the latter issue; that is, how releases of contaminants from various waste forms are modeled in GoldSim.

The basic concept for modeling the release of a contaminant (i.e., using a *Source* element) is that any container (e.g., drum, box, etc.) in which the waste resides must first fail to potentially the contaminant. If the drum or box has an inner liner; both the container and liner must fail before contaminants may be released to the environment. Once the containers have failed, then any matrix in which the contaminant may be bound begins to degrade (in a congruent manner) and the contaminant is released as the matrix degrades. Therefore, failure mechanisms for the containers and degradation rates for any waste matrices binding the contaminants must be defined to model the source release.

Once exposed, contaminants are released into a *Cell Pathway* element associated with the *Source* element. The *Cell Pathway* element associated with the source may contain multiple fluid or solid media with partition coefficients among the media. Any contaminants released into the *Cell Pathway* are assumed to be instantaneously and completely mixed and equilibrated throughout all media. Solubility limits can be imposed on the fluid media in the *Cell Pathway*[246]. Thus matrix degradation, partitioning, and solubility can be modeled directly using a *Source* element; however, any other release mechanism must either be translated into these processes or modeled separately and the results input to the model, which adds greatly to the complexity in development.

The inventory examination in Appendix D indicates that numerous waste forms (e.g., activated metals, fuel-like elements, resins, glass, etc.) are present in the wastes buried in the SDA and BCBG sites. Three types of mass release mechanisms must be modeled based on the most prevalent types of waste forms in the SDA and BCBG (Anderson and Becker 2006; Holdren et al. 2006):

- *Surface wash*—an equilibrium partitioning model for wastes with surface contamination that could be removed via washing,
- *Dissolution*—a model in which the waste matrix undergoes dissolution for those contaminants encapsulated in a matrix not allowing diffusion, and
- *Diffusion*—a model for those contaminants in waste forms (e.g., sludges) that can diffuse to the surface.

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[246] If isotopes of the same element are modeled in GoldSim, the sum of the dissolved concentrations for all isotopes of an element cannot exceed the solubility limit (GTG 2005).

Once the waste has been exposed upon container failure, the different waste forms found in the buried waste sites undergo different release mechanisms as listed above. Therefore, these mechanisms must be modeled to provide a representative source term for exposure and risk modeling. The implementation of the release mechanisms is described in detail in this appendix.

The Surface Wash Mass Release Mechanism

The surface wash mechanism is used for those wastes with external contamination (e.g., Ac-227, Am-243, C-14, etc.) that could be washed off by water contacting the wastes (Anderson and Becker 2006). Typical SDA waste forms include general laboratory wastes, personal protective equipment, and rags from glove box cleanup (Anderson and Becker 2006; Holdren et al. 2006). The surface wash release mechanism is implemented as an equilibrium partitioning model using a waste form-solution partition coefficient, K_{wf}, to indicate how strongly the contaminant is sorbed to the waste form (Anderson and Becker 2006; Sullivan 2006). The values of the waste form-solution partition coefficients[247] used in the most recent Idaho Site remedial investigation modeling are provided in Table 103 (Anderson and Becker 2006). Conceptually, this partition coefficient is very similar to the more typical soil-solution partition coefficient, K_d (Sullivan 2006).

[247] In GoldSim, the equivalent molar values for partition coefficients must have the same value (GTG 2005). In other words, one mole of Ac-227 will not sorb differently than one mole of Ac-225. The mass-based values in Table 103 are adjusted so that the equivalent molar values are equal for GoldSim implementation. However, in so doing the same surface wash mechanism is applied to all isotopes for the elements Table 103 and thus may have a small impact on these other elements.

Table 103. Distribution Coefficients for the SDA Isotopes undergoing Surface Wash (Anderson and Becker 2006)

Isotope	$K_{wf,general}$ (mL/g)	$K_{wf,resin}$ (mL/g)		Isotope	$K_{wf,general}$ (mL/g)	$K_{wf,resin}$ (mL/g)
Ac-227	225	---		Pu-239	2500	---
Am-241	225	---		Pu-240	2500	---
C-14	0.4	19		Ra-226	575	---
Cs-137	1000	---		Sr-90	60	---
I-129	0	19		Tc-99	0	19
Nb-94	500	---		U-233	15.4	---
Np-237	23	---		U-234	15.4	---
Pa-231	8	---		U-235	15.4	---
Pb-210	270	---		U-236	15.4	---
Pu-238	2500	---		U-238	15.4	---

Assuming that the waste form, porous medium (e.g., contaminated soil in the waste area), and solution are always in equilibrium and that absorption can be represented linearly, the modified retardation coefficient[248] obtained from the pertinent material balance is (Sullivan 2006):

$$R' = 1 + \frac{\rho K_d}{\theta} + \frac{\rho_{wf} V_{wf} K_{wf}}{\theta V_e} \qquad [41]$$

where ρ is the bulk density of the porous media, θ the volumetric moisture content, ρ_{wf} and V_{wf} the waste form density and volume, respectively, and V_e the volume of the porous media (assuming both soil and waste form) and solution system. Rearranging the above equation provides the following relationships for the modified retardation coefficient:

[248] The parameter R' is denoted the "modified retardation coefficient" because the typical representation of this coefficient is $R = \rho K_d/\theta$ when there is only a single absorbing medium. The retardation coefficient represents the degree to which contaminant movement is retarded relative to that of the solution because of the absorbing medium.

$$
\begin{aligned}
R' &= 1 + \left(\frac{\rho}{\theta}\right)\left[K_d + \left(\frac{\rho_{wf} V_{wf}}{\rho V_e}\right) K_{wf}\right] \\
&= 1 + \left(\frac{\rho}{\theta}\right)\left[K_d + \left(\frac{m_{wf}}{m_e}\right) K_{wf}\right]
\end{aligned} \qquad [42]
$$

Therefore, the normal contaminated soil-water partition coefficients (or K_d's) in GoldSim for those elements (e.g., Ac-227, Am-243, C-14, etc.) undergoing surface wash are modified by the mass weighted waste form-solution partition coefficient to implement the surface wash model with minimal effort. The necessary waste form-solution partition coefficients are provided in the Idaho Site remedial investigation reports (Anderson and Becker 2006; Holdren et al. 2006). Solubility limits are also imposed on the fluid in the *Cell Pathway* element into which the contaminants are released (GTG 2005).

The Dissolution Mass Release Mechanism

The second mass source release mechanism that must be modeled is dissolution. This mechanism is used for those contaminants that are an integral part of the wastes (Anderson and Becker 2006). Typical waste forms include cement, grout, glass, or activated metals in which the activation products are not released until the base metal corrodes (Anderson and Becker 2006; GTG 2005; Holdren et al. 2006). Release of contaminants from the matrix is assumed to be congruent with the degradation or dissolution of the matrix; however, degradation of the waste matrix does not begin until exposed, for example, after container failure (GTG 2005). The dissolution release mechanism is implemented as a *fractional* degradation rate.

Although matrix degradation rates are often expressed on a surface area basis (i.e., units of mass/area/time), these rates in GoldSim are expressed as *fractional* rates:

$$\textit{fractional rate}\,[1/\text{t}] = \textit{absolute rate}\,[\text{M/L}^2/\text{t}] \times \textit{specific area}\,[\text{L}^2/\text{M}] \qquad [43]$$

where t is time, M is mass, and L is length. Because of large uncertainties in the geometry of the matrix and absolute degradation rates, especially over long times, it tends to be very difficult to model the temporal variability in the degradation rate, and the GoldSim preference is to express degradation as a constant—albeit uncertain—rate, k_s, with units of ($1/t$) (GTG 2005)[249]. Various waste forms (e.g., activated metals, glass, grout, etc.) would likely have different degradation rates—each would be given its own inventory and degradation rate in a detailed GoldSim *Source* element. Fortunately, the degradation rates (also described as dissolution or corrosion rates) provided for the wastes form buried in the SDA and BCBG are given as fractional rates making their use in the GoldSim very straightforward (Anderson and Becker 2006; Holdren et al. 2006). The fractional rates are provided in the GoldSim model.

The Diffusion Mass Release Mechanism

The final mass source release mechanism that must be modeled is diffusion. This mechanism is typically used for contaminants such as volatile organic compounds (VOCs) that diffuse through sludge or cement-encased wastes (Anderson and Becker 2006; Holdren et al. 2006). Although diffusion is implemented as a mass transport pathway between elements in GoldSim, the *Source* element does not include a diffusion release mechanism (GTG 2005). Thus either a diffusion release model must be

[249] Temporal variation in the fractional degradation rate can be expressed in GoldSim; however, this expression can lead to problems when attempting to integrate container failure and degradation. There is no way to determine the time since failure in GoldSim and thus a time variant degradation rate would have to be a function of simulation time and not time since failure. It is thus simplest from this respect to use a constant and uncertain degradation rate for each realization.

implemented as an external routine called from GoldSim or the diffusion model must be approximated using existing failure and waste form degradation processes in GoldSim.

Semi-Infinite Diffusion Release Model

Two models are typically used to approximate the contaminant release from a diffusion process. One model is based on treating the waste form as a semi-infinite medium where the surface concentration is assumed to remain zero. The cumulative fractional release (CFR_∞) is a function of time, t (Crank 1975; Sullivan 2006):

$$\mathrm{CFR}_\infty = 2\left(\frac{\mathrm{SA}_{\mathrm{wf}}}{\mathrm{V}_{\mathrm{wf}}}\right)\sqrt{\frac{\mathrm{D}_{\mathrm{wf}}\,\mathrm{t}}{\pi}} \qquad [44]$$

where SA_{wf}, V_{wf}, and D_{wf} are the waste form[250] surface area, volume, and diffusion coefficient, respectively. Unfortunately the maximum diffusion model in Equation 44 cannot be easily approximated in GoldSim.

Diffusion from a Cylindrical Waste Form

Because the diffusion release model in Equation 44 cannot be easily approximated in GoldSim, a more accurate representation of the diffusion release is examined for potential use. The basic waste form is assumed to be a 55-gallon drum, which is a cylindrical waste form with height H and radius R. The concentration at the surface of the waste form is again assumed to remain zero. For this model, the cumulative fractional release (CFR) is given as the product of two infinite series (Nestor 1980; Sullivan 2006):

---

[250] The waste form is a 55-gal (0.21 m^3) drum with inside height of 0.83 m and inside radius of 0.29 m.

$$\mathrm{CFR} = 1 - \frac{32 S_q S_c}{\pi^2} \qquad [45]$$

where

$$S_c = \sum_{m=1}^{m=\infty} \frac{1}{\beta_m^2} \exp\left[-\left(\frac{\beta_m}{R}\right)^2 D_{wf}\, t\right]$$

$$S_q = \sum_{n=1}^{n=\infty} \frac{1}{(2n-1)^2} \exp\left[-\left(\frac{(2n-1)\pi}{H}\right)^2 D_{wf}\, t\right]$$

and β_m are the roots of the zeroth-order Bessel function and the other parameters are the same as for Equation 44.

Diffusion Model Comparison for Buried Wastes

Two values of the diffusion coefficient are provided for the SDA volatile organic compounds (VOCs): 2×10^{-10} and 2.5×10^{-10} m^2/s (Anderson and Becker 2006; Holdren et al. 2006). These values are larger than the maximum acceptable value of 1×10^{-10} m^2/s for a waste form diffusion coefficient suggested in the DUST-MS model (Sullivan 2006) used by Idaho Site personnel for SDA VOC modeling (Anderson and Becker 2006; Holdren et al. 2006). For a 55-gallon drum, diffusion coefficients between 1×10^{-10} and 2.5×10^{-10} m^2/s result in all of the contaminant diffusing out of the waste form (based upon the semi-infinite model in Equation 44) in between 390 and 980 days. Therefore, the approximation of the diffusion model in GoldSim will not likely have a critical impact on exposure predictions when compared to the assessment period.

Assuming a diffusion coefficient of 1×10^{-10} m^2/s, the cumulative fractional releases for the two diffusion models (Equations 44 and 45[251]) are compared in Figure

[251] For the cylindrical waste form model described in Equation 45, only the first 20 roots of the zeroth-order Bessel function were used to estimate the releases in Figure 115. It has been shown that, in general, the first ten such roots can provide a sufficiently accurate result (Sullivan 2006).

115. Either model appears appropriate for a screening-type exposure analysis; however, neither can be implemented using the current *Source* element (GTG 2005). A diffusion release model must be implemented in the GoldSim model, called from an external subroutine or program, or approximated using the processes currently available in the GoldSim Source element. All of these are potential solutions; however, the focus here is to use the existing GoldSim *Source* element because of the rapid nature of dissolution process and the ability to easily implement the solution stochastically.

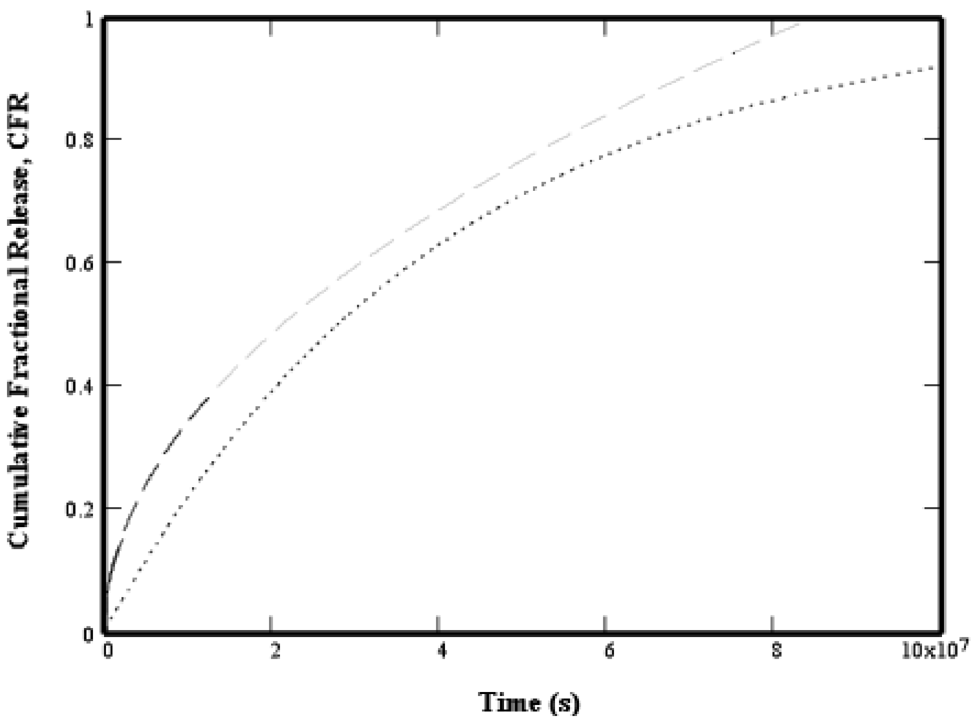

Figure 115. Cumulative fractional release (CFR) as a function of time for the semi-infinite (Equation 44, dashed) and cylindrical (Equation 45, solid) waste form models assuming a 55-gal drum and diffusion coefficient of 1 x 10^{-10} m^2/s. The assumptions of the semi-infinite model only apply for the initial portion of the release as illustrated.

An Approximate Diffusion Release Model Using the GoldSim *Source* Element

The simplest and most efficient solution to implementing a diffusion release model in GoldSim is to use the fractional degradation process already used in the GoldSim *Source* element. On the surface, this notion may seem a bit strange; however, it will be shown that an approximate diffusion release model can be implemented using the existing *Source* element. Both models illustrated in Figure 115 are based on numerous assumptions and, therefore, neither model can be claimed to be correct. However, both models have been shown to be useful for screening type exposure and risk assessments (Anderson and Becker 2006). The intent here is to define yet another useful model relying upon the existing fractional degradation process model in the *Source* element.

The congruent degradation process in the *Source* element (assuming constant failure and degradation rates) essentially indicates that the cumulative fractional release of a contaminant can be described as a first-order exponential decay process (GTG 2005):

$$CFR_{exp} \propto \left(1 - e^{-k_s t}\right) \qquad [46]$$

where k_s is the constant fractional degradation rate. Although the release relationships in Figure 115 are not exponential in nature, they do suggest (based on general shapes) that an exponential decay representation (i.e., Equation 46) may adequately represent the diffusion process for a screening type exposure analysis. This general agreement would allow the extant *Source* element to be used to represent a diffusion release mechanism by simply defining an equivalent fraction degradation rate.

An obvious and easy choice of an equivalent degradation rate is that based on the time required to reach one-half of the initial concentration (i.e., the "half-life" of the diffusion release process described in Equation 45). Numerical techniques are used to determine the diffusion "half-life" for a 55-gal drum and given diffusion coefficient. The diffusion "half-lives" were estimated for a series of diffusion coefficients between 1×10^{-11} and 2.5×10^{-10} m^2/s and the following least-squares power law relationship was fit between the diffusion "half-life", t_D, in seconds and waste form diffusion coefficient, D_{wf}, in m^2/s:

$$t_D[s] = \frac{1}{\left(356m^{-2}\right)D_{wf}[m^2 s^{-1}]} \qquad [47]$$

with an $R^2 \approx 1.0$. An equivalent constant degradation rate, λ_D, can then be defined as:

$$\lambda_D[s^{-1}] = \frac{\ln(2)}{t_D[s]} = \ln(2)\left(356m^{-2}\right)D_{wf}[m^2 s^{-1}] = \left(\frac{247}{m^2}\right)D_{wf}[m^2 s^{-1}] \qquad [48]$$

The constant rate defined using Equation 48 would be the fractional degradation rate used in the GoldSim *Source* element to approximate the diffusion release from a waste form.

Figure 116 illustrates the relationship between the releases obtained using the approximate model versus those obtained using the semi-infinite or cylindrical waste form models from Equation 44 and Equation 45, respectively. Although the approximate diffusion model (using a constant waste form degradation rate) initially underestimates contaminant release relative to the diffusion models (by design), the general shape of the approximate release curve is similar to those for the actual diffusion models and provides releases bracketed by those of the diffusion models for times greater than the diffusion "half-life" value.

From the results in Figure 116 it appears reasonable to approximate the diffusion release of contaminants from drum wastes using the fractional degradation model in the GoldSim *Source* element with a constant rate computed from Equation 48. The diffusion process, based upon the models presented in this appendix, appears to occur much more rapidly than the other transport processes needed to estimate exposure risks for a 1,000-year assessment period. Under these circumstances, the most reasonable alternative model that can be implemented easily using the GoldSim *Source* element is to assume that the contaminants are loose and their releases are not impeded by diffusion through the waste matrix. The results of the approximate diffusion release model are compared to the results obtained when the contaminants are assumed to be loose in Appendix G to determine the impact of diffusion on exposure and risk.

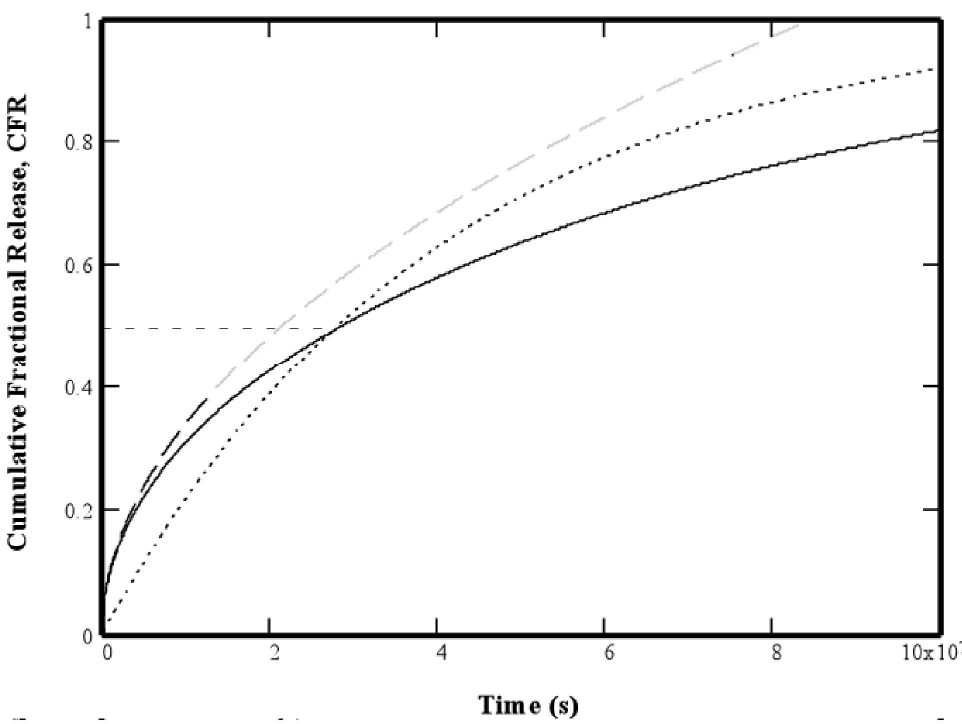

Figure 116. Cumulative fractional release (CFR) as a function of time for the semi-infinite (Equation 44, dashed), cylindrical (Equation 45, solid), and approximate (Equation 48, dotted) waste form models assuming a 55-gal drum and diffusion coefficient of 1 x 10^{-10} m^2/s.

Conclusions

Source release models have been defined describing the surface wash, matrix degradation, and diffusion contaminant release mechanisms. These mechanisms represent the dominant mass release mechanisms for the waste buried in the Idaho Site SDA and Oak Ridge BCBG. The models defined in this appendix can be easily implemented using the existing GoldSim Source elements without modification. Whereas the surface wash and dissolution models defined here are exact representations of the simplified models defined for screening risk assessment purposes, the diffusion model is an *approximate* model and the results from use of this model are, therefore, approximate. A test case is examined in Appendix G to examine the usefulness of the results obtained using the diffusion model.

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APPENDIX F

DEFINING VADOSE ZONE NETWORK PATHWAY ELEMENTS FOR THE SUBSURFACE DISPOSAL AREA AND BEAR CREEK BURIAL GROUNDS

The subsurface areas under both the Idaho Site Subsurface Disposal Area (SDA) and Oak Ridge Bear Creek Burial Grounds (BCBG) are prone to preferential flow. The area under the SDA is fractured basalt and that under the BCBG is karst. Modeling the flows and contaminants movement from the burial sites through the environment is enhanced if this basic phenomenon can be implemented in the GoldSim model. This appendix describes the implementation of fractured flow in the screening risk tool.

The foundation for modeling fractured flow is the GoldSim *Network Pathway* element, which provides an efficient solution (using a Laplace-transform approach) to fractured flow using a series of interconnected one-dimensional *Pipe Pathway* elements (GTG 2005a). To use the *Network Pathway*, a *fracture network* is specified describing the pipes in the network, how they are connected, and the geometry of and flow rate through each pipe. The transport properties (e.g., infill material, coating, matrix diffusion zones, etc.) for the pipes are defined in a *fracture set* describing groups of pipes. GoldSim allows sampling from a predetermined set of fracture networks to represent uncertainty in the model (GTG 2005a).

The *Network Pathway* allows numerous transport parameters and mechanisms (e.g., porous coatings and infill, matrix diffusion, stagnant zones, and suspended solids) to be modeled in the fractured zone. However, two issues become evident when examining the information available for both sites. The first issue is that it is very difficult to characterize the nature of the fracture zones beneath the two prototype sites. *Fracture networks* are typically created using a "discrete fracture network generation and flow simulation code" (GTG 2005a); however, such an endeavor is outside the scope of this research. Second, the information required to characterize pipe coatings, matrix diffusion stagnant zones, etc. will not likely be available for the sites. Therefore, the implementation of fractured flow must be based on information other than data.

The implementation of fractured flow in the screening risk tool must either be abandoned or a stylized version used. Fractured flow was considered of sufficient importance to contaminant transport in the prototype sites that it was implemented in the model. Because of a lack of data, the following assumptions and simplifications were made to allow fractured flow to be implemented in the screening risk tool:

- Without a fracture network available for a site, the example network provided in the GoldSim *Contaminant Transport Module User's Guide* (GTG 2005a) was used and "calibrated" to basic characteristics of the site subsurface. This network is illustrated in Figure 42 in Chapter VI.
- Because of a lack of data, the pipes are assumed to be coated with a porous medium and there are no matrix diffusion or stagnant zones. Only the interbed zone has a porous infill material.
- The fracture zone is "calibrated" to a low-porosity *Pipe Pathway* element so that the maximum concentration output and time of maximum output agree.

The nature in which fractured flow is implemented for each site is described in the sections to follow.

Idaho Site Subsurface Disposal Area (SDA) Vadose Zone

The vadose zone underlying the SDA is very extensive and was represented in the screening model by three zones of 73, 17, and 93 m in depth corresponding to the layers represented in Figure 40 in Chapter VI. One of the conceptual models considered by

Idaho personnel to model the subsurface areas beneath the SDA was a series of low-porosity, high permeability media (Anderson and Becker 2006). The model employed in the most recent remedial investigation report is a dual-continuum model (Holdren et al. 2006), which could not be replicated in the GoldSim model. Instead, the low-porosity medium was used to "calibrate" the *Network Pathway* element used in the model.

The initial step in defining the fractured networks for the SDA is to define GoldSim *Pipe Pathway* elements representing the three vadose zones in the screening risk tool. The general properties of these Pipe elements (of 73, 17, and 93 m in length) include a porosity of 0.05, dispersivity of 5 m, and no retardation. A unit mass of 1 g (of a conservative tracer) was injected into a *Pipe Pathway* element (at time 0 yr) and the mass output from the pipe was characterized as illustrated in Figure 117.

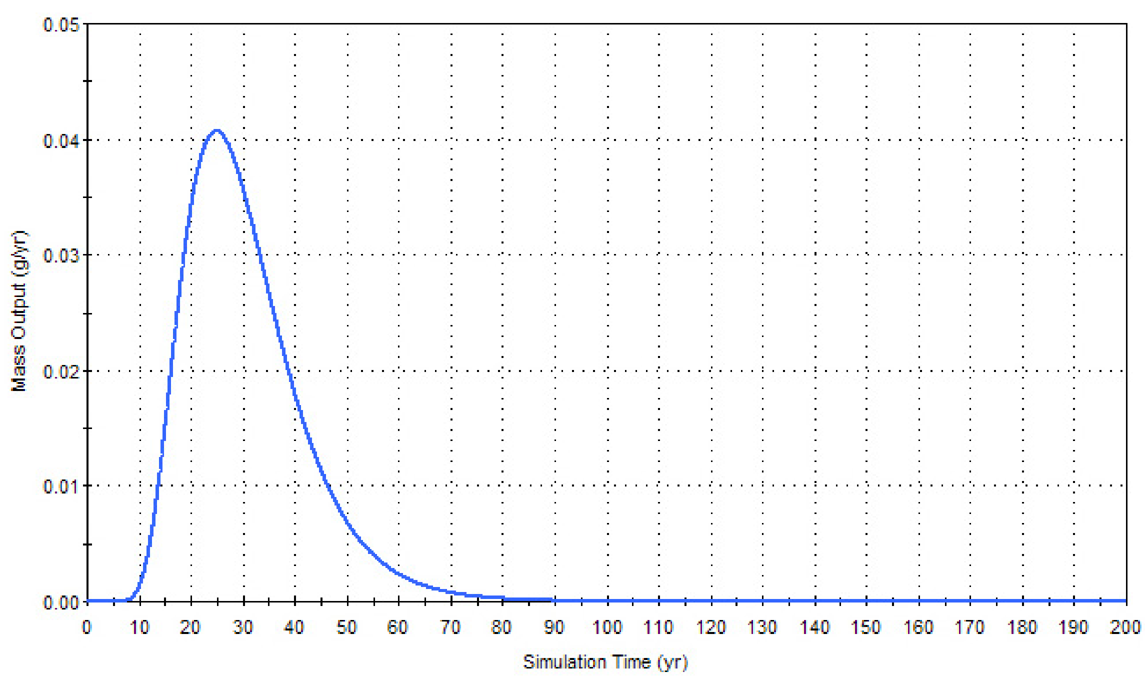

Figure 117. Mass versus Time Relationship for Pipe Element of Length 73 m with Porosity of 0.05 and No Retardation. (Maximum = 0.041 g/yr at 25 yrs)

For the 73 m pipe whose output is illustrated in Figure 117, the maximum mass output of 0.041 g/yr was found at 25 yrs. For pipes of 93 m and 17 m, the maximum mass outputs of 0.035 and 0.14 g/yr, respectively, were found at simulation times of 33 and 3.2 yr, respectively. These parameters (i.e., maximum output and time of maximum output) represent the basic characteristics of the fractured flow networks that are defined for the three vadose zone regions modeled for the SDA.

For a unit mass input for a conservative tracer and the 26-pipe example fracture network shown in Figure 40 in Chapter VI (GTG 2005a), the moisture content, water flux (cm/yr), and surface area (m^2) were initially set to their expected values and the coating thickness (cm), network pipe lengths (m), and total flow through the network pipes (m^3/yr)[252] were varied to determine whether the characteristic parameters could be approximated using the fracture network. Figure 118 illustrates the relationship between maximum mass output and time of maximum output for the results of the simulations representing the possible variations in the input parameters. The three sets of intersecting lines on Figure 118 illustrate the positions of the characteristic parameters for the 17 m, 73 m, and 93 m zones (from upper left to lower right).

Figure 118 illustrates that the expected characteristics of the three low porosity zones for the SDA vadose zone can be captured using the fracture network based on varying the pipe length and coating thickness. (The surface area was found to not impact the fracture results and will not be mentioned again.) For the expected conditions of the three SDA vadose zones, the corresponding fracture zone characteristics are

- Zone 1 (73 m): Length (all pipes) 25 m and Coating Thickness 54 cm.

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[252] These parameters are the only ones that will impact the mass output charactertics for the assumptions made in defining the fracture network.

- Zone 2 (17 m): Length (all pipes) 4 m and Coating Thickness 62 cm.
- Zone 3 (93 m): Length (all pipes) 55 m and Coating Thickness 31.5 cm.

The differences between the mass output rate for the original equivalent porous medium and the Network Pathway are illustrated in Figure 119 for Zone 1 (73 m). Note that the maximum mass output rate is approximately the same for both; however, the tail from the fracture network is longer and differently shaped. The next step is to determine the fracture zone characteristics for the various flow and moisture conditions that will be encountered for the various probabilistic cases that may be encountered during modeling.

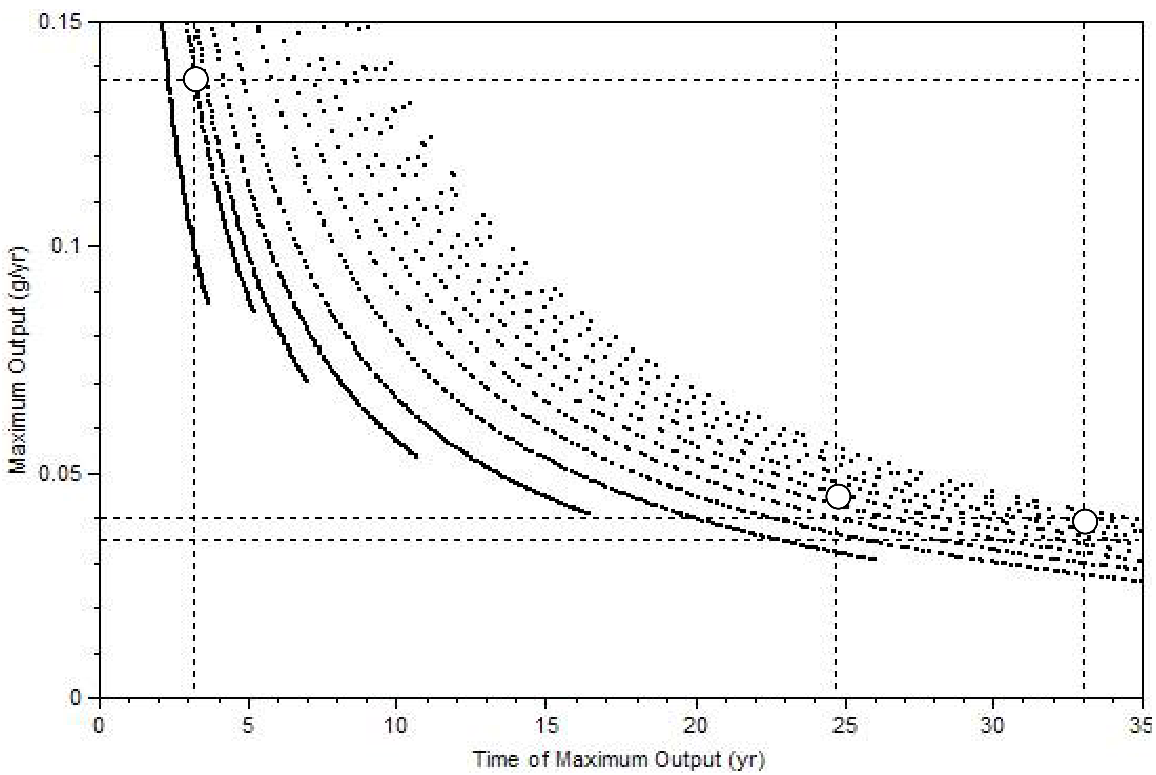

Figure 118. The Relationship between Maximum Mass Output and Time of Output for Variations in Input Parameters for the Selected Fracture Network (GTG 2005a)

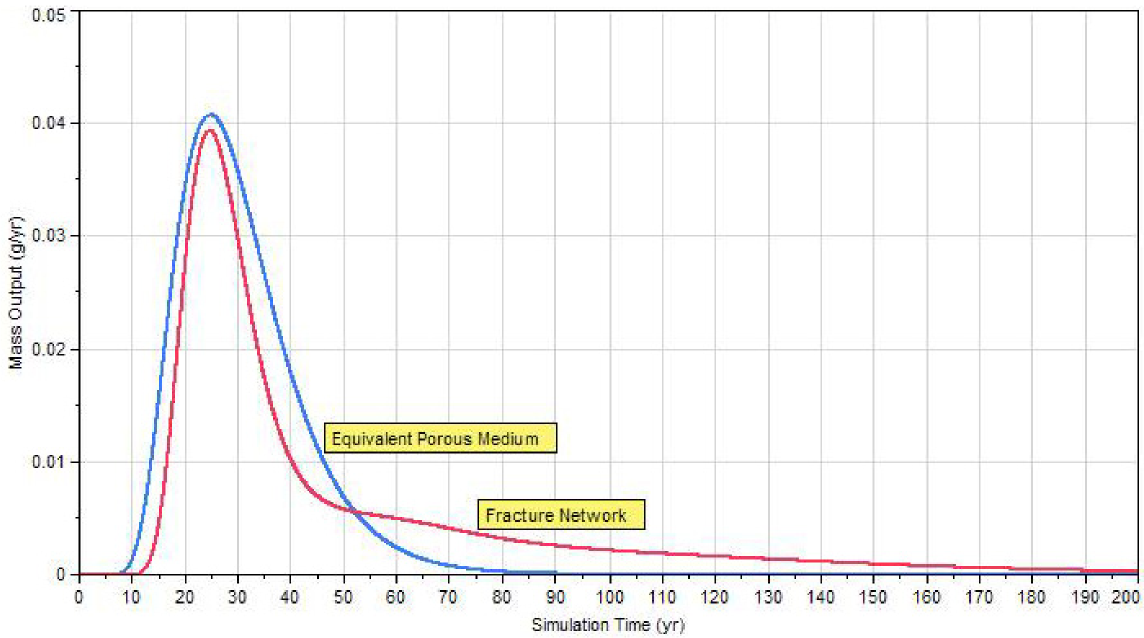

Figure 119. Relationship between the Fracture Flow Representation and Equivalent Porous Medium for SDA Vadose Zone 1 for a Unit Mass Input of an Unretarded, Conservative Tracer (73 m, expected conditions)

A fracture network only applies to a single set of flow and transport conditions. Therefore, all possible fracture networks must be predefined and then the appropriate network selected based on the input flow and transport properties. Because all networks must be predefined, an additional set of assumptions must be made to implement fractured flow for the screening risk model. The input flow to the fracture zone may take different values during realizations both because of variation in the nominal flux of water as well as impacts from flooding and other transport phenomena modeled in the tool. The moisture content may also vary but relatively less dramatically. Fracture networks must be defined that capture the impacts of variation in flow and moisture content.

An example of how fracture networks were defined for a given vadose zone is illustrated in Figure 120. A set of 41 fracture networks were defined to represent the range of input flows (equally-spaced) to the network and the model run to determine the maximum output rate and time for the 41 networks. The (log-log-linear) relationship between the parameters is represented by the solid line on Figure 120. The set of parameters from the corresponding low porosity zone (divided into 13 regions[253]) are also shown on Figure 120 (as dotted lines). For each set of parameters from the low porosity zone, the network with the closest agreement was selected. The resulting network identifiers were placed in a lookup table from which the screening model selects (to define the appropriate fracture network) based on the input flow to the fracture zone[254].

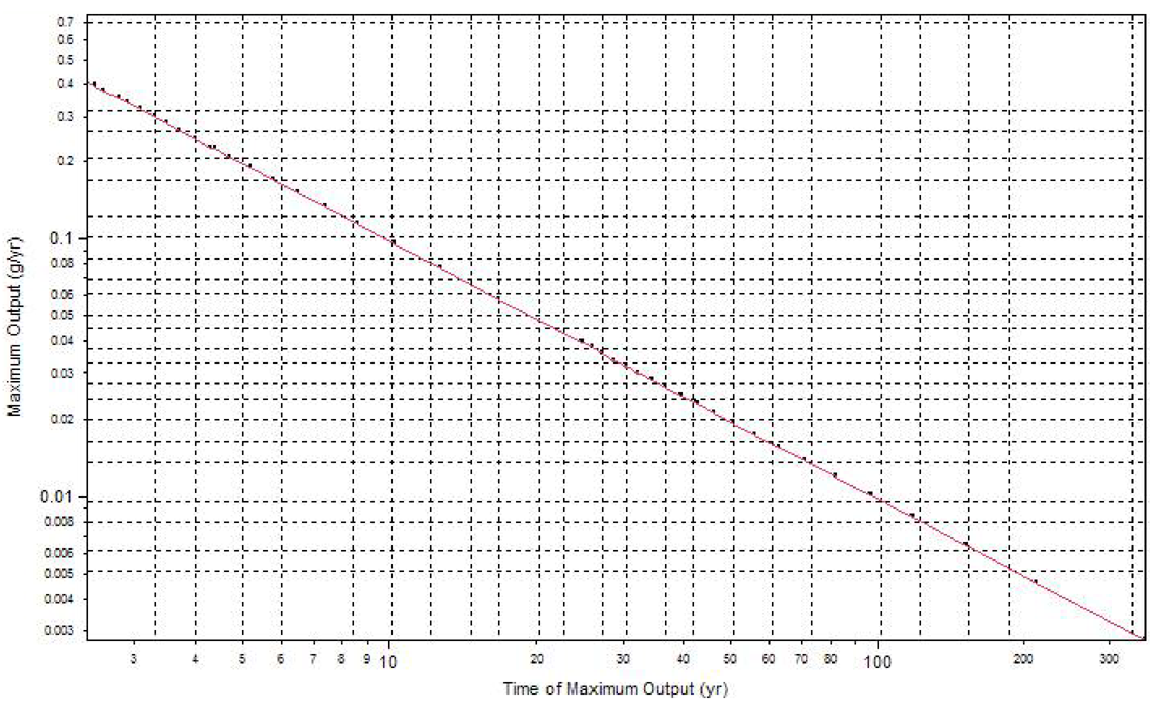

Figure 120. The Relationship between Maximum Output and Time for 41 Fracture Networks Defined to Represent the 73-m Vadose Zone Network. The Dotted Lines Represent the Characteristic Parameters from the Low Porosity Zone

[253] The regions correspond to the following percentiles: 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, and 99.

[254] The results indicated that the impact of moisture content on the results was much smaller than that of the flow rate and thus only the flow rate was used to select the network.

Bias in the Fracture Network Representation of Flow and Transport

The dual-porosity, dual-permeability model used in the Idaho Site SDA remedial investigation cannot be modeled in GoldSim. Three alternative approaches are available: 1) use a single "equivalent" porous medium, 2) use a network pathway incorporating one or more fracture networks, or 3) call an external program implementing the dual-porosity, dual-permeability model. The method used in this model to implement fractured flow is reasonable for a screening risk model considering the limited information available. The low-porosity, high-permeability equivalent porous medium tested by Idaho Site personnel (Anderson and Becker 2006) for potential SDA remedial investigation use[255] was used as the basis for defining the fracture networks used in the screening risk model. The resulting fractured flow representation is considered an excellent melding of the possible flow and transport representations allowing for stochastic analysis.

However, in GoldSim one must predefine all needed fracture networks before running the model, which, as illustrated above, necessitates a discretization into a selected number of networks[256]. This discretization introduces biases into the flow and transport representation, which is controlled by the number of networks used to represent the equivalent porous medium. The degree of bias is illustrated by the difference between the parameters representing from the fracture network selected and those for the original porous medium as illustrated in Figure 120. The bias can be reduced, if desired, by increasing the number of networks to a larger number.

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[255] For SDA remedial investigation modeling, the use of a single equivalent porous medium was rejected, and a dual-porosity, dual-permeability model was selected (Anderson and Becker 2006).

[256] The original intent in the GoldSim model is to sample from a set of fracture networks to represent uncertainty in the fracture flow representation. However, when using the fracture network to represent the flow of a conservative tracer through an equivalent porous medium, only a single such network may represent the desired flow. Thus the process becomes selecting networks based upon the input flow characteristics and not sampling from a predefined set of fracture networks.

Oak Ridge Bear Creek Burial Grounds (BCBG) Vadose Zone

The vadose zone for the Oak Ridge Bear Creek Burial Grounds (BCBG) is very small in extent and may even be missing from some areas of the BCBG because of the very shallow groundwater at the site. Travel times from the BCBG to the saturated zone and surface water appear to be very short. Therefore, the manner in which preferential flow is implemented for the BCBG and the accuracies of the corresponding predictions are of much less importance than those for the Idaho Site SDA.

The basic approach for defining fracture networks for the BCBG is different than that for the SDA because of the type of information available. The SDA fracture networks were developed to represent the flow through an equivalent low-porosity, high-permeability porous medium. However, although an equivalent porous medium can be defined for the BCBG subsurface areas, fractured flow modeling[257] was performed for the BCBG remedial investigation and this more information is used to define fracture networks for the screening risk model (SAIC 1996).

The basic parameter used to define the fracture networks for the BCBC is the velocity in the fracture. A range of 55 m/yr (182 ft/yr) to 1.1×10^4 m/yr (3.65×10^4 ft/yr) was used to model transport in the areas around the BCBG (SAIC 1996). Assuming a logarithmic distribution of possible velocities in the fracture, the geometric mean of this range, 790 m/yr (2600 ft/yr), is used to center the fracture networks defined for the BCBG[258].

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[257] A one-dimensional transport model, CRAFLUSH, for a system of parallel fractures was used to model flow through the karst subsurface underlying the BCBG (SAIC 1996). Impacts on contaminant fate and transport resulting from heterogeneity, anisotropy, and spatial fracture distribution were not included in the CRAFLUSH modeling.

[258] The matrix porosity and dispersivity are given as 0.04 and 3 m (10 ft), respectively (SAIC 1996).

The mean velocity, $\bar{v}$, of a conservative, unretarded tracer is an indication of the rate of travel of the centroid of mass and can be described by (USEPA 1999)

$$\bar{v} = \frac{\int_0^\infty \left(\frac{1.5L}{t}\right) C(t)Q(t)dt}{\int_0^\infty C(t)Q(t)dt} = \frac{\int_0^\infty \left(\frac{1.5L}{t}\right) C(t)dt}{\int_0^\infty C(t)dt} \qquad [49]$$

where *C*(*t*) is the output concentration as a function of time, *t*, *Q*(*t*) is the flow rate (which is assumed constant and thus cancels), and *L* is the length of the pipe. It is assumed that the velocity in the fracture given in the Oak Ridge remedial investigation (SAIC 1996) can also be described by Equation 49 and the selected network fracture will result in a mean velocity[259] corresponding to the velocity in the fracture.

The BCBG vadose zone can be represented by four layers as described in Figure 40 in Chapter VI. Previous experience with the GoldSim *Network Pathway* indicated that regions very short in extent do not significantly impact the results and thus the four regions are condensed into two regions of 4 m each without significant impact on the results. From an analysis of possible fracture networks, the average velocity of 790 m/yr is obtained when the lengths of all network pipes are 0.25 m and the coating thickness is 0.34 cm for the upper zone (assumed to consist of sandy and loamy soils). Similar fracture networks are used to describe both BCBG vadose zone regions:[260]

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[259] The GoldSim *Integrator* element is used to approximate mean velocities using Equation 49. The *Integrator* element uses *Euler integration* to integrate numerically the rate of change (in this case concentration or the like) and, to provide accurate results, must often be applied over small time steps because the rate of change is assumed constant over each time step (GTG 2005b).

[260] The coating thickness for the lower vadose zone, which was assumed to consist of clay and loamy soil, corresponding to an average velocity of 790 m/yr was 0.29 cm (versus 0.34 cm for the upper region). The small differences in the fracture networks result from differences in the materials comprising the subsurface and thus coating the network pipes.

- Zone 1 (4 m): Length (all pipes) 0.25 m and Coating Thickness 0.34 cm.
- Zone 2 (4 m): Length (all pipes) 0.25 m and Coating Thickness 0.29 cm.

To represent the variation in fate and transport from differences in flow to the BCBG vadose zone areas, a set of 41 fracture networks were defined in a way similar to that for the SDA. However, unlike the results for the SDA, there was no apparent correlation between the velocity, flux, and moisture content. Thus, instead of selecting the appropriate network based on the input parameters (e.g., flux, moisture content, etc.), a network is randomly selected from the possible networks (using a uniform distribution) to model flow through the areas representing the BCBG vadose zone.

Bias in the Fracture Network Representation of Flow and Transport

As described for the Idaho Site SDA, the only manner to use the GoldSim network pathway representation is to predefine all needed fracture networks before running the model (GTG 2005a), which, as illustrated above, necessitates a discretization of the flow network into a selected number of networks. This discretization introduces biases into the flow and transport representation, which is controlled by the number of networks used to represent the equivalent porous medium. The degree of bias is illustrated by the difference between the parameters representing from the fracture network selected and those for the original medium. The bias can be reduced by increasing the number of networks and running more simulations in the case of the BCBG. However, unlike the situation for the SDA where a single network could be defined for a given set of input conditions, a random network is selected; therefore, a sufficient number of realizations are needed to adequately capture the uncertainty in the vadose zone flow and transport.

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APPENDIX G

GOLDSIM SCREENING RISK TOOL VERIFICATION RESULTS

A conceptual burial site model was defined in Chapter V to allow screening estimates to be made for both the exposure and standard industrial risks associated with remedial actions for Department of Energy (DOE) buried waste sites. The conceptual model allows for an integrated, comprehensive, and transparent analysis of the significant risks confronting the disposition of a contaminated waste site. This conceptual burial site model was implemented in Version 9.60 of the GoldSim Monte Carlo simulation software (GTG 2005a; b; c) as described in Chapter VI.

The GoldSim simulation software allows the critical components described in Chapter V to be captured in a screening risk analysis tool as described in Chapter VI. Transport of contaminants in GoldSim is represented as mass fluxes among the exposure media (e.g., air, water, soil, etc.) described in the model. The software allows these important features and processes to be modeled both deterministically and stochastically to analyze the impacts of uncertainties on the resulting exposure and risk estimates. The exposure and risk estimates made using the screening risk tool are based on the best information possible. However, any such software tool may be used erroneously or correctly applied to the wrong site. Even if applied correctly, the exposure and risk results generated using this or any such software tool are subject to different interpretations.

Development of the screening risk model was aided by the availability of a generic performance assessment (PA) model[261] developed by Tauxe (2004; 2005). In fact, the generic PA model was the starting point for developing the screening risk tool developed in this research. The author is indebted to Tauxe and the fine example that his model set for estimating exposure risks related to the final disposal of radioactive wastes.

The generic PA model by Tauxe (2004) was expanded to include additional radionuclides, chemicals, fractured media, transport pathways, receptors, and standard industrial risks. Thus additional verification is needed to assure that these new features function as intended. The screening tool describes both arid and humid conditions and can be used to estimate exposure and industrial risks before, during, and after remedial actions have been performed. Remedial alternatives include either managing the wastes in-place or retrieving the wastes for treatment and ultimate disposal elsewhere.

There are many exposure media represented in the screening risk tool that are interconnected in various ways to represent the potential transport pathways leading from sources to potential receptors. Another way to visualize both the media and transport pathways represented by the conceptual burial model was provided in Table 24 in Chapter VI. The media and exposure pathways implemented in the screening risk tool are compared to those in the generic PA model (Tauxe 2004; 2005). The current model is more comprehensive in terms of describing both exposure and industrial risks than that by Tauxe (2004; 2005) and applied to baseline, remedial, and post-closure conditions.

Three sets of "switches" are programmed into the screening risk tool using the GoldSim *Dashboard* element (GTG 2005b; c) that can be used to control 1) the various

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[261] The generic performance assessment model by Tauxe (2004) used as the basis for the screening risk tool is available at http://www.neptuneandco.com/goldsim/generic/index.html (accessed March 13, 2008).

pathways for contaminants from sources to potential receptors, 2) how remedial actions are to be performed, and 3) general characteristics including retardation, solubility, organic degradation, etc. as shown in Figure 33 in Chapter VI. *The first thing that must be recognized is that an exhaustive verification and documentation of such a complex model is prohibitive. Instead, verification of the major features of the screening risk tool is described in this appendix to provide assurance that the results produced by the tool are reasonable and meaningful.*

The general verification of the screening risk tool is presented in three phases. The first, and most important, verification of the screening risk tool is the material balance over all contaminants and media. The second level of verification is to examine critical features of the model one-at-a-time (e.g., source release, important transport pathways, etc.). Finally, specific cases involving the desired set of remedial alternatives are evaluated. The remedial alternatives in this research are grouped into either 1) managing buried wastes in-place or 2) retrieving wastes for treatment and disposal. The various controls fall into these categories and can be used to determine the impact of the selected remedial options on the life-cycle risks for dispositioning the waste sites.

Material Balance Verification

The first, and ultimately most important, verification of the results produced by the screening risk tool is the overall material balance. A material balance is maintained in the system for all contaminants over all exposure media during the simulation. Examples of material balance results for the Subsurface Disposal Area (SDA) and Bear Creek Burial Grounds (BCBG) over the 1,000-year assessment period are provided in Figure 121 and Figure 122, respectively. The difference between the top and bottom figures for each is based on whether radioactive decay is enabled or disabled[262]. The results of the material balance are the primary indication that the screening tool is functioning properly and are checked each time a simulation is run.

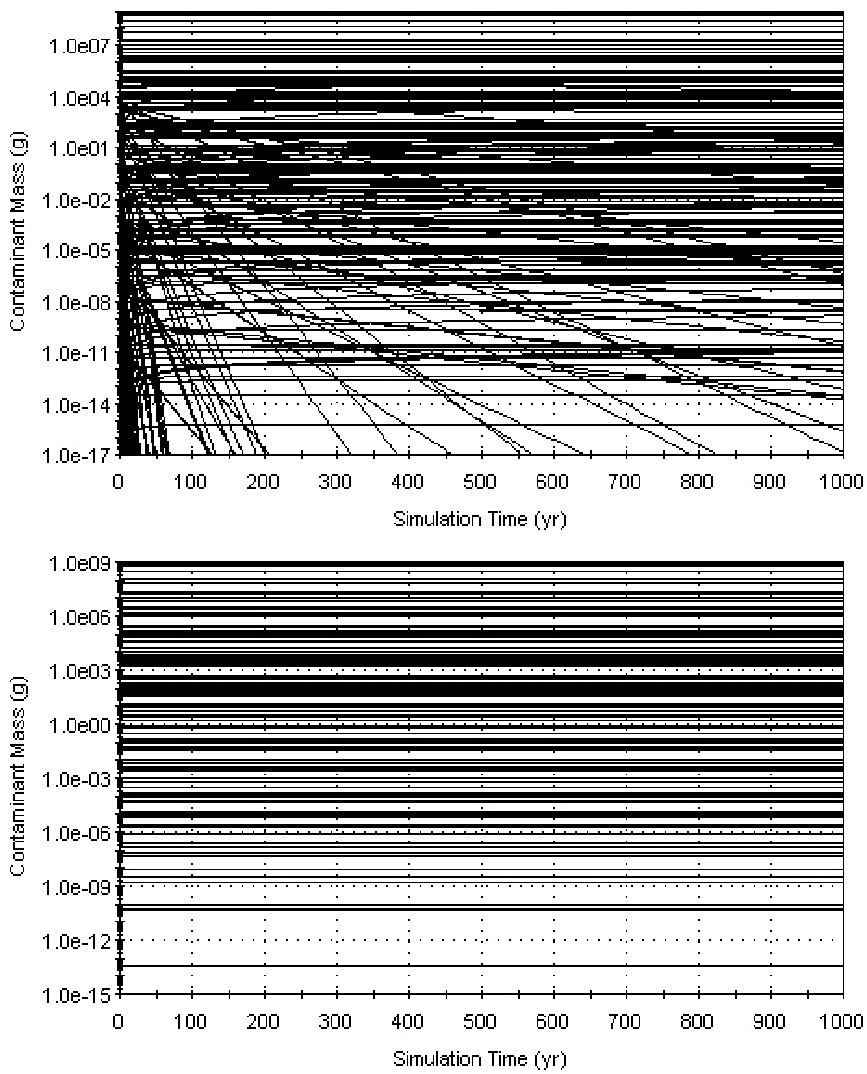

Figure 121. Example Material Balance for the Subsurface Disposal Area (Top: Radioactive Decay; Bottom: No Decay)

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262 Radioactive decay is controlled from the GoldSim *Model|Options|Contaminant Transport* menu selection. A similar process, organic degradation, is implemented using the radioactive decay platform and thus no independent verification results are provided for the degradation process.

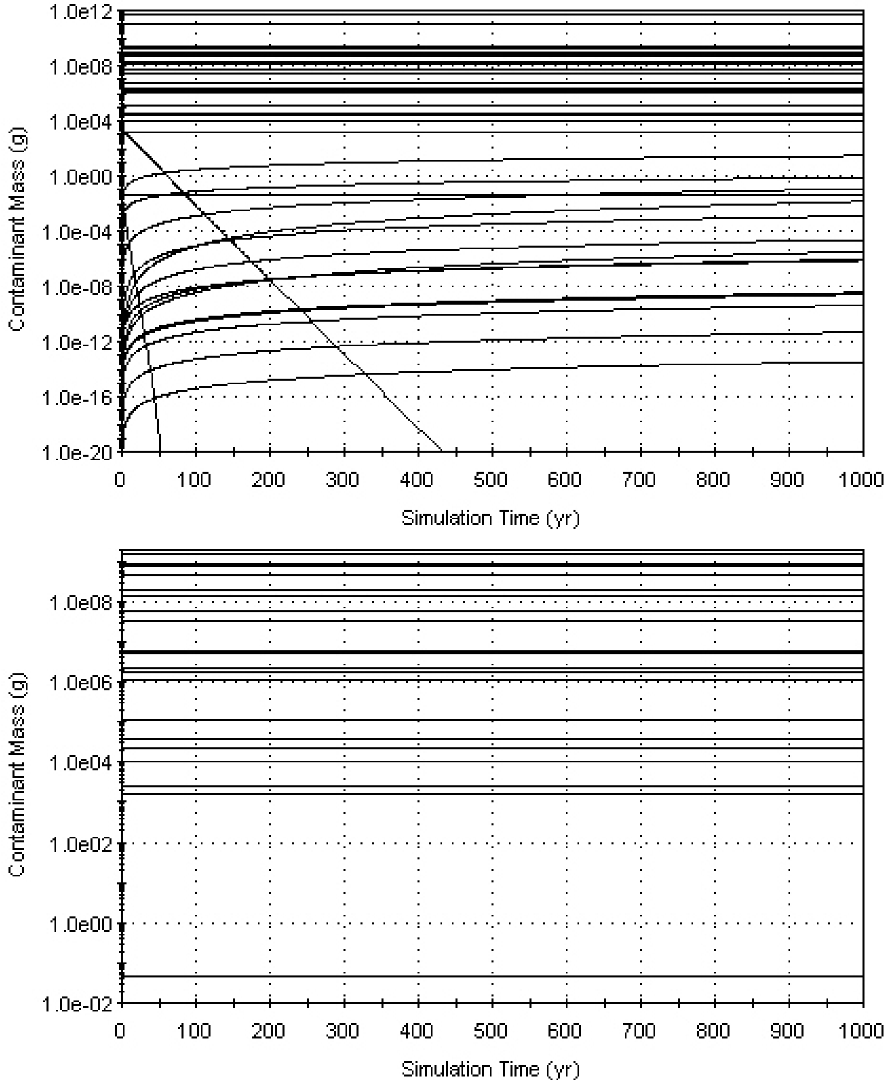

Figure 122. Example Material Balance for the Bear Creek Burial Grounds (Top: Radioactive Decay; Bottom: No Decay)

Simple Transport Verification Tests

The simple verification tests are one- or few-at-a-time tests to examine and exercise the various features implemented in the screening risk tool. The tests proceed generally along the lines of the conceptual site model that links sources of contaminants to receptors via transport pathways and exposure routes to estimate exposure risks to potential receptors. The exposure risk analysis is then extended to the types of standard industrial tasks and risks needed to disposition the buried wastes in the site.

Source Release Model Verification

The first verification tests involve source release modeling and the resulting flux to the waste areas. As illustrated in Appendix D, the wastes buried in the SDA appear to be much more complex in terms of the nature and inter-mixing of contaminants, waste forms, and containers than those wastes buried in the BCBG[263]. Therefore, the focus in this section will be on SDA source release modeling (although the BCBG releases were verified in a similar manner).

As described in Appendix E, releases from waste forms are impacted by 1) whether or not contaminants are in containers (e.g., drums, boxes, etc.) that limit the exposure of contaminants to the surrounding environment and/or 2) whether or not the contaminants are included in a matrix (e.g., glass, resin, grout, etc.) that limits the release of contaminants to the surrounding environment. Both these impacts are modeled in the screening risk tool based on the waste form specific inventories from Appendix D.

As described in Appendix D, containers in the screening risk tool are assumed to be either polyethylene-lined or unlined 55-gallon drums that were stacked or dumped (failing at rates specified in SDA modeling reports (Anderson and Becker 2006; Holdren et al. 2006)) or boxes assumed to fail immediately upon placement. Contaminants in containers are either loose or in a matrix that can undergo degradation releasing the contaminants. The material in a container must be exposed before degradation occurs.

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[263] From the information examined for the Bear Creek Burial Grounds (BCBG) in Appendix D, few of the wastes were either buried in containers or associated with a waste form.

Once exposed, contaminants are assumed to undergo one of three release mechanisms: surface wash, dissolution, and diffusion. However, only dissolution can be directly modeled in GoldSim (GTG 2005a). As illustrated in Appendix E, approximate solutions to the surface wash and diffusion release mechanisms are implemented in the screening risk tool. The diffusion release mechanism is approximated using a dissolution process and thus is verified in the same manner as dissolution. The surface wash release mechanism was implemented as a simple extension to retardation in the GoldSim *Cell Pathway* element described in Appendix E, and its verification is directly tied to that of the retardation transport process tested below.

Hundreds of contaminants and numerous waste forms are modeled in the screening risk tool. Many SDA contaminants (e.g., uranium isotopes, plutonium isotopes, volatile organic compounds, etc.) primarily exist in only one or two waste forms. Other contaminants (e.g., C-14, Cl-36, Tc-99, etc.) exist in numerous waste forms and may or may not be contained. Because of uncertainties in the distributions of contaminants in waste form and containers, the failures of containers, and the release of contaminants once exposed, there is a large spectrum of releases over time possible from the waste forms to the environment surrounding the wastes.

In the SDA remedial investigation modeling, contaminant releases were modeled as functions of time for specific expected and bounding cases and the results were input to the transport modeling code (Anderson and Becker 2006; Holdren et al. 2006). This arrangement allowed contaminants to be added to the source term on an incremental basis in keeping with the inventory estimates developed by Idaho Site personnel. No such ability exists to add contaminants incrementally to a GoldSim *Source* element. One could, on the other hand, generate a series of source terms (one for each contaminant) that could be input to the screening risk model (analogously to the SDA modeling). However, this requires not only the generation of hundred of source term time series, but removes the possibility of making the source term stochastic. The issues of how to divide the estimated inventory among waste forms and containers becomes even more complex.

It was decided to place the entire inventory (distributed among waste forms and containers) in the site initially to allow stochastic modeling of container failure, contaminant release, and the resulting flux to the environment surrounding the burial site. However, this decision has ramifications. The magnitudes of effects are likely too large and the timing of effects may be out of phase. Furthermore, the potential effects of short-lived contaminants (e.g., Co-60) may have already passed and the impacts of institutional controls on limiting site access and exposure may be not sufficiently restrictive[264].

There is a trade-off between the ability to represent the variation in buried waste inventory over time and the ability to represent uncertainties in the components (e.g., inventory, container failure, etc.) affecting the source term. Because the assessment time is typically much longer than the disposal time (i.e., less than 20 years) uncertainties in the inventory estimates are very large, it was decided that a stochastic approach would be taken to source term modeling. The time at which all wastes are buried is treated stochastically to evaluate the impact of this assumption on the predicted results[265].

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[264] For example, if wastes that were buried between 1950 and 1970 were assumed instead to have been buried at a single time (e.g., 1950, 1960, or 1970), then the resulting transport into the environment and potential impacts on receptors will vary based on this assumption.

[265] For deterministic evaluation, the entire waste inventory is buried as early as possible (i.e., 60 years before the intended remedial action date assumed to be 2010) to allow for maximum contaminant transport into the environment before remedial action could be taken at the site. For stochastic modeling purposes, the burial period is allowed to vary uniformly between 40 and 60 years to allow the impact of these assumptiosn on resulting risks to be characterized.

The contaminants modeled in the screening risk tool can be distributed throughout various containers (which may fail over time). Once contaminants are exposed (i.e., containers fail), contaminants are released into the environment at a rate based on whether or not they are bound in a matrix, diffuse through the waste, or undergo a surface wash process. For example, many SDA contaminants (e.g., the uranium and plutonium isotopes) are limited in how they are distributed throughout containers, waste forms, and waste areas. A small number of the isotopes (e.g., C-14, Cl-36, Tc-99, etc.) were buried in multiple waste forms both contained and loose. The volatile organic compounds (VOCs) in the SDA were either buried loose or contained in lined, 55-gallon drums. An example of a contained and diffusing VOC is carbon tetrachloride in the SDA.

It would be confusing to select numerous contaminants to verify the results from the screening risk tool. To simplify presentation, three contaminants are selected to demonstrate that the tool is behaving as expected. The contaminants for the SDA are Pu-239, Tc-99, and carbon tetrachloride and U-238, Th-232, and PCBs for the BCBG. These contaminants cover the spectra of important containment, waste form, waste area, and transport processes and represent some of the highest potential risks to receptors. The source releases for SDA contaminants by containment and waste areas[266] (for the deterministic case with 50-percentile values and all transport pathways disabled) are provided in Figure 123 through Figure 126. Any mass associated with initial drums failures is transferred before the first recorded time step.

[266] Although the contaminants in the SDA were divided into two waste areas in Appendix D, three waste areas were needed to model the BCBG. Therefore, the contaminants in the second SDA waste area were split into two waste areas (i.e., WA02 and WA03) for modeling purposes. Furthermore, barrier failures can either be based on the predicted or random failure times (i.e., from the Model|Options| Contaminant Transport|Source Term|Barrier failure type selection). Therefore, even though the inventories and failure rates are the same for two of the SDA waste areas, the contaminant fluxes from the two areas may be different if random failure times are used. It was decided to employ random barrier failure times for the screening risk tool as the impact should be small on the results.

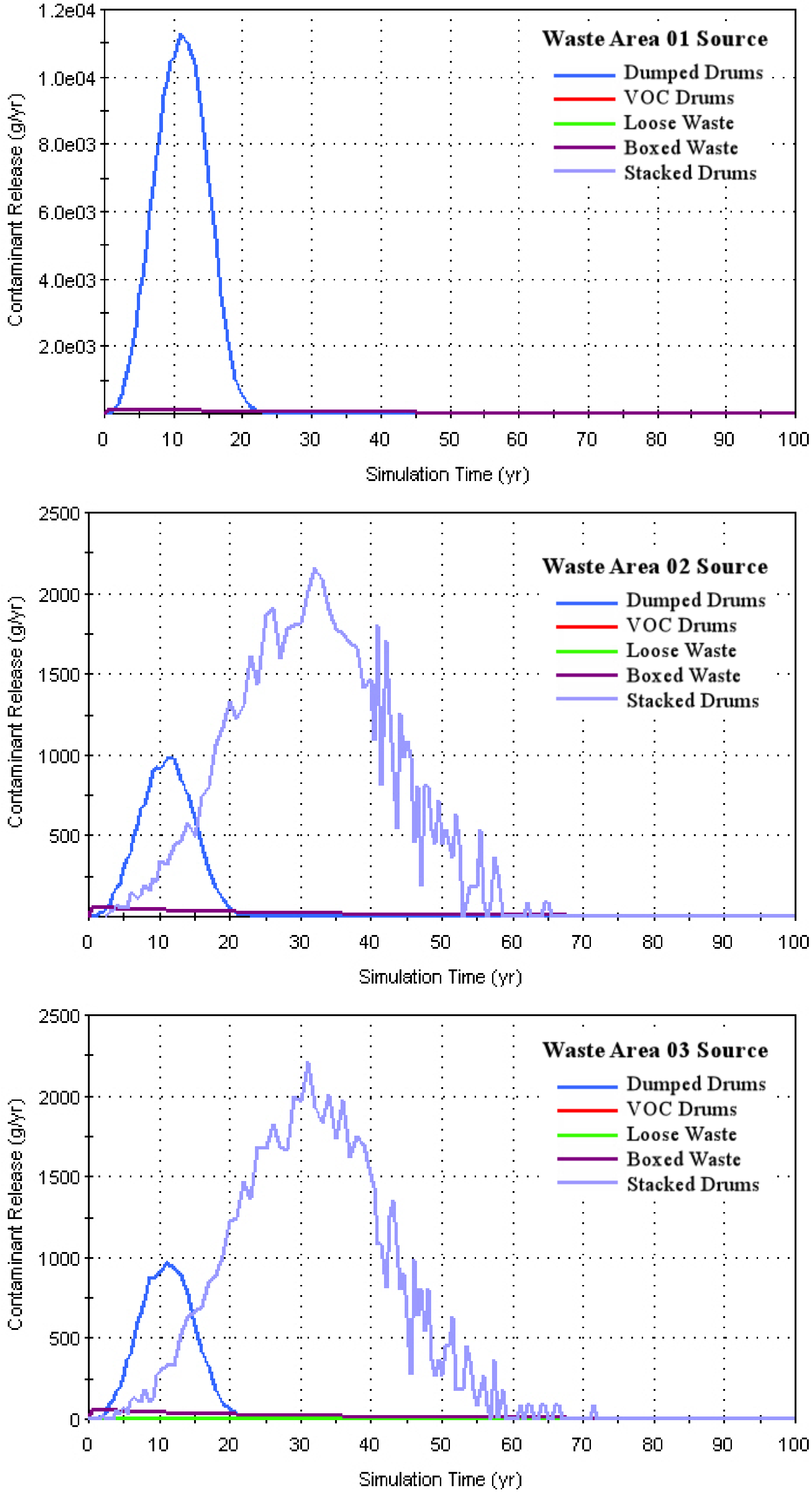

Figure 123. Example SDA Pu-239 Source Releases

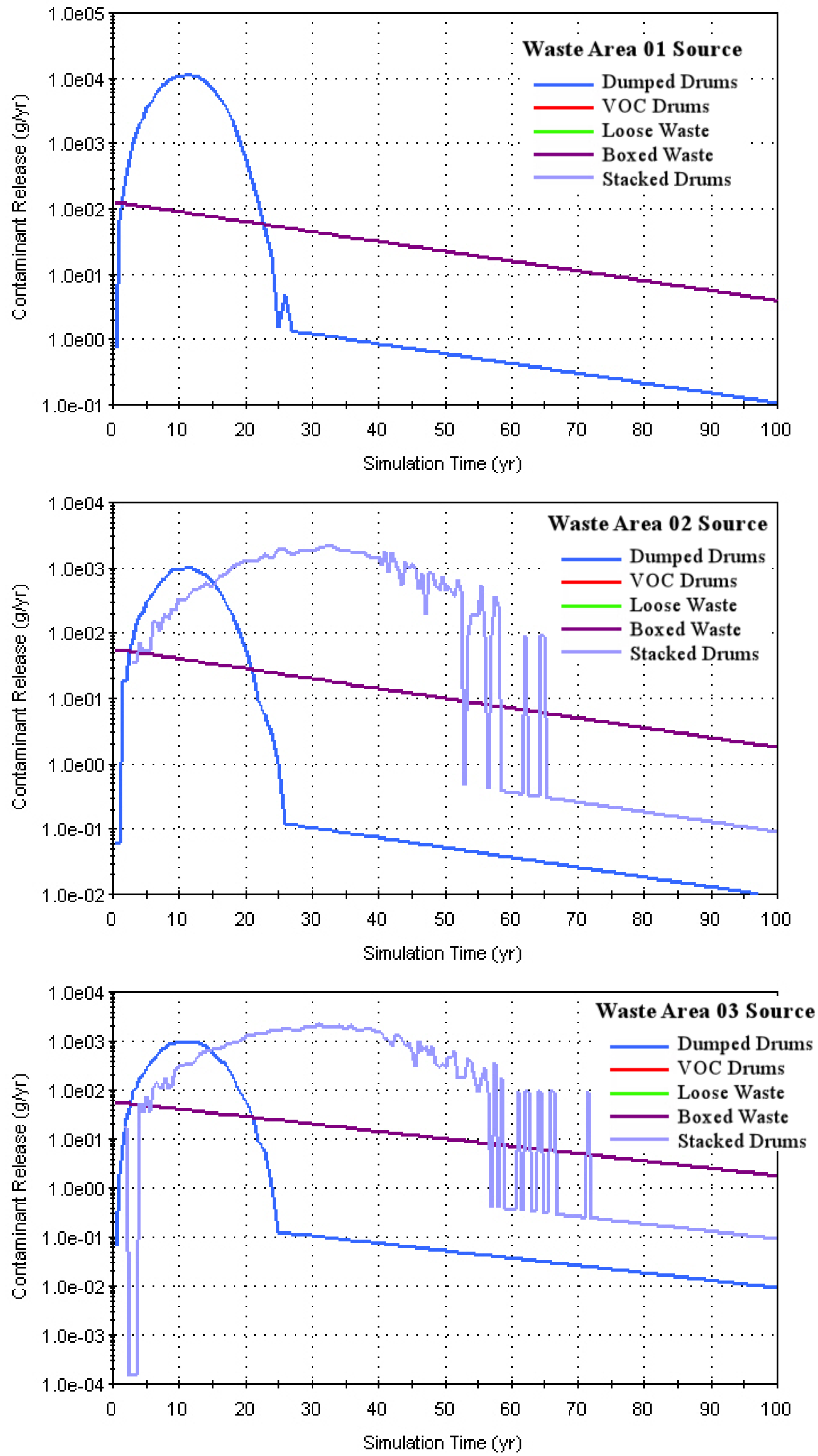

Figure 124. Example SDA Pu-239 Source Releases (semi-logarithmic scale)

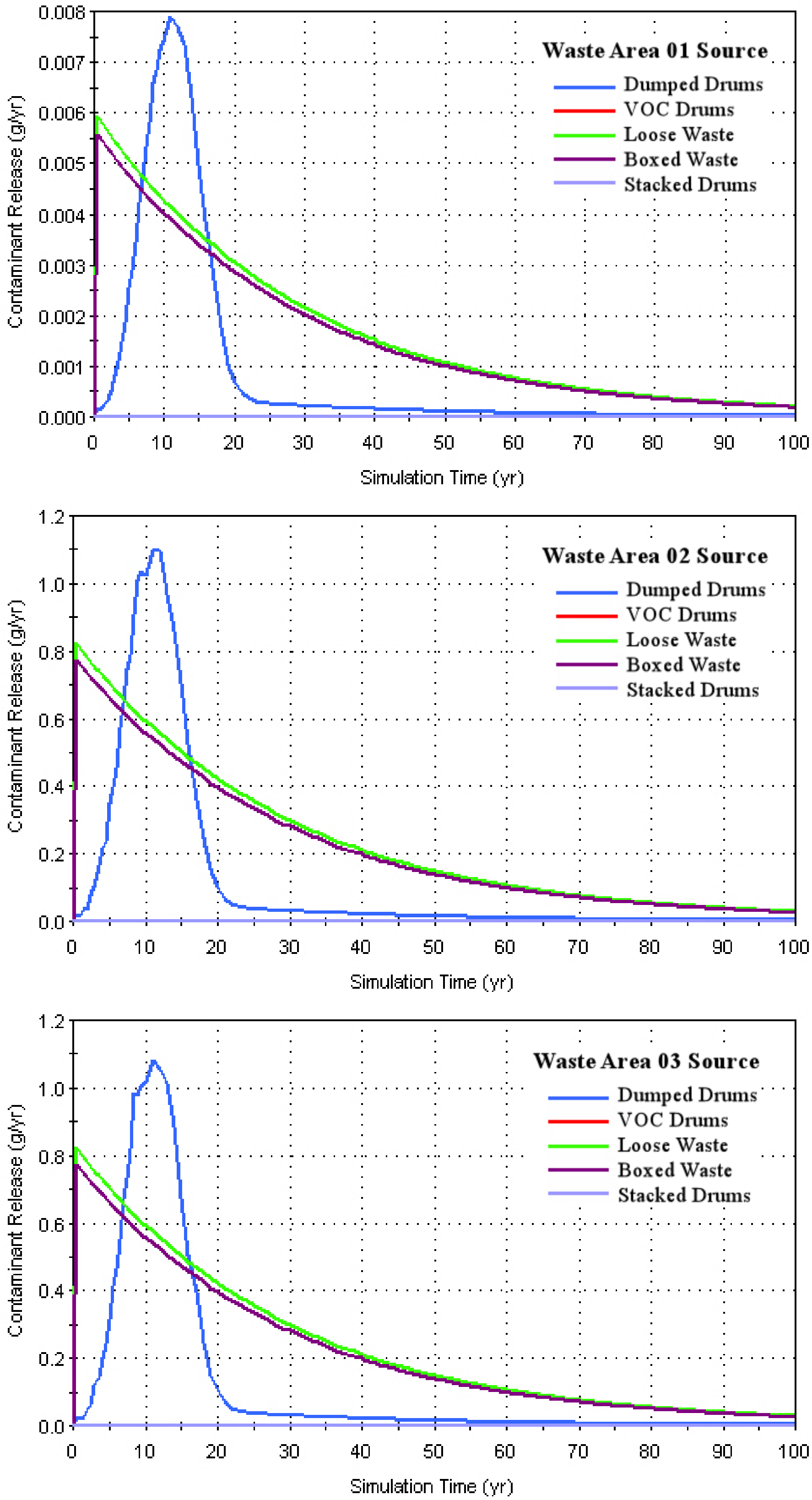

Figure 125. Example SDA Tc-99 Source Releases

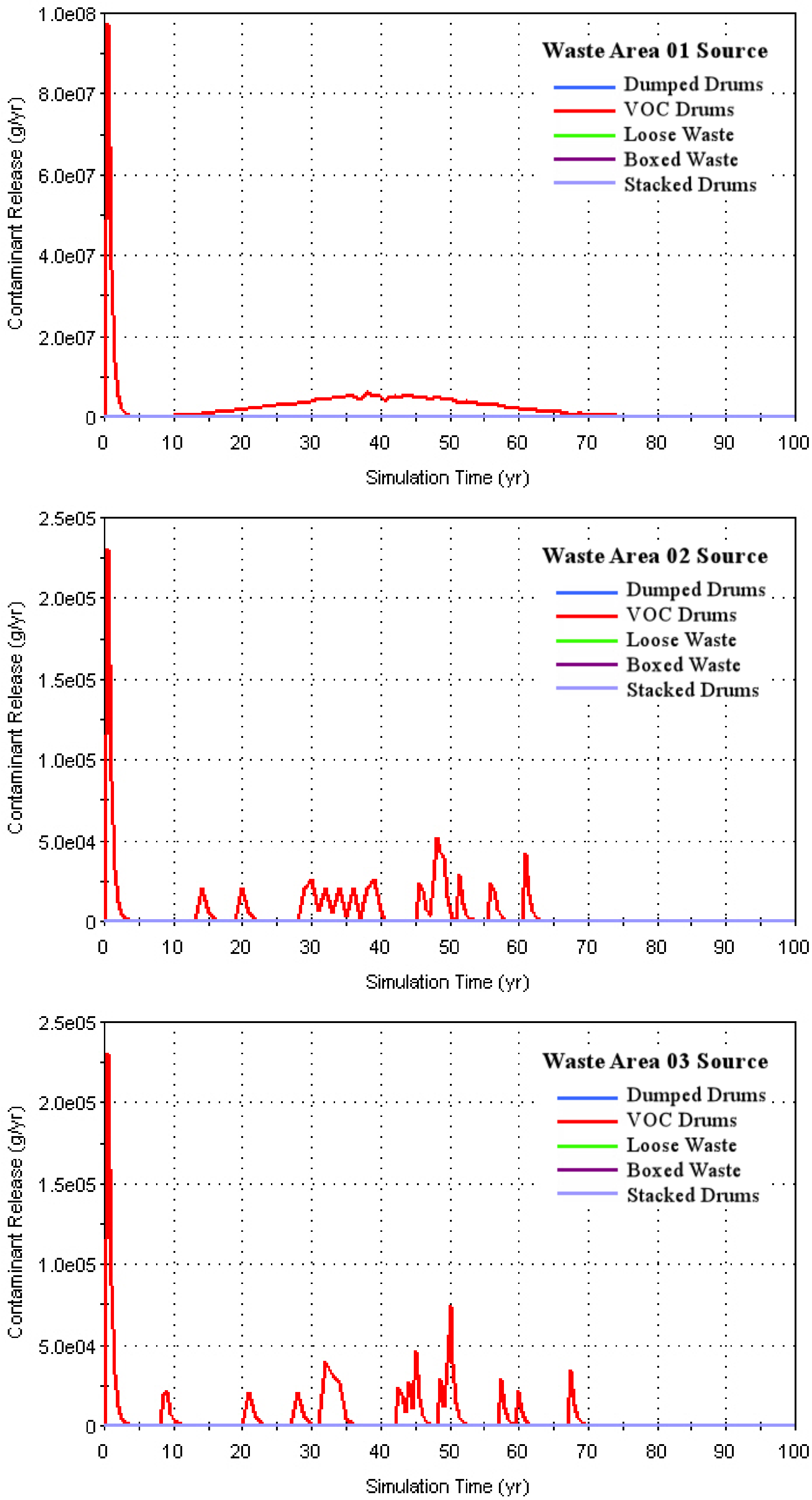

Figure 126. Example SDA Carbon Tetrachloride Source Releases

The Pu-239 is distributed in the SDA primarily in drums throughout the waste areas. The majority of Pu-239 is in a form that undergoes surface wash, and the release the Pu-239 (as illustrated in Figure 123) into the waste areas (where the surface wash mechanism is implemented via partitioning) is largely controlled by drum failure rates. However, a small fraction of Pu-239 is in fuel-like elements; the release of this material is controlled by a dissolution-type process as shown in Figure 124.

The Tc-99 in the SDA is distributed among drummed, boxed, and loose wastes in metal, fuel-like, resin, and glass waste forms. The release of Tc-99 into the waste areas is considerably more complicated as shown in Figure 125. The release of this important (and often mobile) contaminant is a function of not only the distribution of Tc-99 among containers and waste forms but also the parameters describing the inventory, container failure, and contaminant release. An example of the large uncertainty in the total source release of a contaminant (in this case, Tc-99) to a waste area is shown in Figure 127.

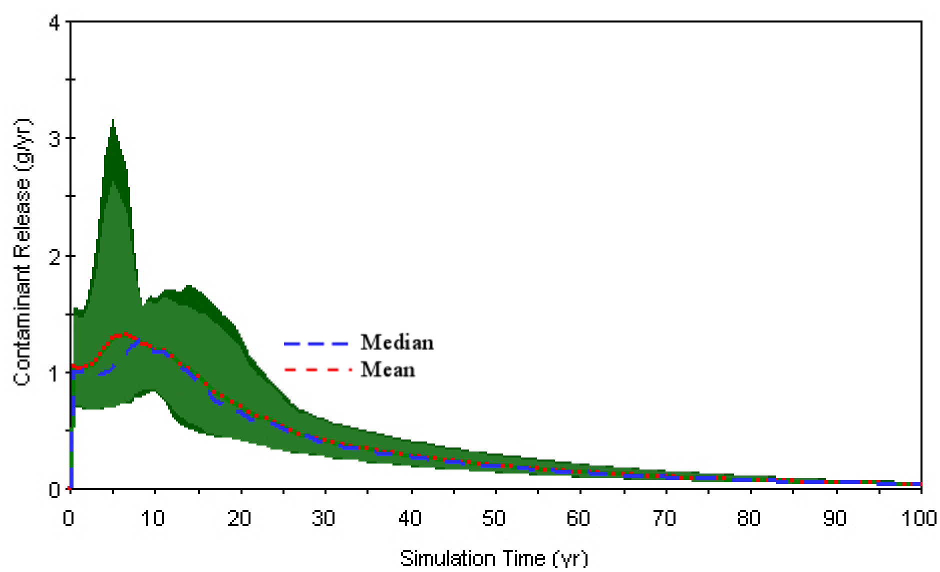

Figure 127. Example Stochastic SDA Tc-99 Source Releases (10 Realizations)

The release of carbon tetrachloride is controlled by diffusion through the waste. This mechanism was approximated by a dissolution release mechanism available in the GoldSim software as illustrated in Appendix E. However, the apparent dissolution rate used to model diffusion tends to be very high when compared to the rates for the other waste forms that undergo dissolution. Because the organic compounds of interest tend to have been buried in drums lined with polyethylene (which fail at a rate that is much slower than the other buried drums), releases to the waste areas for carbon tetrachloride and other organic compounds that diffuse from the wastes are controlled by the drums failure rate more so than by the diffusion rate as illustrated in Figure 126.

The source releases for three BCBG contaminants (i.e., U-238, Th-232, and PCBs) are provided in Figure 128 through Figure 130 as points of comparison to the SDA source releases. As suggested in Appendix D, few of the contaminants of potential concern for the BCBG appear to be either in containers or associated with waste matrices. For example, a small fraction of the total uranium inventory (as illustrated in Figure 131) and other contaminants, primarily VOCs, were buried in drums in Waste Area 01 (WA01). The remainder of the uranium in WA01 was buried loose either in waste matrices or subject to the surface wash mechanism. Because of the manner in which the surface wash mechanism was implemented in the screening risk tool, any exposed contaminants subject to this mechanism are immediately transferred to the impacted Waste Area. This type of transfer may result in the inventory being transferred before the first GoldSim timestep for which information is recorded for display[267].

[267] Please refer to the GoldSim manual for details on actual versus recorded timesteps (GTG 2005a).

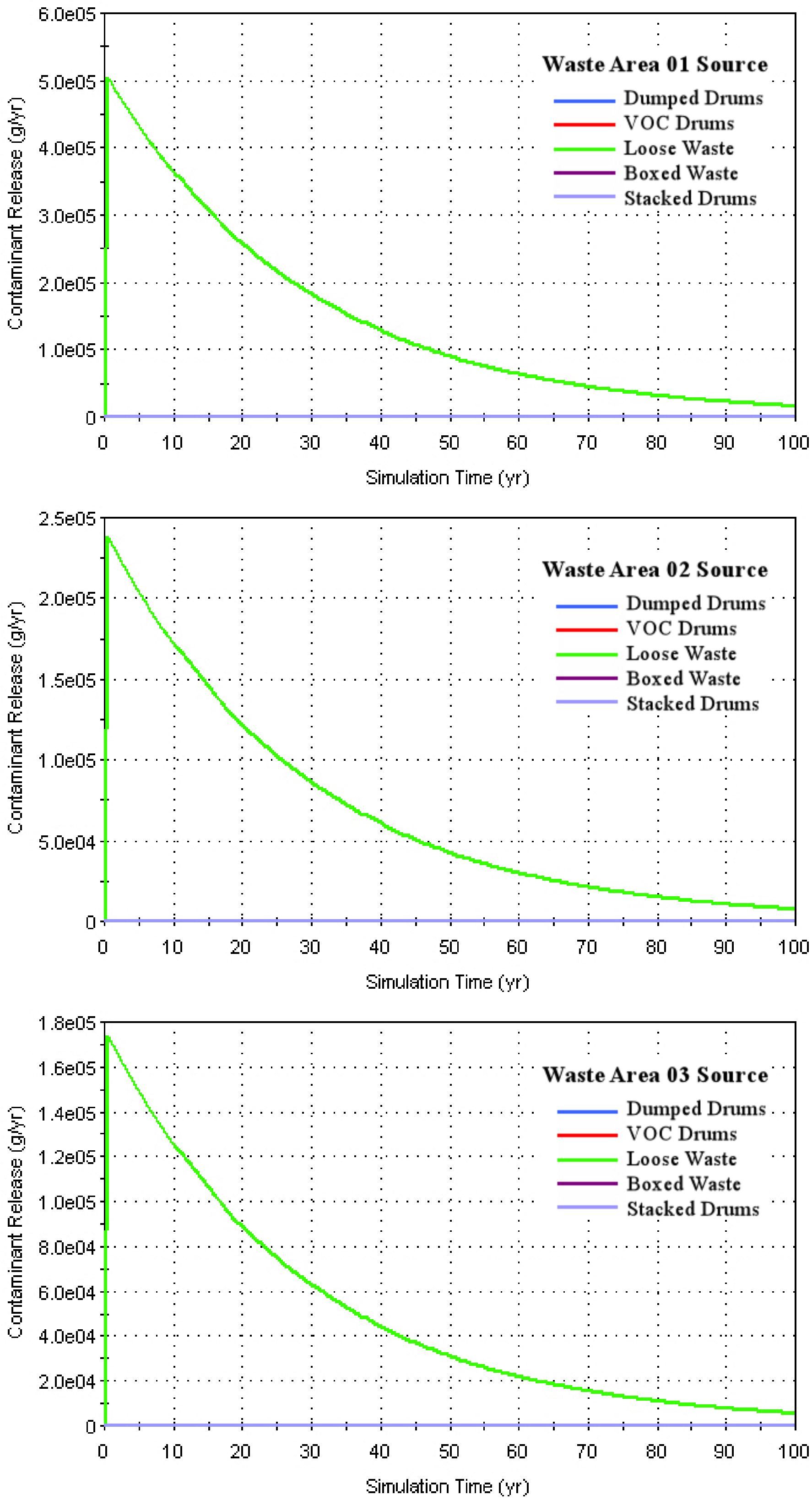

Figure 128. Example BCBG U-238 Source Releases

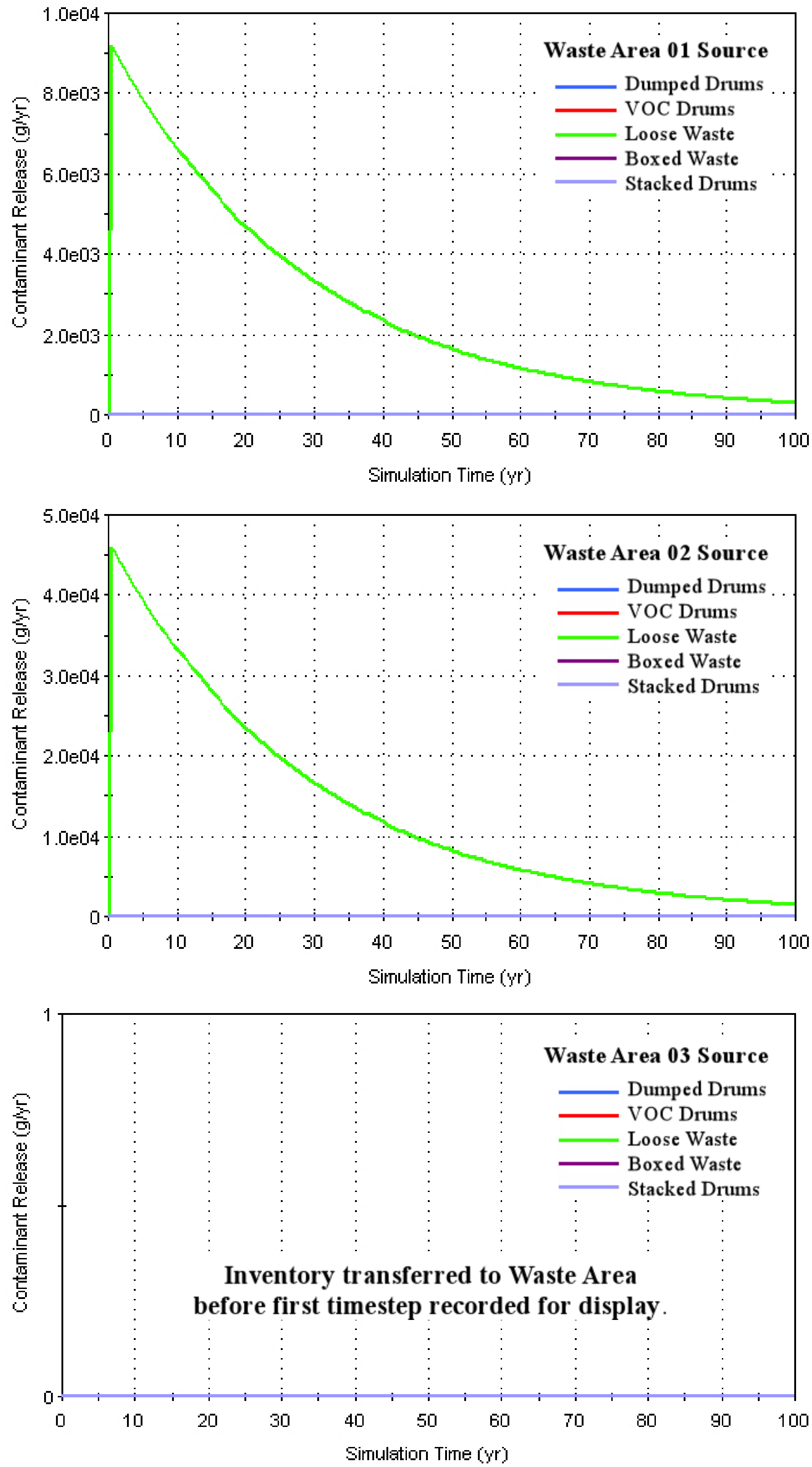

Figure 129. Example BCBG Th-232 Source Releases

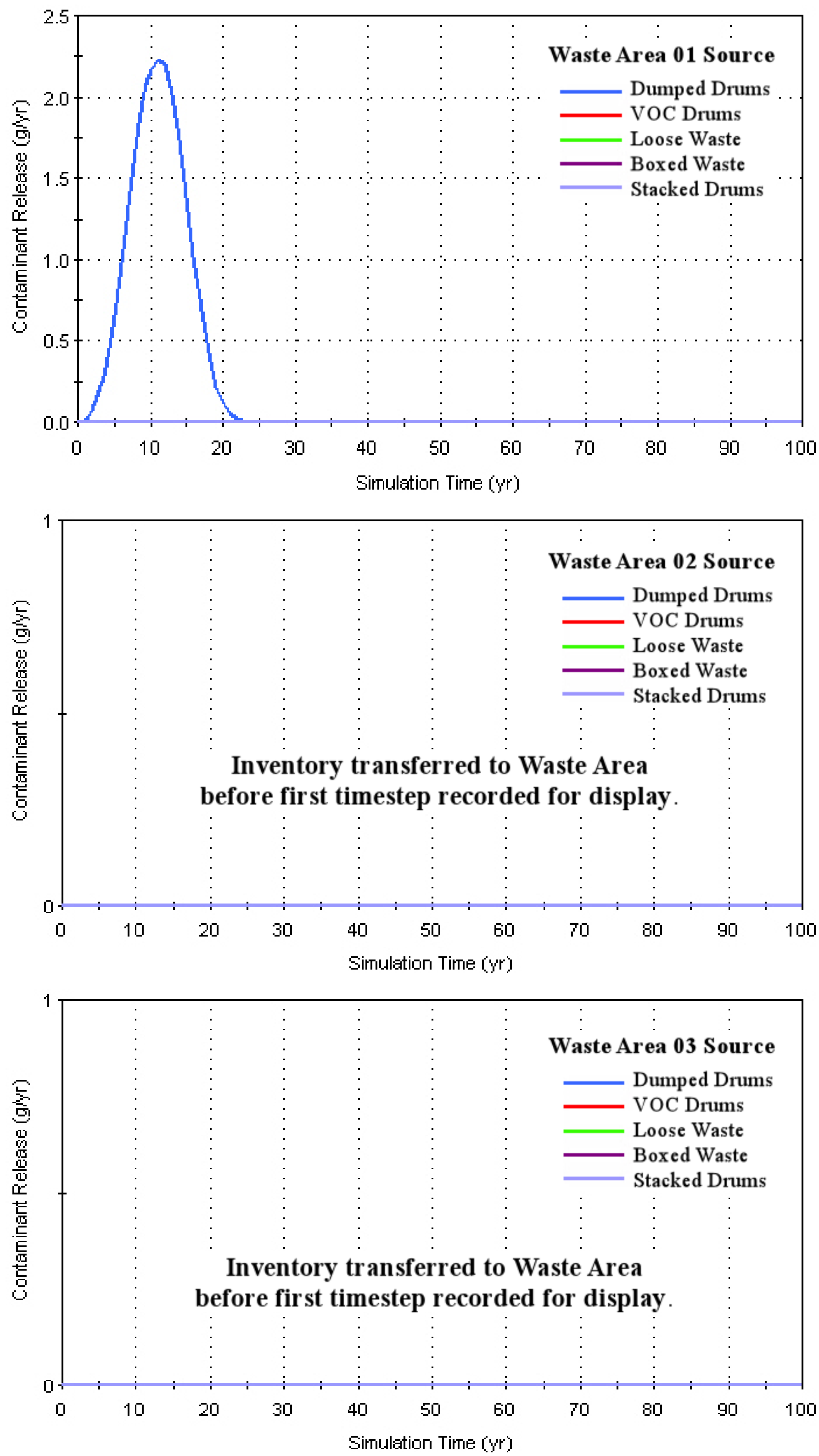

Figure 130. Example BCBG PCBs Source Releases

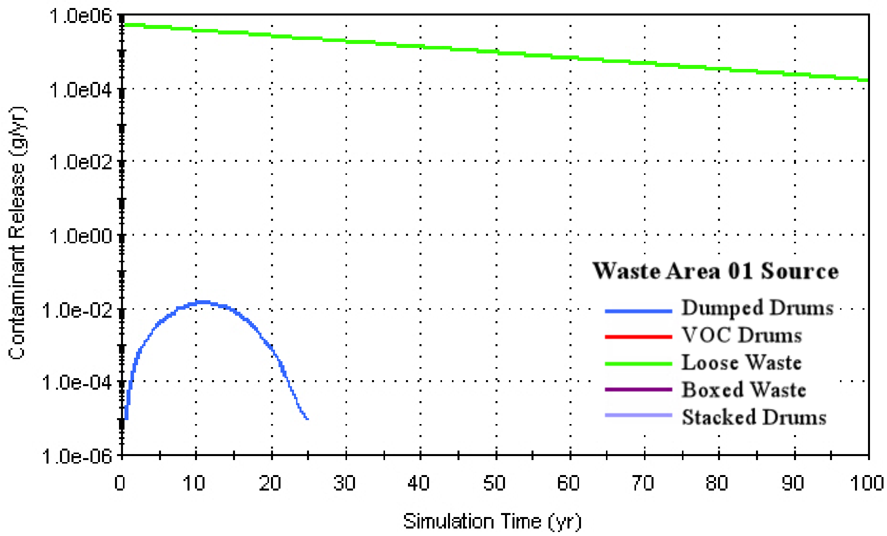

Figure 131. Example BCBG U-238 Source Releases (Semi-logarithmic Scale)

None of the BCBG buried wastes containing Th-232 appeared to have been contained in drums although some of the Th-232 in WA01 and WA02 was associated with fuel-like wastes and this contamination is released via dissolution as illustrated in Figure 129. Some of the Th-232 was buried loose; this fraction of the inventory was transferred before the first GoldSim timestep recorded for display. For example, the 302 kg of Th-232 expected to have been buried in WA03 (from Appendix D) was transferred from the WA03 Source element to Waste Area 03 (i.e., a *Cell Pathway* element) although this transfer is not shown in Figure 129.

A small fraction of the PCBs buried in the BCBG were contained in drums (in Waste Area 01 as indicated in Figure 130). None of the PCBs were assumed to have been associated with a waste matrix and all were subject to the surface wash mechanism once exposed. As with the Th-232 in Waste Area 03, this subjects the bulk of the PCBs that were originally buried in the BCBG to immediate transfer to Waste Areas 02 and 03 as illustrated in Figure 130.

The source term results provided in Figure 123 through Figure 131 illustrate the ability of the screening risk tool to model complicated source releases to the environment. The same release models are implemented in the screening risk tool that were used to describe the releases in the SDA remedial investigation modeling (Anderson and Becker 2006; Holdren et al. 2006); however, the models in the screening risk tool can be treated stochastically as illustrated in Figure 127 for the hundreds of contaminants considered.

The trade-off in implementing stochastic source release modeling in GoldSim is that the source inventory must be available at time zero, which is different than how wastes were buried in DOE burial grounds. However, considering that the time over which wastes were typically buried in these sites (e.g., 20-30 years) are more than an order of magnitude less than the assessment period (e.g., 1,000 years) and having the ability to vary the placement time and treat uncertainties in inventory and source release parameters, it is felt that the trade-off is reasonable[268].

Transport Model Verification

After contaminants are released into the environment (or, in the case of the screening risk tool, a Waste Area), they are transported to receptors via various pathways (e.g., advection, diffusion, etc.). The various transport pathways that can be modeled in the screening risk tool and how the pathways relate to one another are described in Table 24 in Chapter VI. Each transport process can be turned on or off prior to running the simulation using the GoldSim *Dashboard* element shown in Figure 33 in Chapter VI.

[268] The benefit of the approach appears even more reasonable if one considers the hundreds of contaminants whose source term time series would have to be estimated externally to the screening risk tool to estimate risks to receptors. A different approach might be to implement the stochastic source term model in a standalone GoldSim model that could be replaced by an alternate, more accurate version if the impact of burying wastes over time is thought to be significant in terms of the other uncertainties in the model.

Furthermore, the desired burial site conditions (i.e., *arid* or *humid*), institutional controls, and media-specific properties (e.g., solubility, retardation, organic degradation[269], etc.) are also controlled using this *Dashboard* element. Finally, whether or not remedial action is taken—versus examining baseline conditions—and the extent of the selected remedial action are also selected from this *Dashboard* element.

Each selection may have an impact on the resulting risk predictions and thus its potential impact was verified. An exhaustive verification of all possible combinations of the items manipulated using the GoldSim *Dashboard* is beyond the scope of this appendix. However, the simple one-at-a-time verification results for the most important transport processes are provided.

No Contaminant Transport. When all the transport-related switches on the *Dashboard* element shown in Figure 33 in Chapter VI are turned off (i.e., unchecked) for either humid or arid conditions, no contaminant transport or movement from remedial action should take place in the system. This situation describes how the screening risk tool was used to generate the source term results described in the previous section. From the information in Table 24 in Chapter VI, contaminants that enter the Waste Areas (or any other GoldSim *Cell Pathway* element (GTG 2005a)) are immediately mixed and partitioned among the media present[270]. Volatile contaminants may be transported from the Waste Area layers to the following media:

[269] A related process, radioactive decay, is controlled from the GoldSim *Model|Options|Contaminant Transport* menu selection.

[270] If contaminants do not enter the Waste Areas (i.e., if they are not released from *Source* elements described in the previous section), they cannot enter the system, be transported, or impact a receptor.

- Surface Soil (via vapor phase diffusion from both layers and plant-induced or animal-induced transport from the Accessible layer),
- Atmosphere (via barometric pumping from both layers),
- Bottom Soil (via aqueous phase advection from the Inaccessible layer),
- Local Saturated and Surface Water Zones (via flooding and/or inundation from both layers), and
- Local Surface Water Zone (via soil run-off).

All but two pathways (i.e., soil resuspension and runoff) in the screening risk tool are tested for Waste Area transport with all pathways disabled. The results from the simulations used to generate the source term information are represented in Figure 132—all the media have the same mass versus time results shown in this figure. The material balance for the Waste Areas is illustrated in Figure 133 showing that no contaminants are exiting these areas as designed.

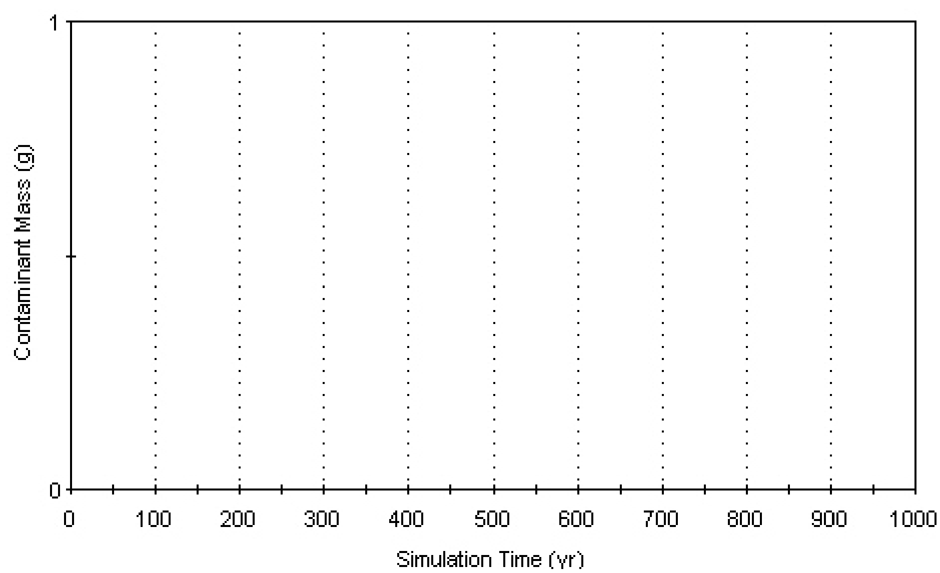

Figure 132. Mass versus Time for Surface Soil, Atmosphere, Bottom Soil, Local Saturated Zone, and Local Surface Water

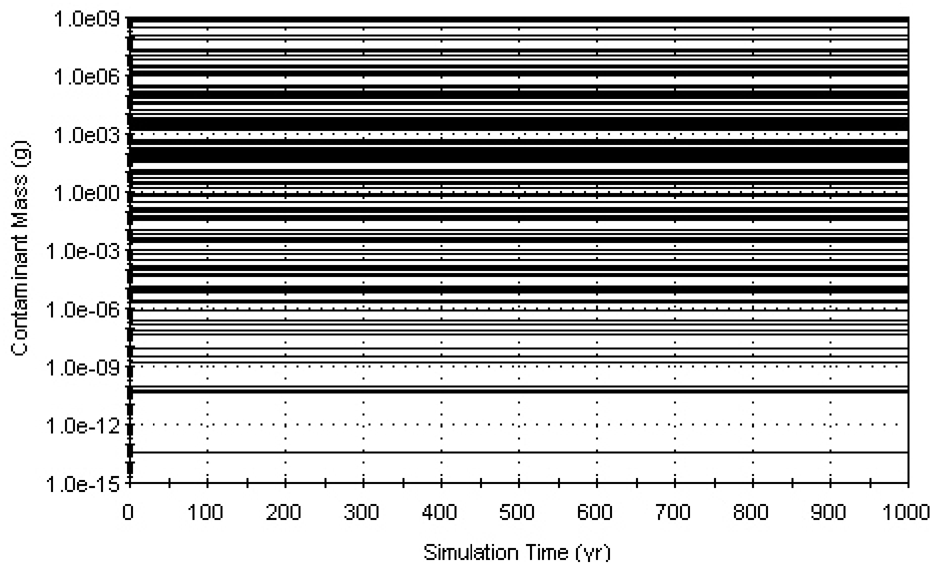

Figure 133. Waste Areas Material Balance for the Subsurface Disposal Area (No Radioactive Decay)

Advective Transport via the Aqueous Phase (including Solubility, Retardation, Colloidal Transport, Flooding, and Inundation) and the Surface Wash Mechanism. Apart from entering the burial site upon exposure and release, the most important process involved with contaminant migration and potential exposures to receptors is likely advection in the aqueous phase[271]. In GoldSim, advection is modeled by defining the flux of a fluid (e.g., water) between two media (GTG 2005a). If there no solubility or other constraints (e.g., retardation) are enabled, contaminants are advected almost immediately (as expected) with water moving through the burial site as illustrated in Figure 134 for Pu-239 in the SDA Waste Area 01 (i.e., WA01). Furthermore, the transport of contaminants is directly tied to drum failure (which was shown previously in Figure 123).

[271] That is, unless a remedial action (e.g., excavation, retrieval, etc.) causes the receptor to move to the contaminant.

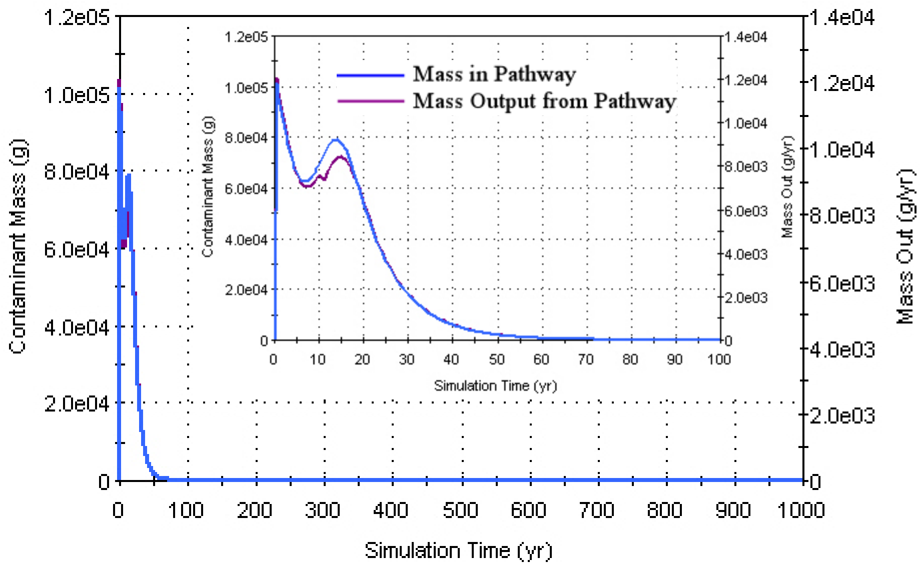

Figure 134. SDA Pu-239 WA01 Transport Results for Advection without Solubility, Retardation, or Release Limited by the Surface Wash Mechanism (Inset shows advection results over the first 100 years)

However, if solubility limits are enabled in the screening risk tool, then concentrations are limited in the GoldSim *Cell Pathway* element, and because the *Cell Pathway* element is well-mixed, the advective mass output from the pathway will also be solubility-limited as illustrated in Figure 135. The imposition of the solubility constraint for Pu-239 decreases the maximum advective flux of this radionuclide out of the Waste Area by almost two orders of magnitude. Perhaps more importantly, however, the solubility limit produces a fairly constant mass flux of Pu-239 from the Waste Area; whereas, the unconstrained case produces a mass flux of approximately zero by about 60 years of simulation time. This "flushing" of contaminants through the system has the potential of producing excessively small exposures for those receptors assumed to have limited access to the site until after the Institutional Control period has been completed.

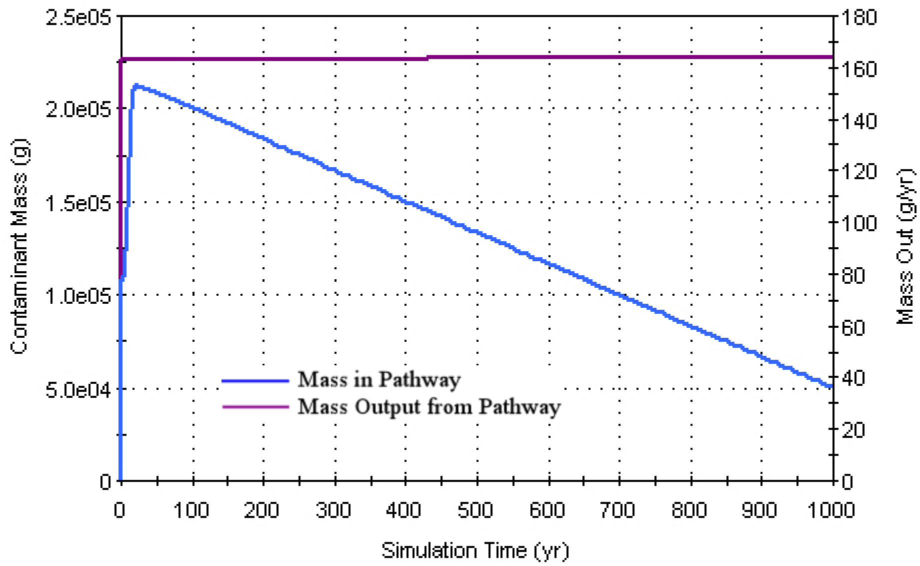

Figure 135. SDA WA01 Pu-239 Transport Results for Solubility-Limited Advection

As described in Appendix C, retardation is implemented in the screening risk tool using linear partitioning. For screening purposes[272], partition coefficients, which use a lumped constant (i.e., often referred to as the "K_d") to represent the degree to which the chemical adsorbs to the solid phase, are used as the default retention parameter (Sheppard and Thibault 1990) despite the limited applicability of the underlying sorption model to actual environmental conditions (Bethke and Brady 2000; Brady and Bethke 2000). When retardation is enabled, the contaminant is instantaneously partitioned between solid and aqueous phases leaving considerably less of the contaminant to be transported from the *Cell Pathway* with the aqueous phase. The expected result of enabling linear retardation (i.e., reduced contaminant transport) in the screening risk tool is illustrated in Figure 136.

[272] For the screening analysis, detailed, site-specific information including spatial and temporal variations in soil pH, porewater composition, organic matter content, etc.) as well as the reaction kinetics for each element (Sheppard and Thibault 1990) will likely be unavailable.

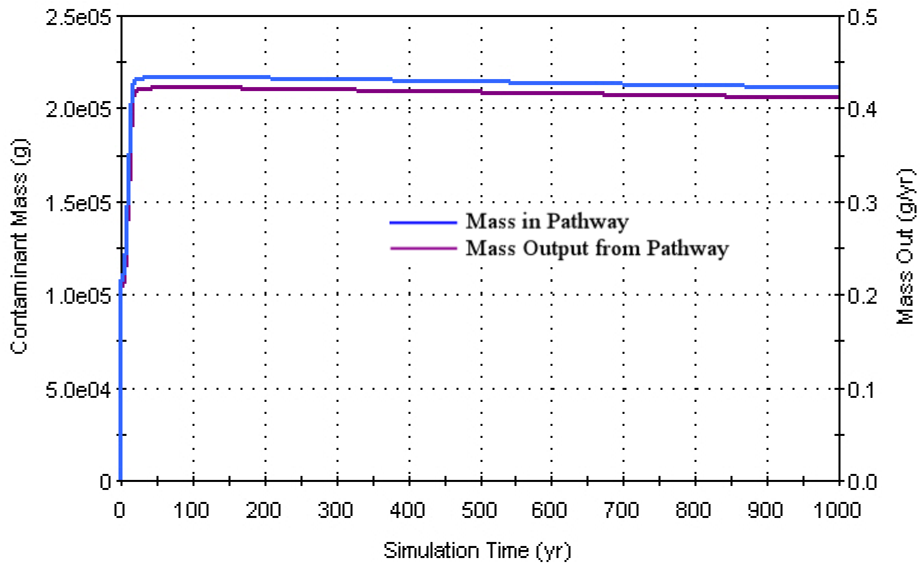

Figure 136. SDA WA01 Pu-239 Transport Results for Retardation-Limited Advection

As described in Appendix C and Appendix E, another use of linear partitioning in the screening risk tool is implementing colloidal transport. Based on the characteristics of the Rocky Flats Plant (RFP) wastes buried in the SDA, only a small fraction of the plutonium in the buried wastes (i.e., less than 5%) is subject to colloidal suspension and facilitated transport out of the Waste Areas. To make the results clearer, the surface wash release mechanism (which also impacts the concentrations of a contaminant among the phases in a *Cell Pathway* element) was disabled to generate the results in Figure 134 through Figure 136. For example, if the surface wash mechanism is enabled and solubility and retardation disabled, then the results in Figure 137 are generated. As expected, the Pu-239 mass release limited by the surface wash mechanism closely resembles the results for the retardation-limited case illustrated in Figure 136. When both retardation and surface wash are enabled, the results illustrated in Figure 138 are obtained (as expected).

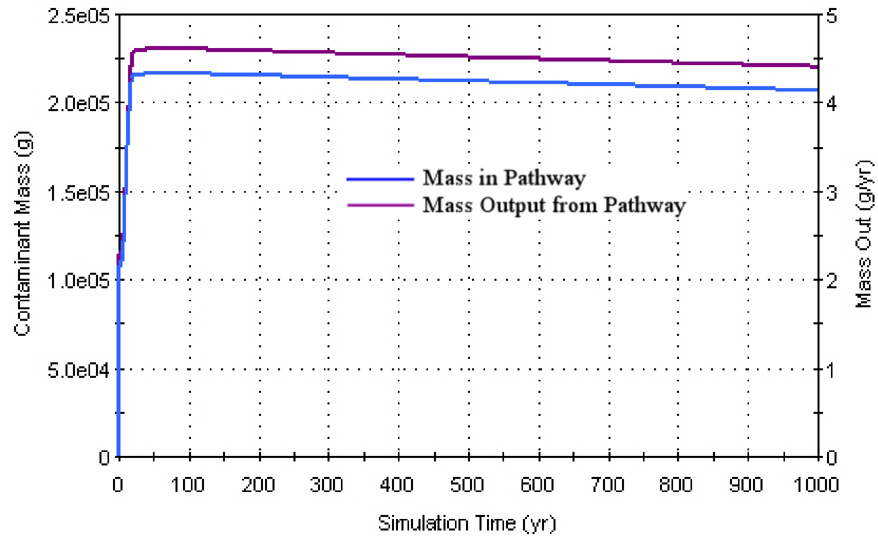

Figure 137. SDA WA01 Pu-239 Transport Results when Surface Wash is Enabled

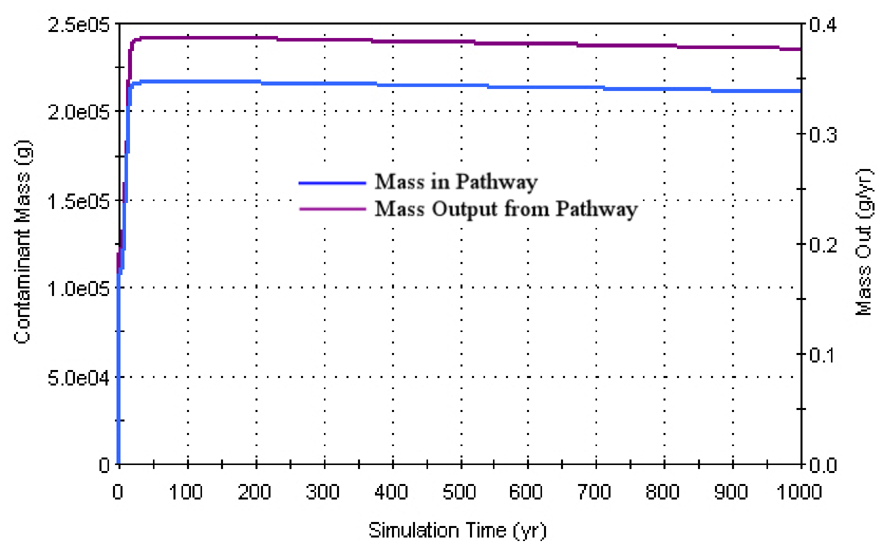

Figure 138. SDA WA01 Pu-239 Transport Results when Retardation and the Surface Wash Release Mechanism are Enabled

For some waste sites, facilitated transport of radionuclides via colloids or other media may provide an important mechanism for contaminant movement through the environment. As described in Appendix C, the use of a specially-defined solid medium, denoted Colloid, allows modeling of facilitated transport in the screening risk tool. A fraction of the plutonium buried in the SDA is of a sufficiently small size that it can form colloidal suspensions and thus move more rapidly through the vadose zone than otherwise. Batchellor and Redden (2004) estimated that 3.7% of the plutonium originating at the Rocky Flats Plant (RFP) was processed in such a manner that it could be suspended in a colloid. The manner in which the colloid mass is computed to allow this amount of plutonium to travel with the advective water flow through the system is described in Appendix C.

When no solubility or retardation constraints are imposed on the system, the flux of plutonium from the Waste Area is very rapid and reduces to nearly zero flux by 60 years of simulation time as illustrated in Figure 134. When retardation is enabled, the flux of plutonium is greatly reduced (and persists over the 1,000-year assessment period). The impact of enabling colloidal transport on the plutonium mass flux is illustrated for the first 100 years of the assessment period in Figure 139. The verification that the percentage of entering plutonium entering the Waste Area is maintained at the target value (i.e., 3.7%) is show in Figure 140. The mass plutonium flux from the *Cell Pathway* at a time of 60 years is 360 g Pu-239/yr and at the end of the 1,000-year assessment period is approximately 16 g Pu-239/yr compared to the maximum mass flux of less than 0.4 g Pu-239/yr for the corresponding case shown in Figure 138. These results illustrate that the implementation of colloidal mass transport from the Waste Areas works as intended (in Appendix C).

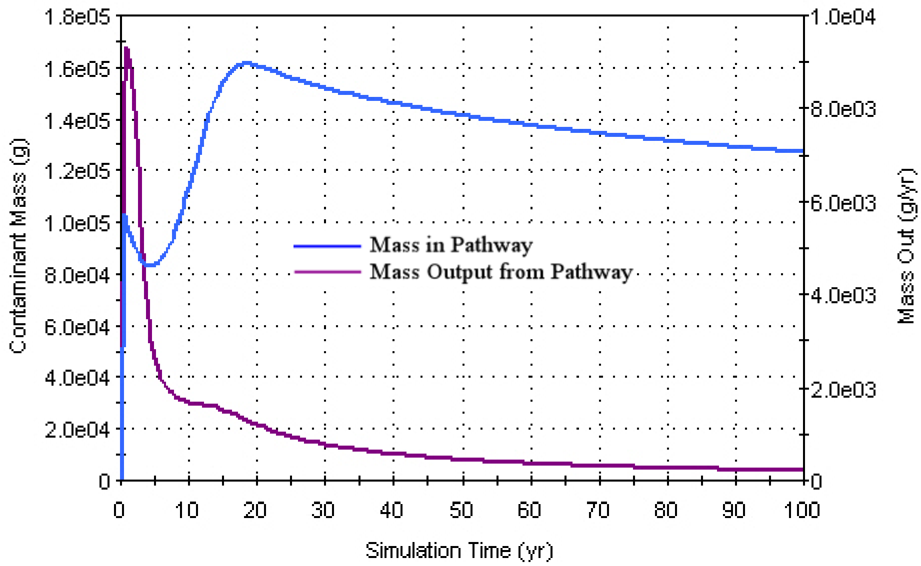

Figure 139. SDA WA01 Pu-239 Transport Results when Retardation, Surface Wash, and Colloidal Transport (3.7% of Total Plutonium) are Enabled

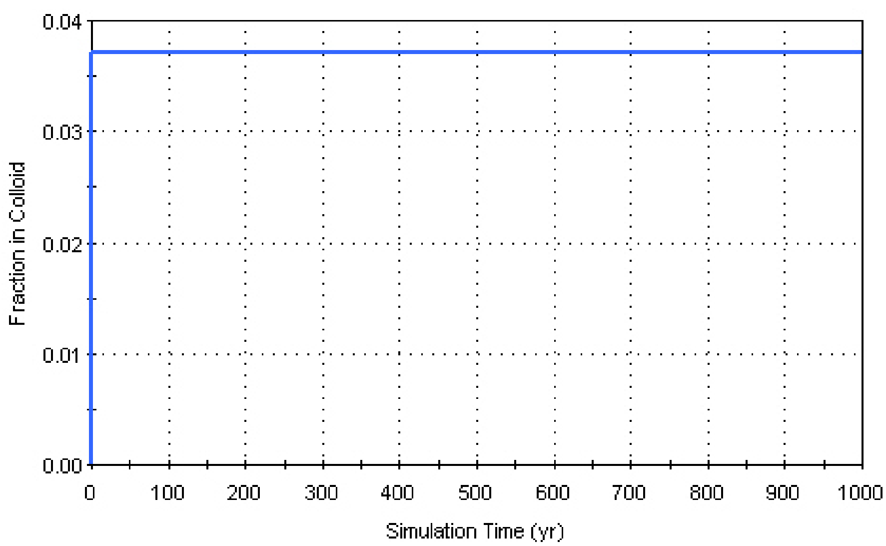

Figure 140. SDA Colloidal Transport Verification Showing the Fraction of Total Pu-239 in Colloids (where Target is 3.7%)

Thus Figure 139 and Figure 140 illustrate that the behavior of colloidal transport from the Waste Areas in the screening risk tool performs as intended. However, once colloids are created and advected from the Waste Areas, they may be transported through the vadose zone to the sole source aquifer below. Because of the difficulties in predicting the correct colloid concentration in GoldSim *Network Pathway* elements (as described in Appendix C), the simplified approach to setting relevant partition coefficients to zero in those regions supporting colloidal transport and for those elements that are suspended in colloids is used. The impact of retardation and colloidal transport and screening in the interbed region is illustrated in Figure 141 through Figure 148.

Figure 141 illustrates the mass fluxes of Pu-239 from the bottom soil and vadose zone regions when all constraints (e.g., solubility, retardation, etc.) and the surface wash mechanism and colloidal transport processes are disabled. The release and transport of Pu-239 through the vadose zone is very rapid and the drinking water concentration (from the local saturated zone) for on-site receptors peaks around 200 years.

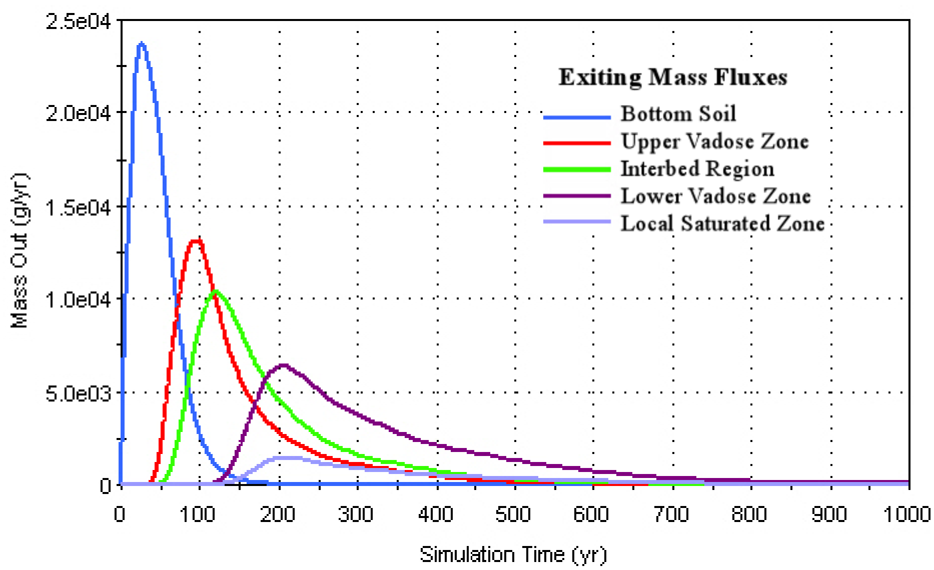

Figure 141. SDA Pu-239 Transport Results for Advection without Solubility, Retardation, or Release Limited by the Surface Wash Mechanism

The concern raised earlier about transport assumptions impacting the predicted on-site receptors (which are limited from the site until after the Institutional Control period has expired) appears to have no basis for drinking water exposure. Similar results for the carbon tetrachloride and Tc-99 are provided in Figure 142 and Figure 143, respectively, for comparison purposes. Carbon tetrachloride is a volatile organic compound that has been found to exceed its limit in the Snake River Plain Aquifer. Tc-99 is a highly mobile contaminant under SDA vadose zone conditions (often assumed to have zero or near-zero partitioning coefficients for all media in the model). Under these least restrictive transport conditions, there is little difference in the fluxes of the various contaminants from the Waste Areas to the aquifer below.

When retardation and the surface wash release mechanism are enabled, little of the Pu-239 exits the bottom soil and what does exit remains in the upper vadose zone during the 1,000-year simulation period as illustrated in Figure 144. On the other hand, the carbon tetrachloride flux is not impacted (as expected) by enabling these constraints as illustrated in Figure 145. The impact of source release on the ultimate transport of contaminants through the subsurface is likely best illustrated by comparing Figure 146 to Figure 143 for Tc-99. Although Tc-99 has zero or near-zero partition coefficients for all media modeled in the screening risk tool, the vast majority of Tc-99 inventory (as illustrated in Appendix D) is associated with either waste matrices (undergoing dissolution) or the surface wash release mechanism. Therefore, although it moves rapidly through the subsurface, this contaminant is source release limited in the screening risk model.

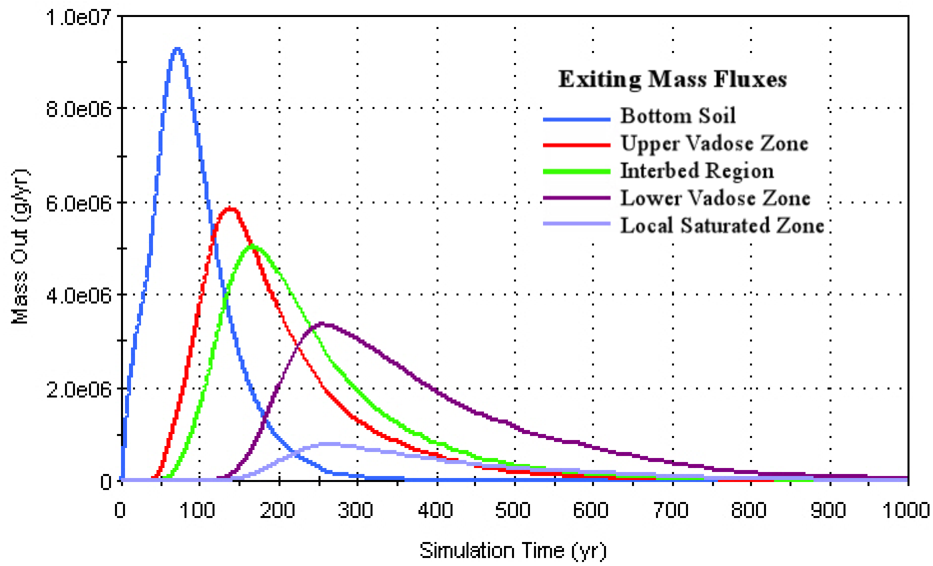

Figure 142. SDA Carbon Tetrachloride Transport Results for Advection without Solubility, Retardation, or Release Limited by the Surface Wash Mechanism

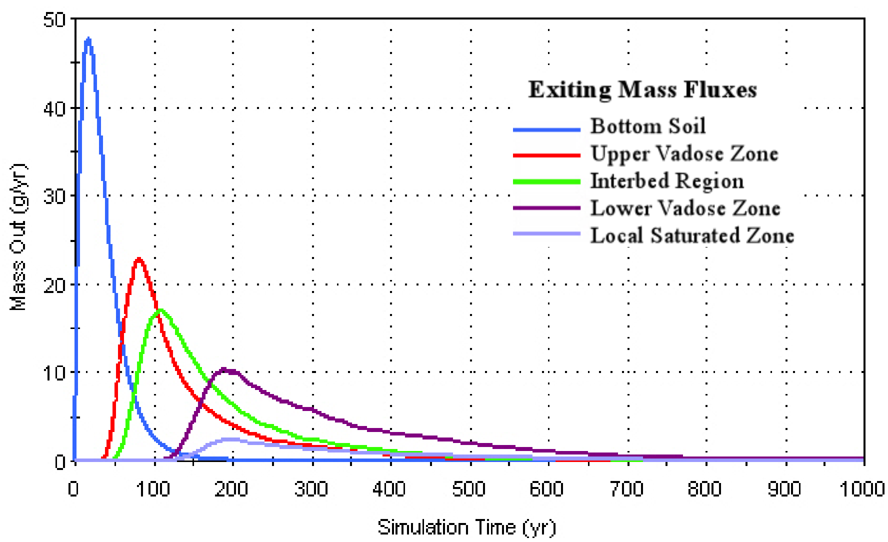

Figure 143. SDA Tc-99 Transport Results for Advection without Solubility, Retardation, or Release Limited by the Surface Wash Mechanism

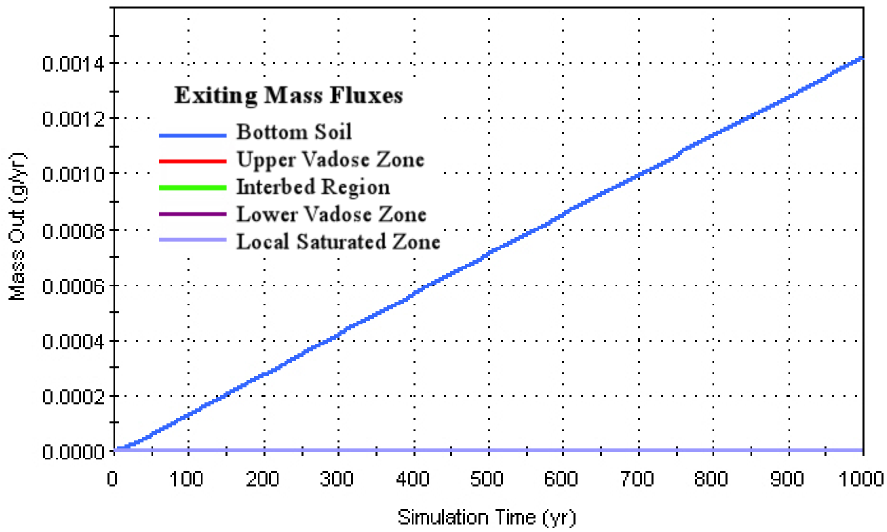

Figure 144. SDA Pu-239 Transport Results for Advection with Retardation and Surface Wash Enabled. (Only Bottom Soil Fluxes are Non-Zero)

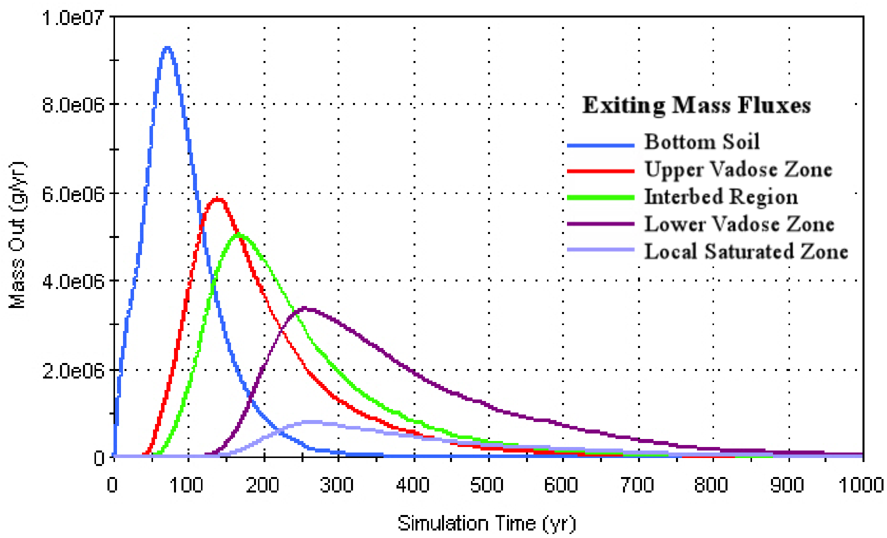

Figure 145. SDA Carbon Tetrachloride Transport Results for Advection with Retardation and Surface Wash Enabled

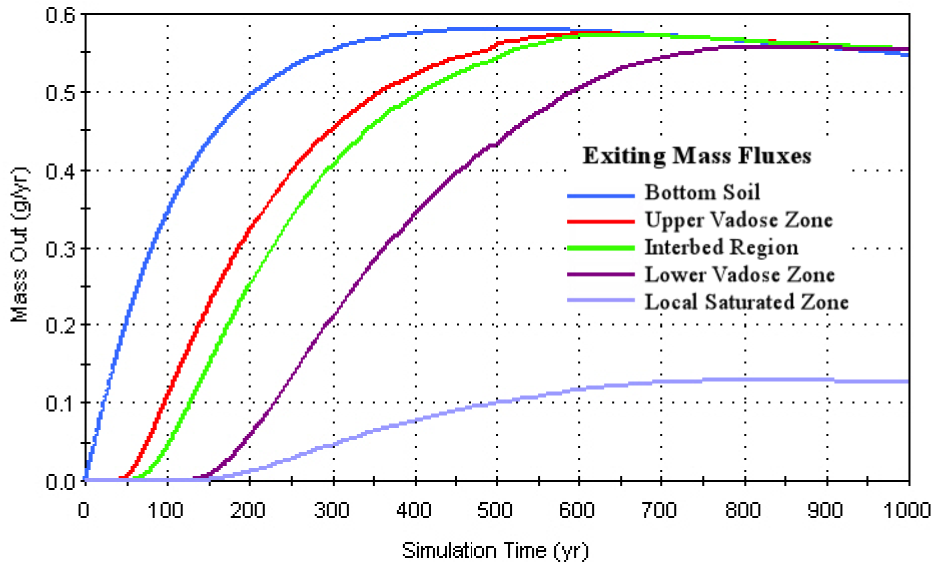

Figure 146. SDA Tc-99 Transport Results for Advection with Retardation and Surface Wash Enabled

The correct baseline information now exists to verify that colloidal transport is performing as designed. The mass flux of Pu-239 through the vadose zone is bounded by the unconstrained release and transport conditions illustrated in Figure 141 and the retarded case illustrated in Figure 144—indicating no Pu-239 migrating to the aquifer during the 1,000-year simulation period. The actual results fall between these two extrema. When colloidal transport is enabled (and colloids are not filtered by the interbed region), the predicted Pu-239 mass fluxes are between the extreme cases as illustrated in Figure 147. Although not apparent in Figure 147, the mass flux from the local saturated zone (i.e., related to the drinking water concentration) is non-zero.

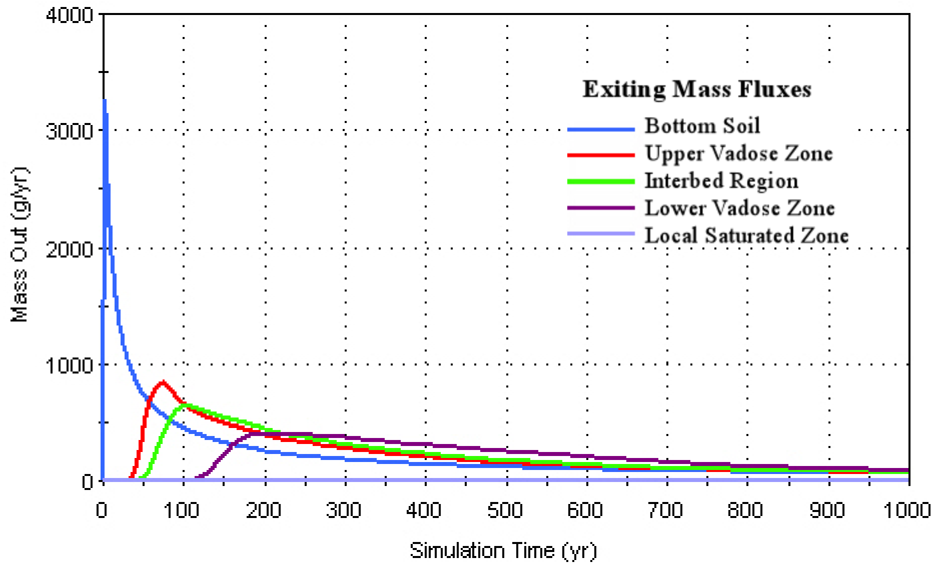

Figure 147. SDA Pu-239 Transport Results for Advection with Retardation, Surface Wash, and Colloidal Transport Enabled (No Interbed Filtering). The Mass Flux from the Saturated Zone is Non-Zero (i.e., less than 2.5 g/yr).

When colloids are filtered by the interbed region, Pu-239 does not reach the saturated zone (and drinking water well) as shown in Figure 148 (and previously predicted for the retardation case in Figure 144). However, under these assumptions, a considerable amount of Pu-239 (over 200 kg total or approximately one-fifth the expected total inventory) would have migrated via colloidal transport from the source to the upper vadose zone interbed zones (or almost 80 m into the vadose zone underlying the SDA). As long as colloids are filtered out by the interbed region and Pu-239 remains adsorbed to the subsurface material in the SDA vadose zone, then perhaps treating the source will produce a protective state. This conjecture is examined in Chapter VII. Finally imposing the solubility constraint on the system has no significant impact on the colloidal transport model as predicted in Appendix C.

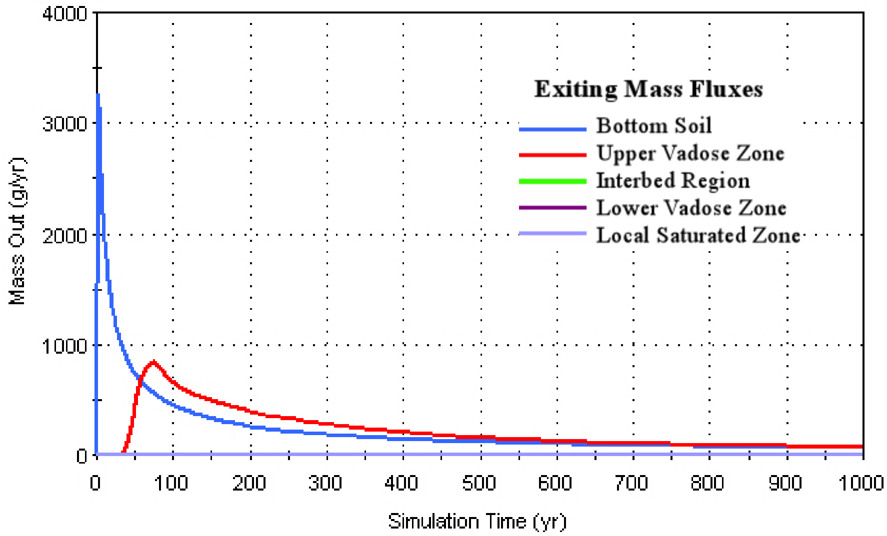

Figure 148. SDA Pu-239 Transport Results for Advection with Retardation, Surface Wash, and Colloidal Transport and Filtering Enabled. The Mass Flux from the Interbed Region is zero.

Like colloidal transport, flooding is a transport mechanism that may impact (advective) contaminant transport from the SDA through the vadose zone. Flooding in the SDA, which impacts all Waste Areas, is implemented in the screening risk model by increasing the water flux for impacted media based on a flood duration and volume as described in Chapter VI[273]. Changing the advective flux may substantially increase GoldSim run time (by up to an order of magnitude). The impact of enabling flooding on SDA mass fluxes is indicated by the results in Figure 149. As anticipated, the increased water advection from flooding produces a large temporary increase in contaminant transport while diluting what remains in the medium. All floods in Figure 149 occur at the same rate; however, those shown occur at recorded timesteps (GTG 2005a). Both the timestep for analysis and for recording can be varied during the simulation.

[273] In the BCBG, flooding is assumed to be subsumed into the large uncertainty in the percolation rate. Please refer to Chapter VI for details.

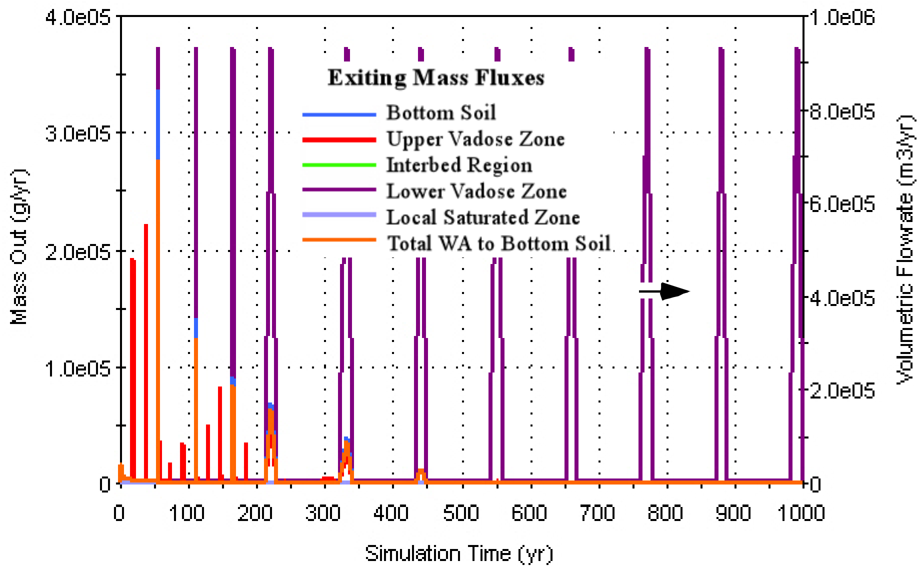

Figure 149. SDA Pu-239 Transport Results for Flooding Conditions (Retardation, Solubility, Flooding, and Colloidal Transport and Filtering Enabled).

Whereas, potential impacts of flooding must only be considered important for the SDA, impacts of inundation on exposure and risk only must only be simulated for the BCBG. As described in Chapter VI and Appendix D, BCBG Waste Area 01 (i.e., WA01) is dry with no inundation flow. Waste Area 02 is that most affected by inundation and the expected inundation period begins every January 1. Waste Area 03 is assumed to be impacted for only 50 days per year. During the inundation period, the aqueous flux through the Waste Areas is split among the vadose zone, saturated zone, and surface water as illustrated in Figure 150 and Figure 151 for the Waste Area 02 Accessible and Inaccessible layers, respectively. In the screening risk tool, inundation is defined based on the available pore space in the Waste Area and thus the impact for the Inaccessible layer is much larger because it is a much larger area for the conditions considered.

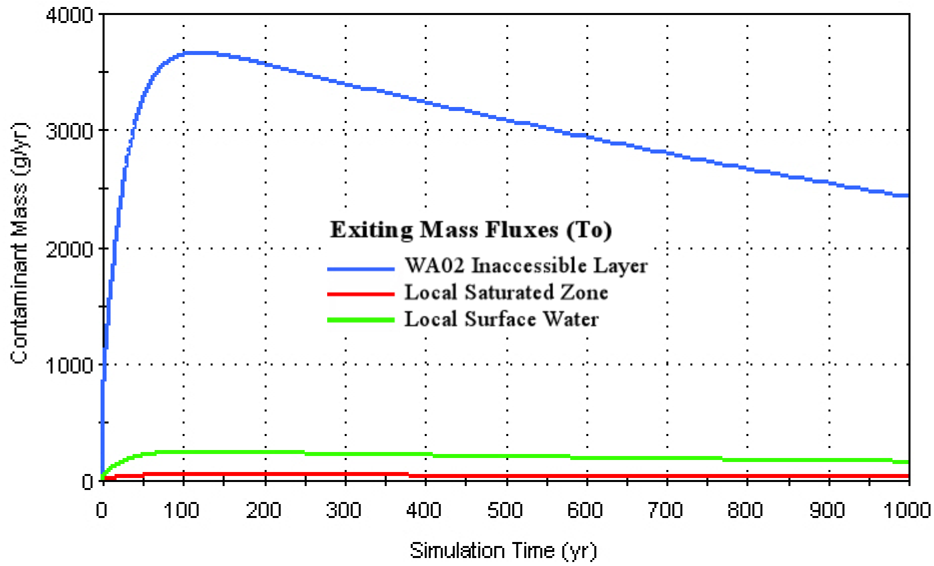

Figure 150. BCBG WA02 Accessible Layer U-238 Inundation Results (Retardation, Solubility, Flooding, and Colloidal Transport and Filtering Enabled).

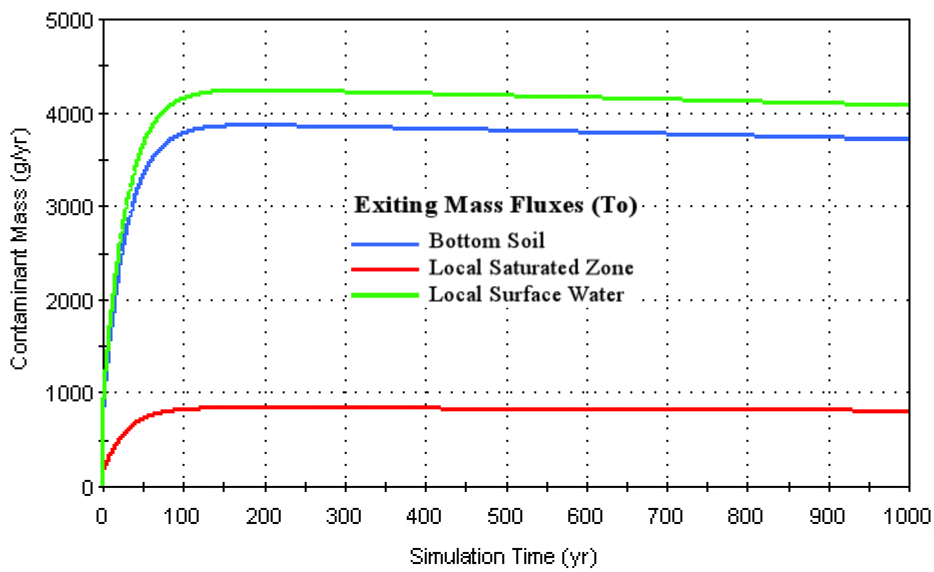

Figure 151. BCBG WA02 Inaccessible Layer U-238 Inundation Results (Retardation, Solubility, Flooding, and Colloidal Transport and Filtering Enabled).

Diffusive Transport via the Vapor Phase and Barometric Pumping. From a cursory examination of the transport pathways, vapor phase diffusion and barometric pumping may help transport significant amounts of volatile contaminants and radioactive gases to the atmosphere above the Waste Areas. Diffusion, which is contaminant transport in both "directions" based on the concentration difference) is implemented using the built-in diffusive link between GoldSim elements (GTG 2005a) as described in Chapter VI. An example of the diffusive transport among the elements comprising the bottom soil to atmosphere (and layers in between) is illustrated in Figure 152 for carbon tetrachloride. These results are anticipated including the fact that there is no net transport of carbon tetrachloride between the Accessible and Inaccessible layers because the concentration is the same for both layers in this particular case.

Weather patterns cause cyclical variations in barometric pressure above the buried waste site. As the barometric pressure decreases, gases can be drawn from the waste site to the atmosphere above the site (Nilson 1991). When the barometric pressure increases, uncontaminated air is forced into the waste areas. The net effect of these cycles may be the transport of volatile contaminants and radioactive gases to the atmosphere where receptors may be exposed. In some cases, the effects may be two orders of magnitude more than that due to molecular diffusion alone (Nilson 1991). As described in Chapter VI, a very simple model for estimating the maximum net impact of barometric pumping on contaminant transport is implemented as a constant annual transfer of air from waste or other affected areas to the atmosphere. An example of the results of barometric pumping from SDA Waste Area 01 is provided in Figure 153. Diffusion and barometric pumping have very similar transfer rates to the atmosphere.

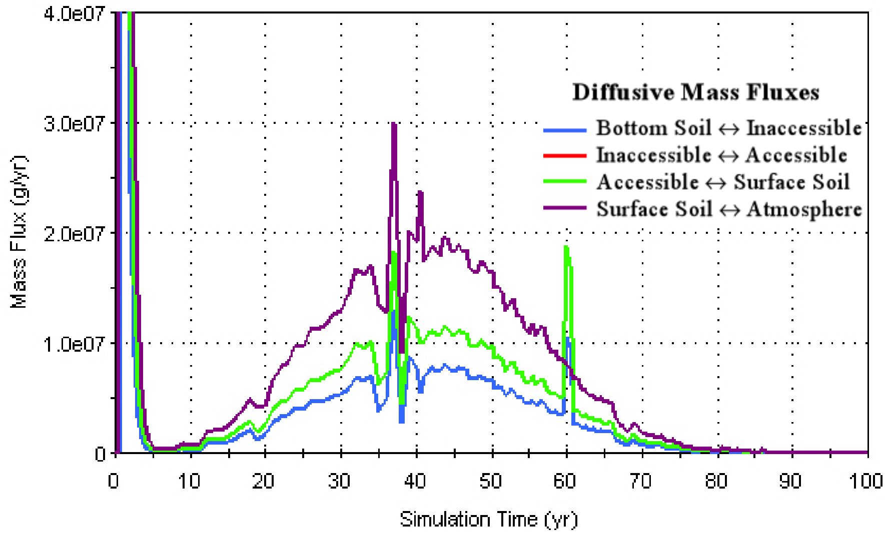

Figure 152. SDA WA01 Diffusion Results (The Ordinate and Abscissa have been Truncated to Better Show Results)

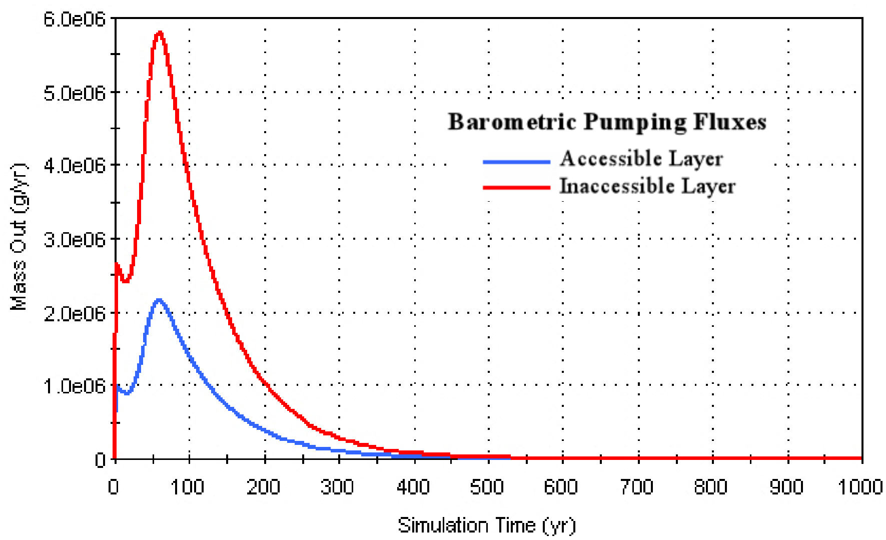

Figure 153. SDA WA01 Barometric Pumping Results

Plant-induced and Animal-induced Transport. The transport mechanisms described to this point are based on physical processes including advection and diffusion. However, biological processes may also transport contaminants from the buried waste site or contaminated soils to potential receptors. The potential significance of biological transport on exposure and risk is highly site-dependent; therefore, the biological transport mechanisms implemented in this screening risk model are designed to prove the concept and provide an idea of the potential impact more than to accurately describe biological transport for all possible plant and animal species near the buried waste sites.

Plant-induced transport of contaminants proceeds by absorption into the roots and then redistribution to the aboveground tissues of the plant (Kennedy and Strenge 1992; Tauxe 2004). During senescence the aboveground plant parts (and contaminants) are incorporated into surface soils, and the roots are incorporated into soils at their respective depths (Tauxe 2004). An example of plant-induced transport of Pu-239 from the Accessible layer of SDA Waste Area 01 is illustrated in Figure 154. For the plant-induced pathway, transport is based on a concentration ratio concept and is proportional to the mass concentration of the contaminant in the layer as shown in the figure.

Animal-induced transport is implemented in a fashion similar to that for plant-induced transport with one distinction. The actions of burrowing animals as they excavate soil may result in soil and contaminant movement to the surface. However, unlike plants, the burrows created may collapse thus moving contamination from the surface downward (Tauxe 2004). Burrow excavation and collapse are modeled in this research as described in Chapter VI. The results for animal-induced transport from the Accessible layer of Waste Area 01 are illustrated in Figure 155. This transport pathway is based on a concentration ratio concept and thus is proportional to the mass concentration of the contaminant in the layer as shown. Animal-induced transport for Pu-239 for these conditions is several orders of magnitude larger than that for plant-induced transport.

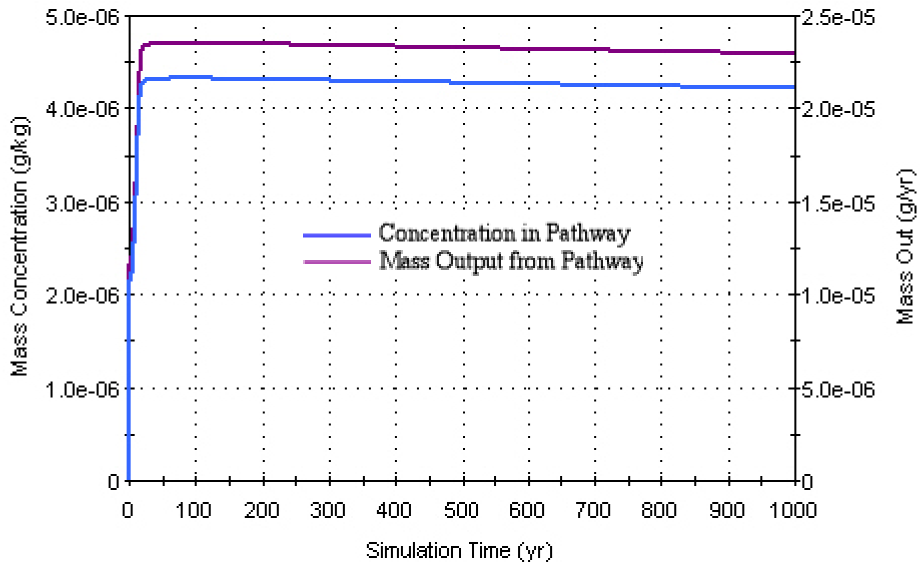

Figure 154. SDA WA01 Plant-Induced Pu-239 Transport to the Surface Soil

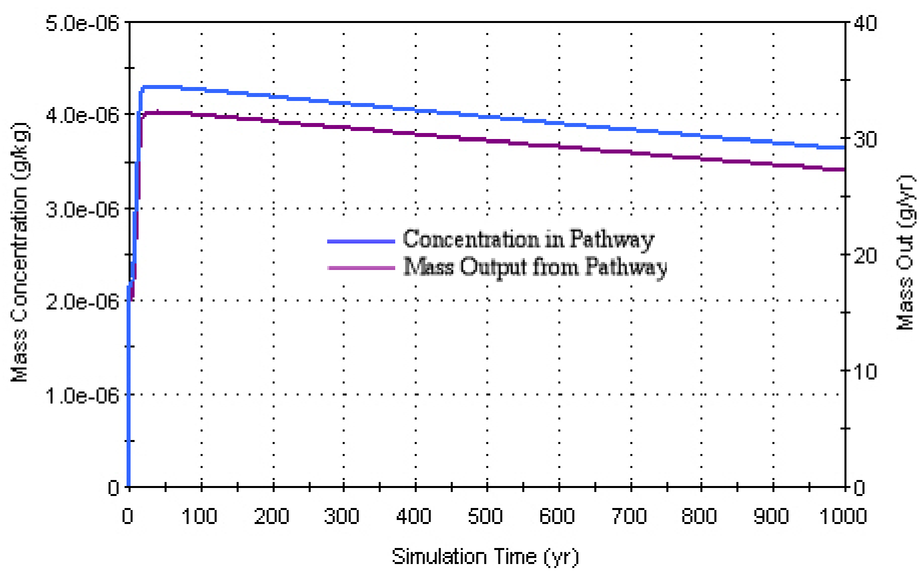

Figure 155. SDA WA01 Animal-Induced Pu-239 Transport to the Surface Soil

Soil Resuspension and Soil Runoff. Two additional transport pathways (i.e., surface soil resuspension to the atmosphere and soil runoff to surface water) are demonstrated based on first allowing contaminants to be transported to the surface soil by animals[274]. The results for surface soil resuspension for the SDA are illustrated in Figure 156. For soil resuspension to the atmosphere, the mass flux output from the surface soil is proportional to the mass concentration in the soil (which is determined by the linear partition coefficient between the soil and aqueous phases).

The results for surface soil runoff for the BCBG are illustrated in Figure 157. For soil runoff to the surface water (which is currently exclusive to the BCBG), the mass flux output from the surface soil is, like resuspension, proportional to the mass concentration in the soil (which is again determined by the linear partition coefficient between the soil and aqueous phases).

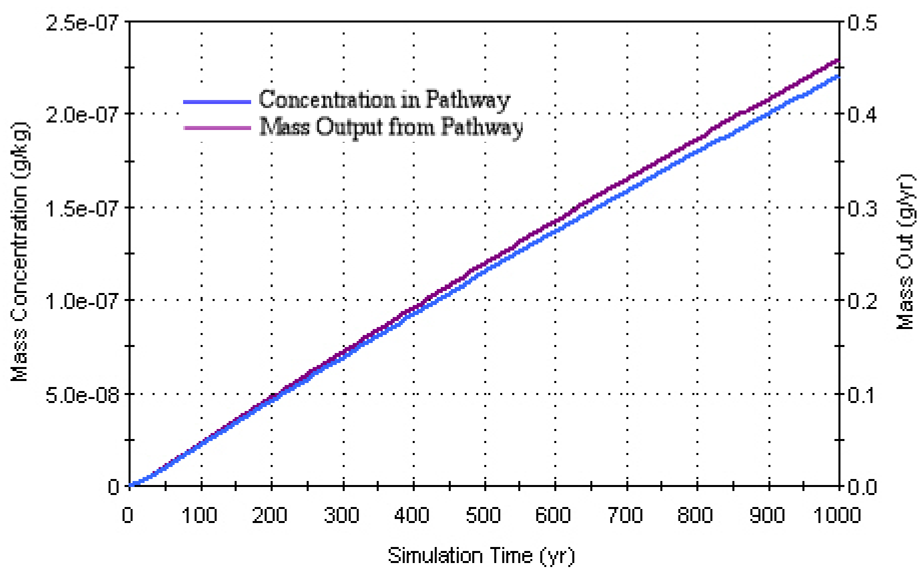

Figure 156. SDA Resuspension of Pu-239 in Surface Soil to the Atmosphere

[274] For demonstration purposes, contaminants must be in the surface soil before these transport pathways can be demonstrated. The simplest method is to use the animal-induced transport pathway examined in the previous section. Retardation must also be enabled so that contaminants will be adsorbed to the surface soil prior to resuspension to the atmosphere or runoff to the surface water.

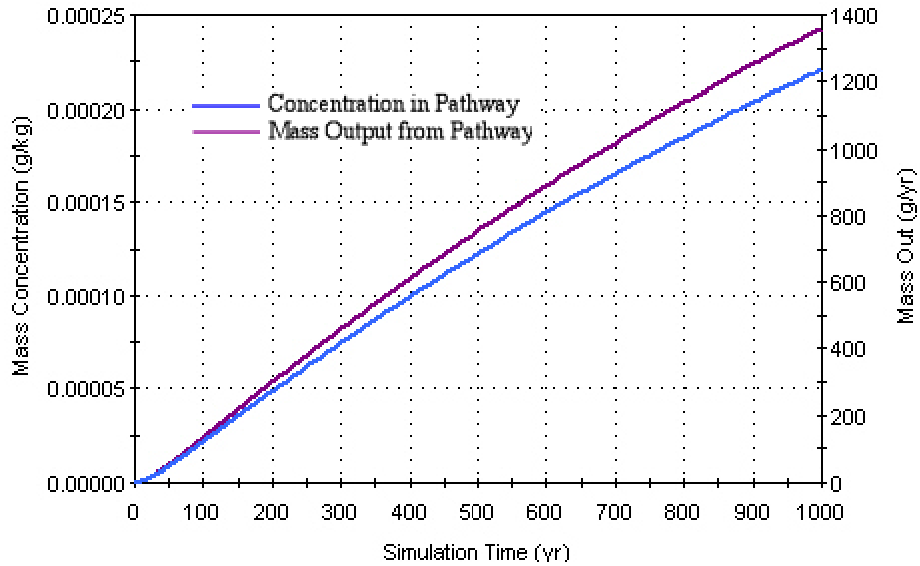

Figure 157. BCBG Runoff of U-238 in Surface Soil to the Surface Water

Remedial Action Verification Tests

A further series of tests were performed to assure that remedial actions were carried out properly in terms of the movement of contaminants corresponding to various remedial actions. For these tests, radioactive decay and organic degradation are disabled to assure there would be no confusion in examining the results (i.e., mass is conserved throughout the simulation because there is no decay or degradation to alternate products).

Two sets of information are provided for each remedial action case. The first set describes the movement of mass associated with the remedial action and an indication that the material balance remains closed. The second set of information concerns the predicted standard industrial injury and fatality risks and probabilities to remedial workers performing the activities. For the verification tests, the direct workers for SDA dispositioning will be the focus although the verification was extended to both direct and support workers for both sites.

Baseline (or "No Action") Conditions

The decision to take no remedial action at a site is a remedial decision, and so the results from this first test set the baseline for those results to follow. When taking no remedial action under the transport conditions imposed on the system (i.e., also no transport), the contaminants in the Waste Areas should remain in-place. The overall material balance and corresponding balance on the Waste Areas are illustrated in Figure 158 and Figure 159, respectively. Each line on these figures represents the mass of a single contaminant during the simulation. Because the purpose of these diagrams is to represent general, temporal changes in contaminant masses for potential remedial actions, the identity of each contaminant is not provided. Per design, no contaminants migrate or are moved from the Waste Areas.

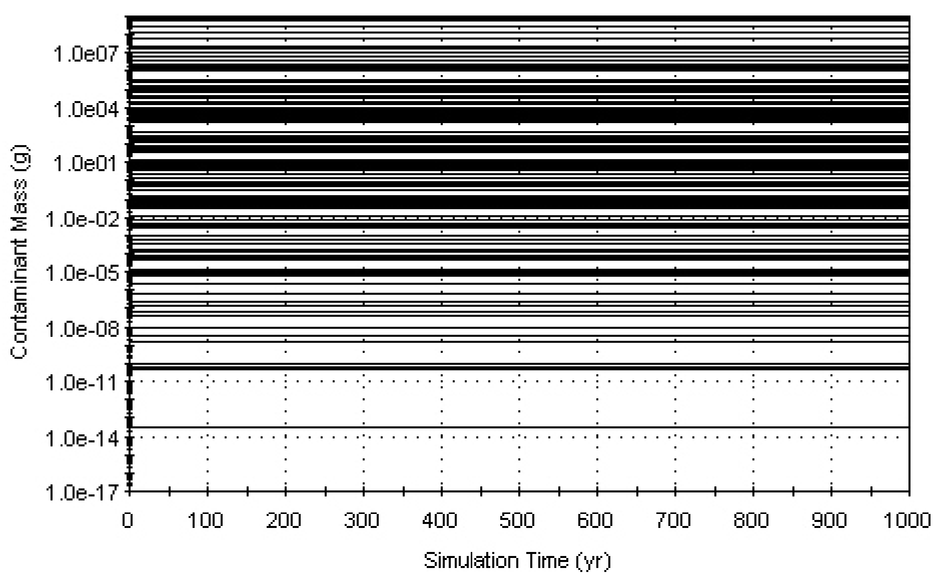

Figure 158. Overall Material Balance for the SDA Baseline Case

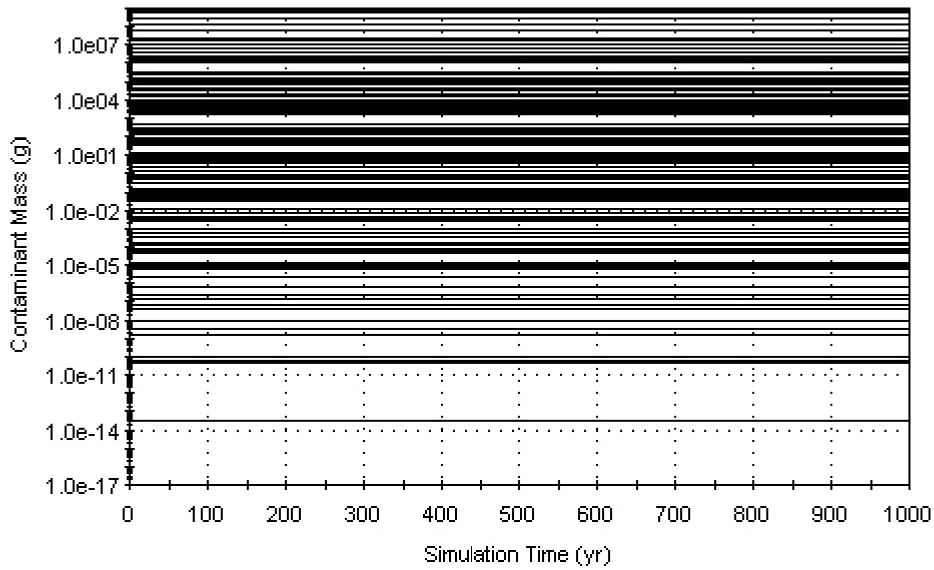

Figure 159. Waste Area Material Balance for the SDA Baseline Case. (These results are for only the Waste Areas and not all Media.)

The risks to direct and support workers supporting either routine or remedial actions for a buried waste site are critical inputs to a risk-informed decision. The direct and support worker injury risks and probabilities for the baseline SDA case are provided in Figure 160 and Figure 161, respectively, for the first 200 years of the assessment period to cover remedial actions and the Institutional Control (IC) period, if applicable[275]. The corresponding worker fatality risks and probabilities are provided in Figure 162 and Figure 163. These standard industrial risks are computed, assuming as a basis, a single worker for one work year and are meant to represent the "background" annual risks posed by working at the site against which remedial action risks should be judged. Because direct worker risks dominate, these risks will be the focus in this appendix from this point forward.

[275] The remedial action period begins at Year 60 and the institutional control period lasts 100 years after burial site closure. These conditions are assumed for all tests described in this appendix.

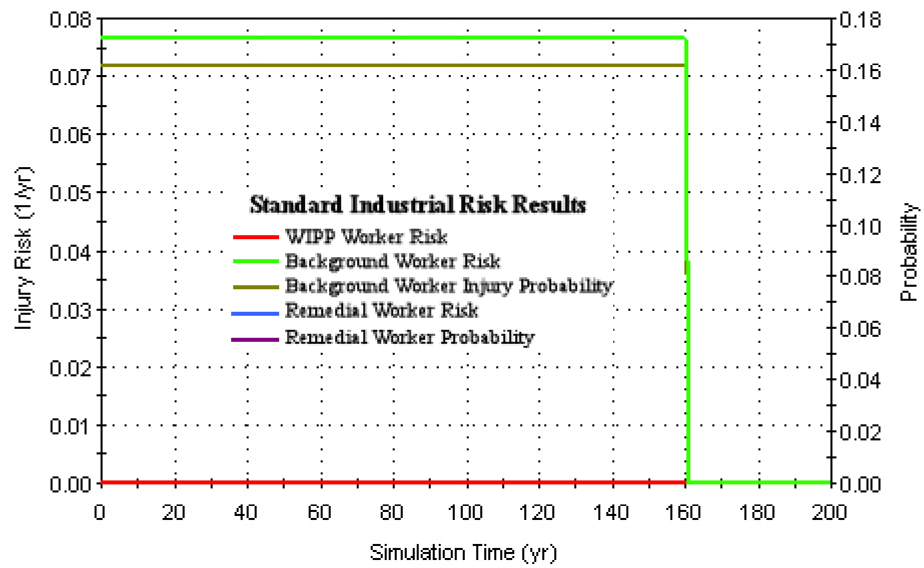

Figure 160. SDA Baseline Direct Worker Annualized Injury Risk and Probability

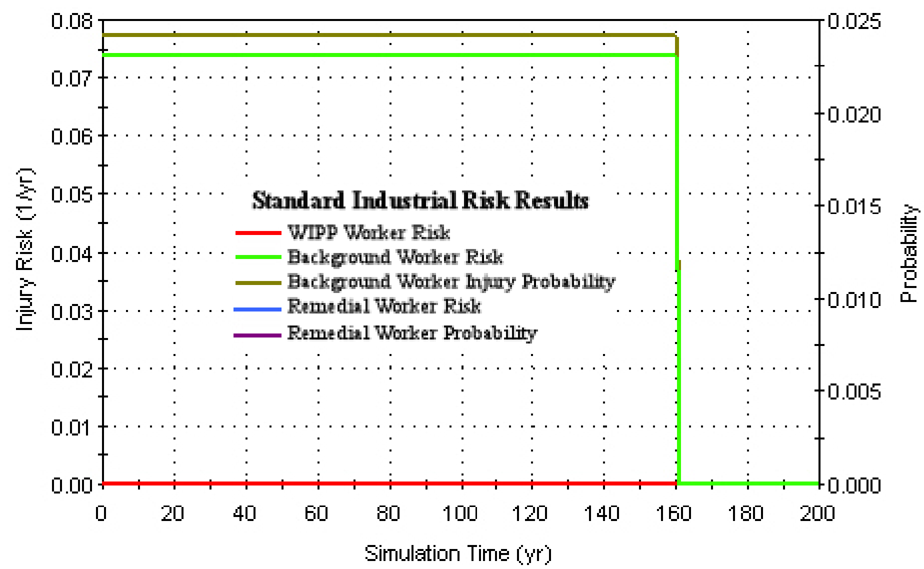

Figure 161. SDA Baseline Support Worker Annualized Injury Risk and Probability

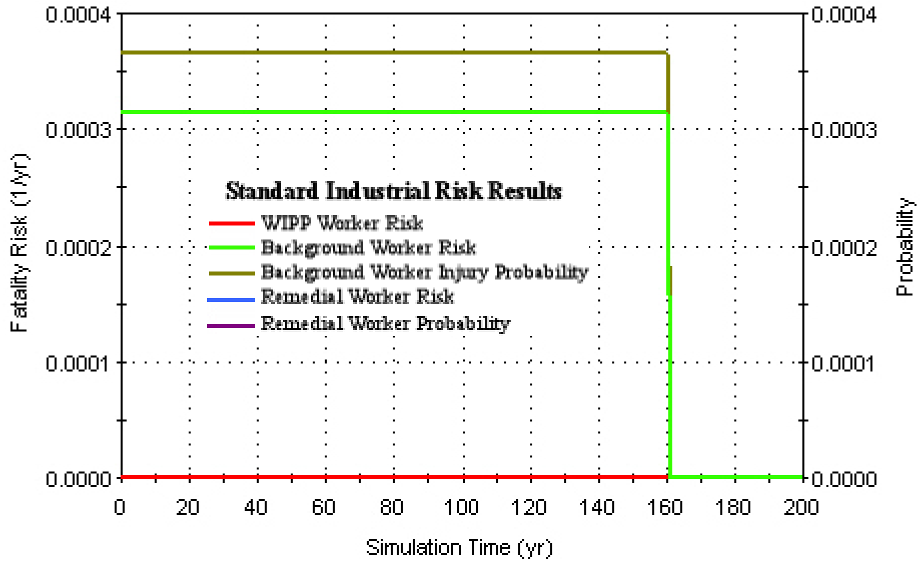

Figure 162. SDA Baseline Direct Worker Annualized Fatality Risk and Probability

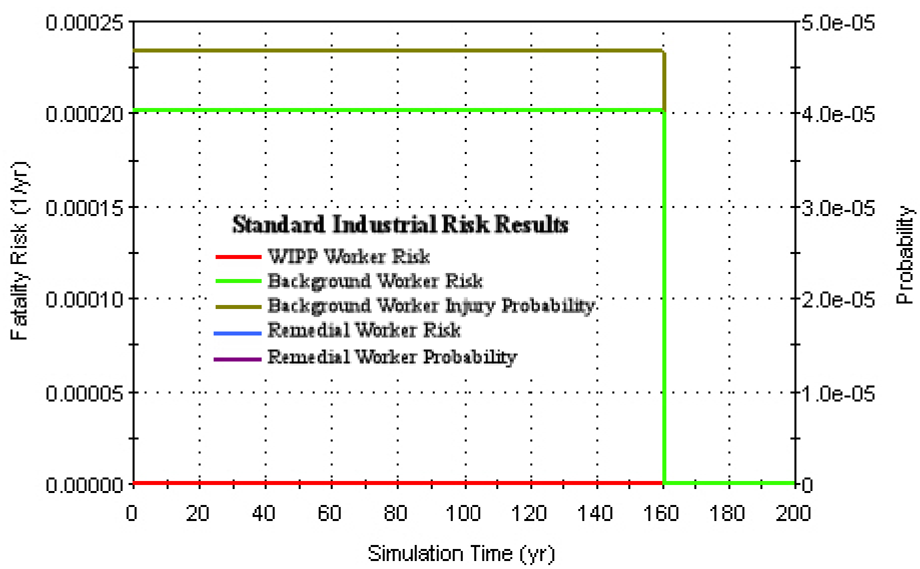

Figure 163. SDA Baseline Support Worker Annualized Fatality Risk and Probability

The Manage-In-Place (MIP) Remedial Alternative

The most straightforward remedial action that can be taken at a buried waste site is to install a surface barrier to reduce the infiltration of water and biotic intrusion into the wastes without any *in situ* treatment. In this remedial option, a surface barrier is installed and then long-term stewardship activities are instituted at the site. As described in Chapter VI, both cap failure and corresponding failure recognition are modeled in the screening risk tool. The results describing how masses are transferred (which, for this case, should be zero) are identical to those in Figure 158 and Figure 159 and will not be reproduced here. The worker risks for performing barrier installation, monitoring, and repairs are illustrated in Figure 164 through Figure 169. To summarize, no contaminants are transferred as expected and risks from characterization and surface installation (i.e., the only steps performed in this step) significantly exceed the background worker risks.

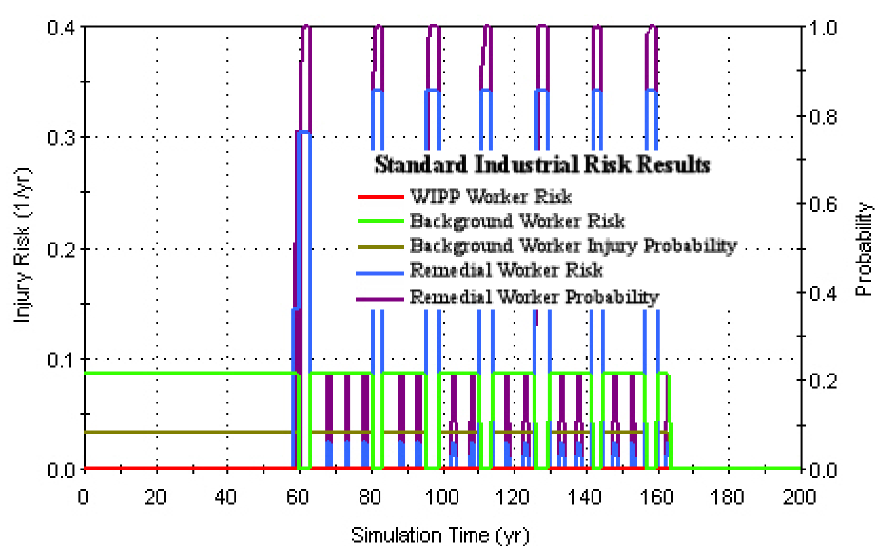

Figure 164. SDA Direct Worker Injury Risks and Probabilities for the Manage-In-Place Scenario with No *In Situ* Treatment (Initial 200 Years). Initial Peaks are from Barrier Installation and Later Peaks from Monitoring and Repairs.

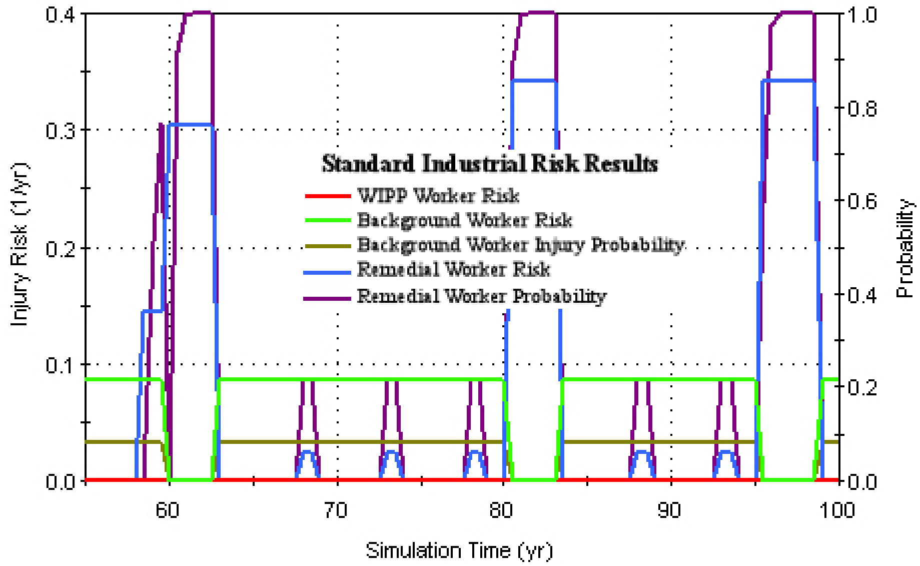

Figure 165. SDA Direct Worker Injury Risks and Probabilities for the Manage-In-Place Scenario with No *In Situ* Treatment (55 to 100 Years). Initial Peaks are from Characterization and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

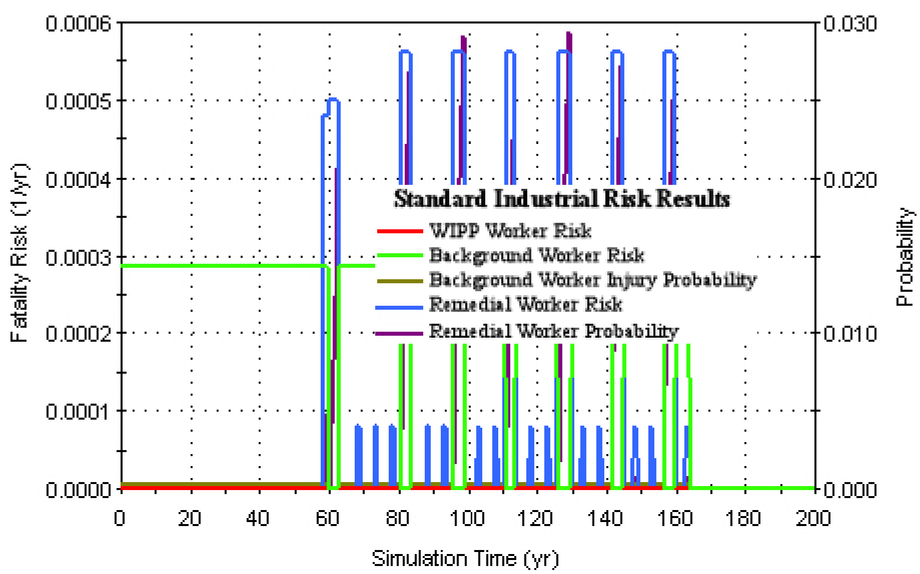

Figure 166. SDA Direct Worker Fatality Risks and Probabilities for the Manage-In-Place Scenario with No *In Situ* Treatment (Initial 200 Years). Initial Peaks are from Barrier Installation and Subsequent Peaks from Monitoring and Repairs.

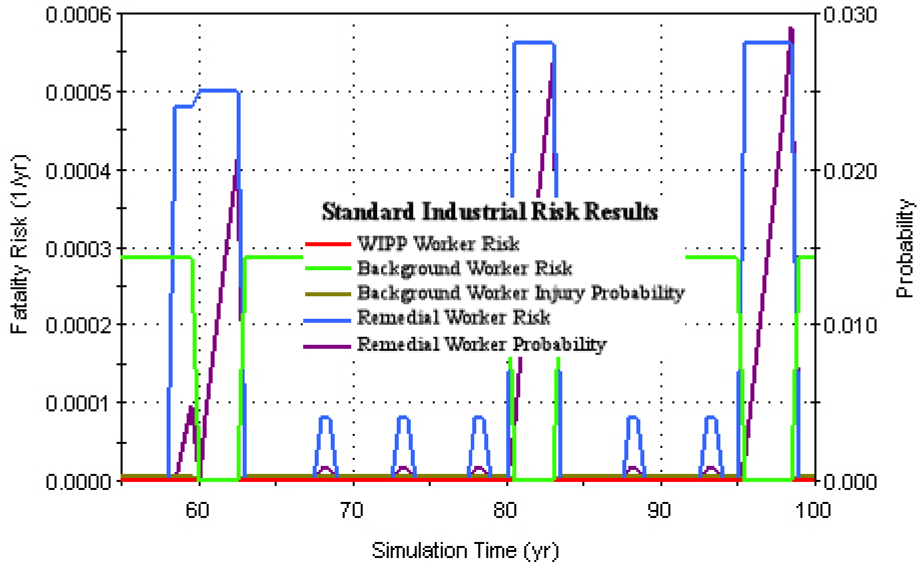

Figure 167. SDA Direct Worker Fatality Risks and Probabilities for the Manage-In-Place Scenario with No *In Situ* Treatment (55 to 100 Years). Initial Peaks are from Characterization and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

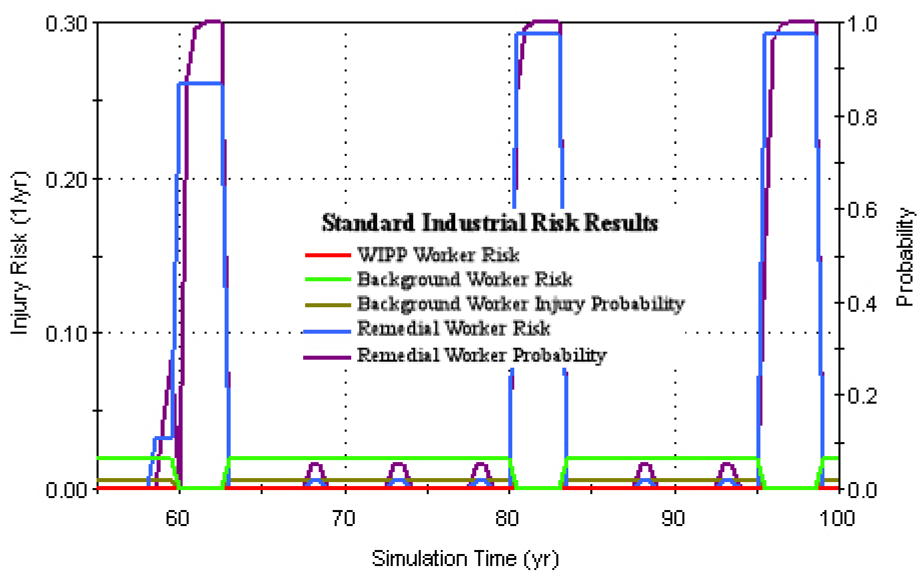

Figure 168. SDA Support Worker Injury Risks and Probabilities for the Manage-In-Place Scenario with No *In Situ* Treatment (55 to 100 Years). Initial Peaks are from Characterization and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

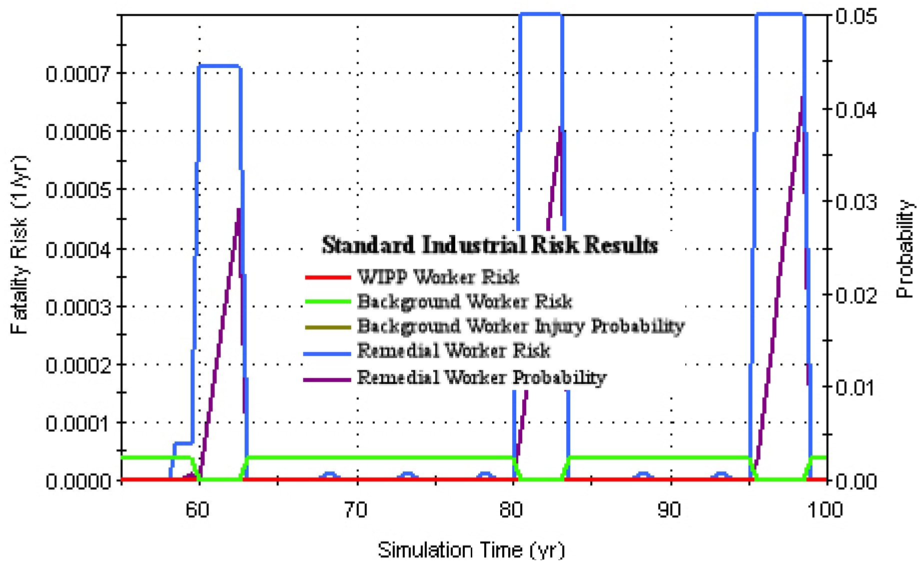

Figure 169. SDA Support Worker Fatality Risks and Probabilities for the Manage-In-Place Scenario with No *In Situ* Treatment (55 to 100 Years). Initial Peaks are from Characterization and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

The next most simple manage-in-place option is to use *in situ* grouting (ISG) to only stabilize subsurface areas against subsidence. As implemented in the screening risk tool, ISG transfers contaminants from Waste Areas to corresponding Disposal Areas in *Cell Pathway* elements[276]. Unlike the previous example, contaminants are transferred as illustrated in Figure 170 and Figure 171. The distributions of contaminants between the grout and disposal cells in the Disposal Area are illustrated in Figure 172 and Figure 173. The grouted fraction is considerably smaller than the ungrouted, which is expected because the ISG impact area for stabilization is approximately 25% of the Waste Area.

[276] GoldSim *Source* elements must have their total inventory in place when the simulation begins. *Cell Pathway* elements are used to simulate simplified *Source* elements for final disposal purposes. Two Disposal *Cell Pathway* elements are used, one for grouted and the other for ungrouted contaminants. Grout failure is modeled as a Poisson process with a mean failure time of 1,038 years (Anderson and Becker 2006; Hanson et al. 2004). Once grout fails, contaminant release is modeled using an exponential distribution to simulate a dissolution process. Contaminants are transferred into Accessible and Inaccessible layers corresponding to their Waste Area counterparts.

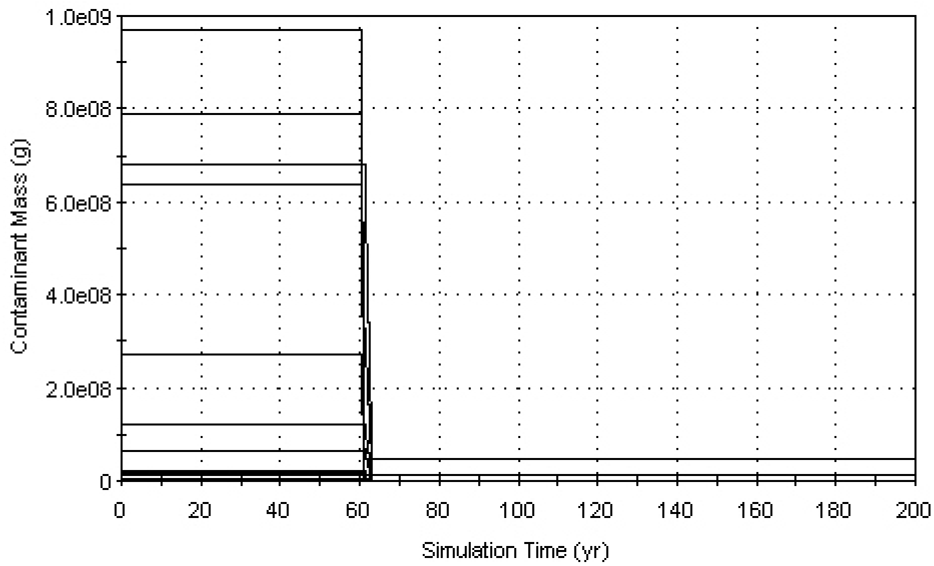

Figure 170. Material Balance for the SDA Waste Areas for the First 200 Years (ISG for Stabilization Begins Just after 60 Years)

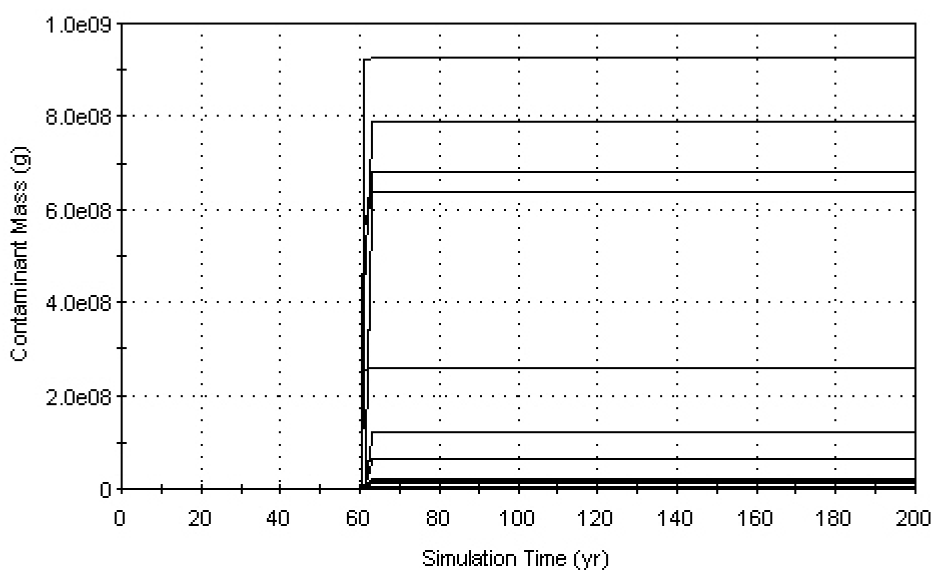

Figure 171. Material Balance for the SDA Disposal Areas for the First 200 Years (ISG for Stabilization Begins Just after 60 Years)

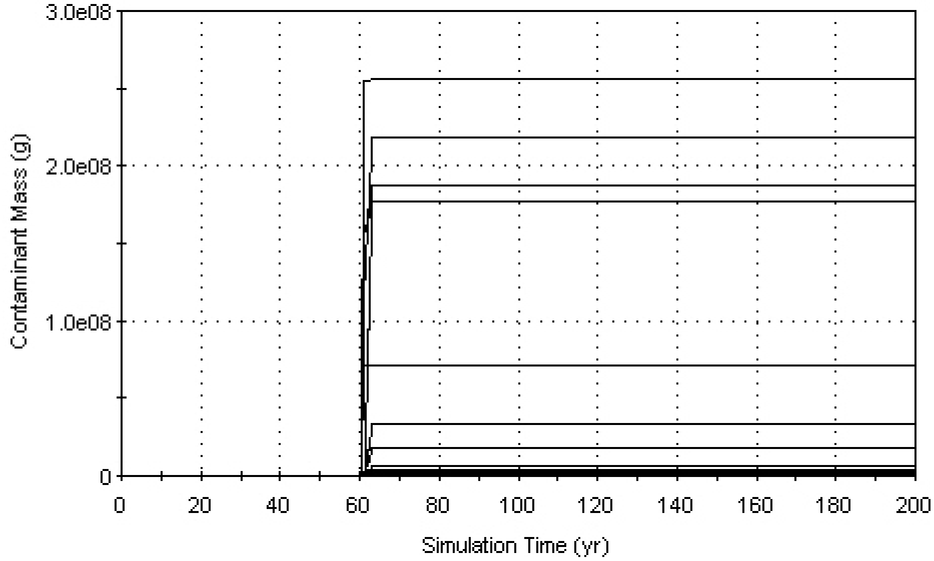

Figure 172. Material Balance for the SDA Disposal Areas—Grouted Material for the First 200 Years (ISG for Stabilization Begins Just after 60 Years)

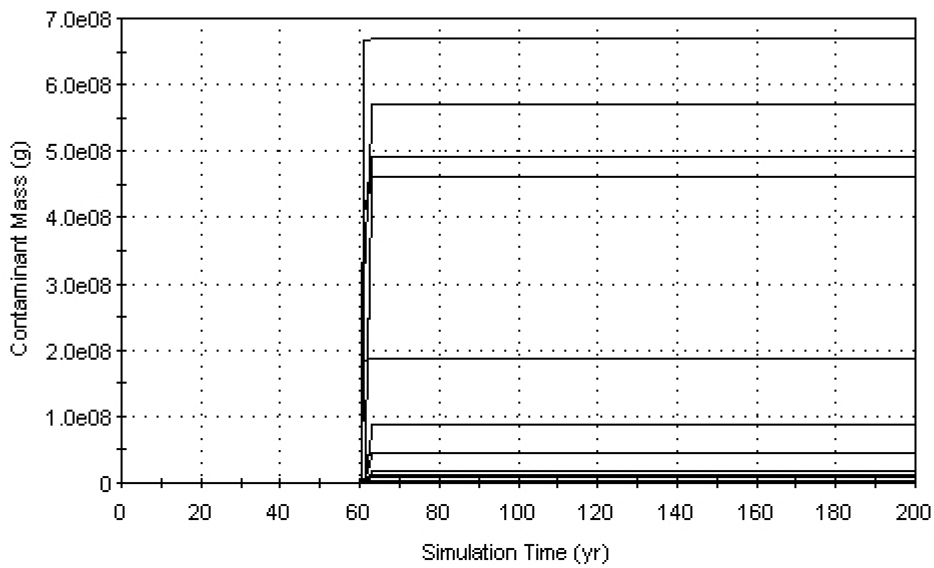

Figure 173. Material Balance for the SDA Disposal Areas—Ungrouted Material for the First 200 Years (ISG for Stabilization Begins Just after 60 Years)

The worker injury and fatality risks for the manage-in-place remedial alternative when *in situ* grouting (ISG) is only used to stabilize selected subsurface areas against subsidence are illustrated in Figure 174 and Figure 175, respectively. In these and subsequent figures, only the direct worker risks are presented as they dominate the support worker risks and both are computed in very similar fashions. For the MIP case with ISG for stabilization only, it may be surprising that the ISG-related injury risks (shown in Figure 174) are comparable to the background risks. However, the background risks are computed on an annual basis and the ISG processing takes place over only a 3-month period illustrating that the ISG step is inherently more hazardous than background risks. The corresponding fatality risks are much higher than the background risks as illustrated in Figure 175.

When, on the other hand, *in situ* grouting (ISG) is used to immobilize contaminants in the subsurface, the ratios of grouted to ungrouted material is much higher as illustrated in Figure 176 and Figure 177, respectively. These results are expected because the ISG impact area for immobilization is approximately 75% of the Waste Area. Because the area impacted and the resulting time required to perform ISG for contaminant immobilization is larger, the worker injury and fatality risks are also larger as illustrated in Figure 178 and Figure 179, respectively.

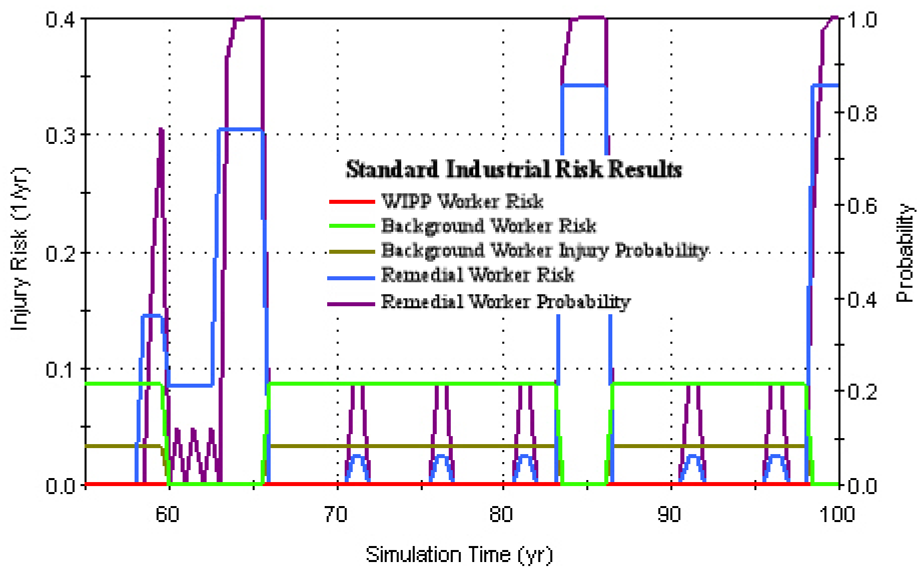

Figure 174. SDA Direct Worker Injury Risks and Probabilities for the Manage-In-Place Scenario with ISG for Stabilization (55 to 100 Years). Initial Peaks are from Characterization, ISG, and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

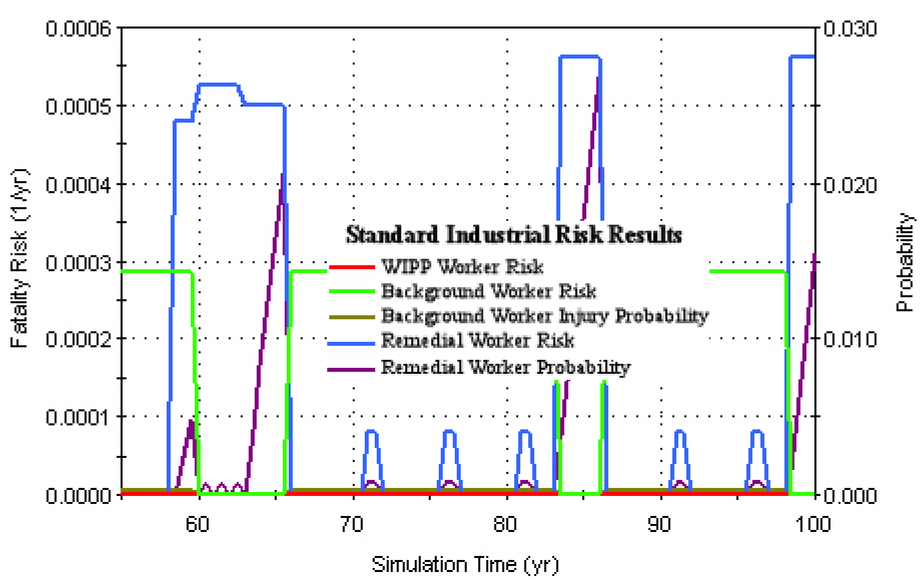

Figure 175. SDA Direct Worker Fatality Risks and Probabilities for the Manage-In-Place Scenario with ISG for Stabilization (55 to 100 Years). Initial Peaks are from Characterization, ISG, and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

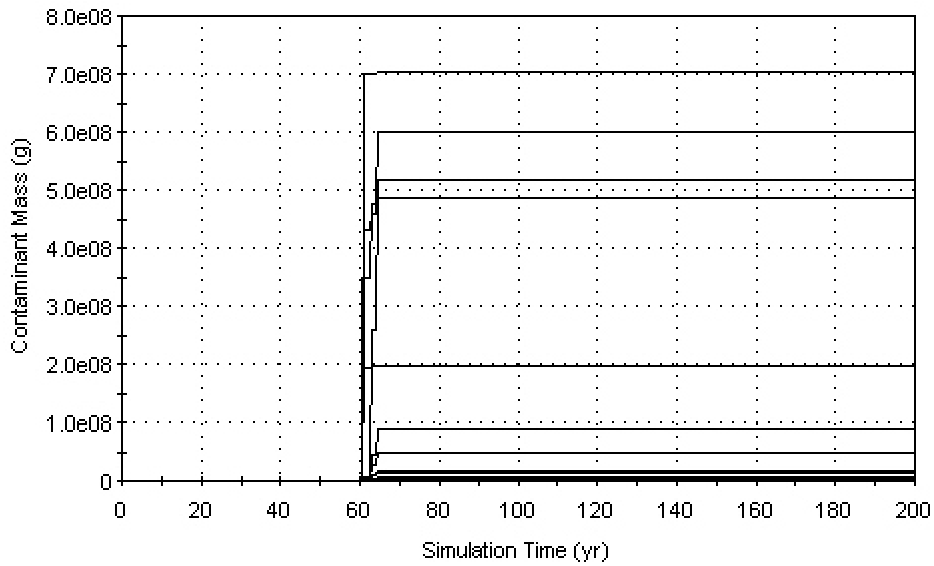

Figure 176. Material Balance for the SDA Disposal Areas—Grouted Material for the First 200 Years (ISG for Immobilization Begins Just after 60 Years)

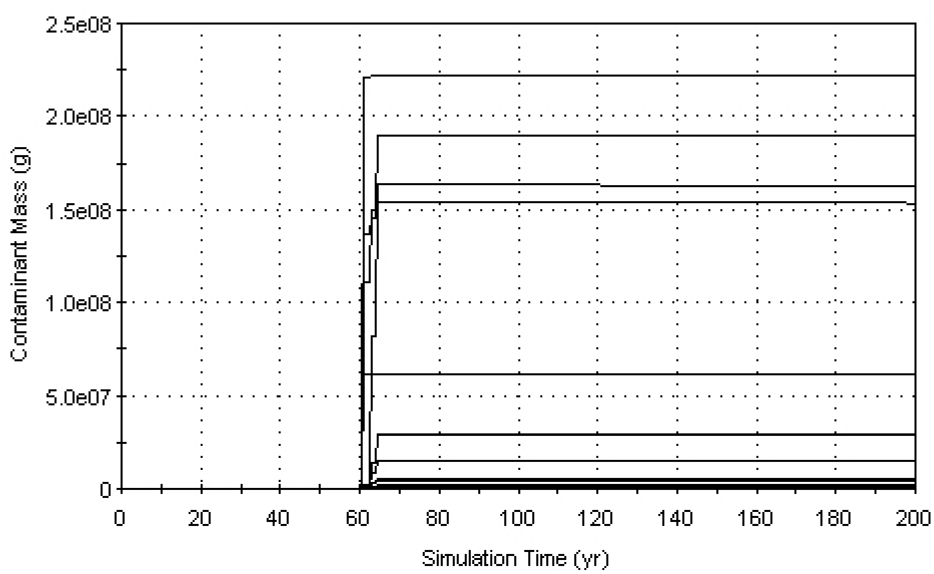

Figure 177. Material Balance for the SDA Disposal Areas—Ungrouted Material for the First 200 Years (ISG for Immobilization Begins Just after 60 Years)

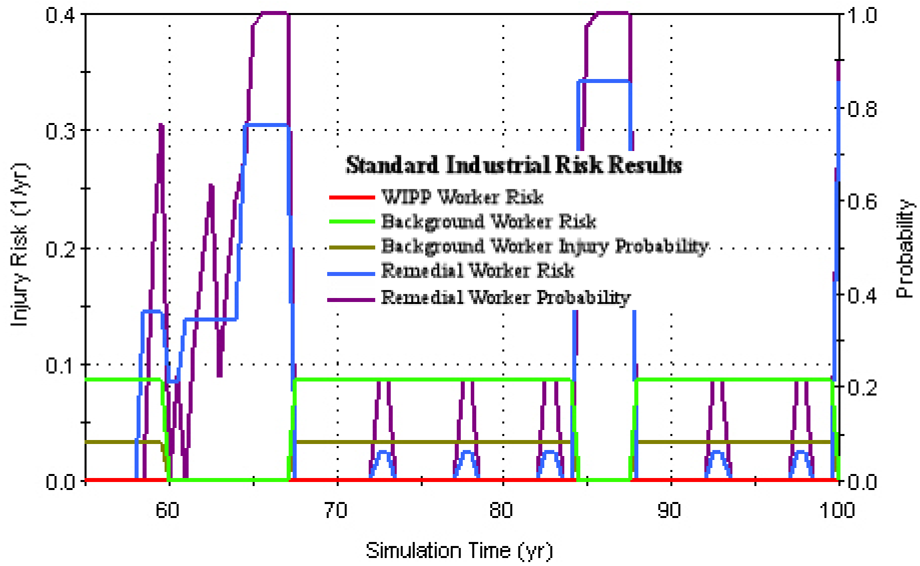

Figure 178. SDA Direct Worker Injury Risks and Probabilities for the Manage-In-Place Scenario with ISG for Immobilization (55 to 100 Years). Initial Peaks are from Characterization, ISG, and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

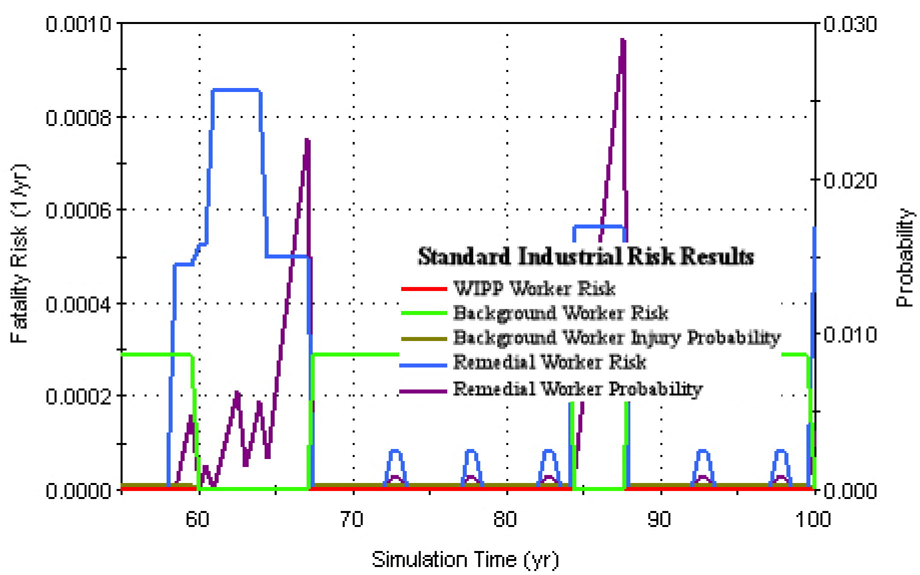

Figure 179. SDA Direct Worker Fatality Risks and Probabilities for the Manage-In-Place Scenario with ISG for Immobilization (55 to 100 Years). Initial Peaks are from Characterization, ISG, and Surface Barrier Installation and Subsequent Peaks from Monitoring and Major Repair Activities.

The Retrieve, Treat, and Dispose (RTD) Remedial Alternative

The most straightforward remedial action that can be taken at a buried waste site is to cap the site and manage the wastes in-place. However, there may be circumstances where buried wastes may require retrieval and treatment for disposal. These circumstances may, for example, be related to the fact that Department of Energy (DOE) wastes were often buried in unlined pits and trenches or "dumped" in liquid form in unlined augur holes. Even if the wastes were placed in drums, many of the drums are likely to have failed since burial (Anderson and Becker 2006). Thus the retrieve, treat, and dispose (RTD) remedial alternative is likely to be considered, if not ultimately selected, for buried waste sites in the DOE Complex.

In the screening risk tool, the RTD alternative is implemented along lines similar to the manage-in-place (MIP) *in situ* grouting (ISG) option in that contaminants are removed from Waste Areas (depending upon the scenario) and divided among Disposal Areas. In the case of the RTD options, Remedial Areas representing packaging, treatment, off-site disposal, etc. may also be used. Implementation of the RTD options are decidedly more complicated as would be the RTD processing. However, despite these difficulties, the appearances of many of the material balance and accident risk diagrams will resemble those for the MIP scenarios.

Only the differences that show how the RTD options perform are illustrated in this appendix. For example, the overall material balance for all RTD remedial options is the same as Figure 158 and thus will not be reproduced here. In fact, the major differences between the MIP and RTD scenarios will be illustrated using the targeted RTD retrieval case with *in situ* grouting (ISG) used for immobilization.

The impact of the basic RTD operations on the contaminants in the Waste Areas is illustrated in Figure 180. In the targeted RTD case, retrieval operations begin around Year 65 where contaminants are moved to Disposal Areas after treatment and packaging around Year 80 as illustrated in Figure 181. In the interim, contaminants are held in the Remedial Areas as illustrated in Figure 182 where the spike shown at around Year 80 on this figure represents the time that contaminants are held. The remainder of the contaminants in the Remedial Areas (i.e., Figure 182) represents the TRU wastes and soil that are transported to the Waste Isolation Pilot Plant (WIPP). Shipments to the WIPP are completed around Year 450 as illustrated in Figure 183. The results of the overall material balance despite all these transfers are the same as those illustrated in Figure 158.

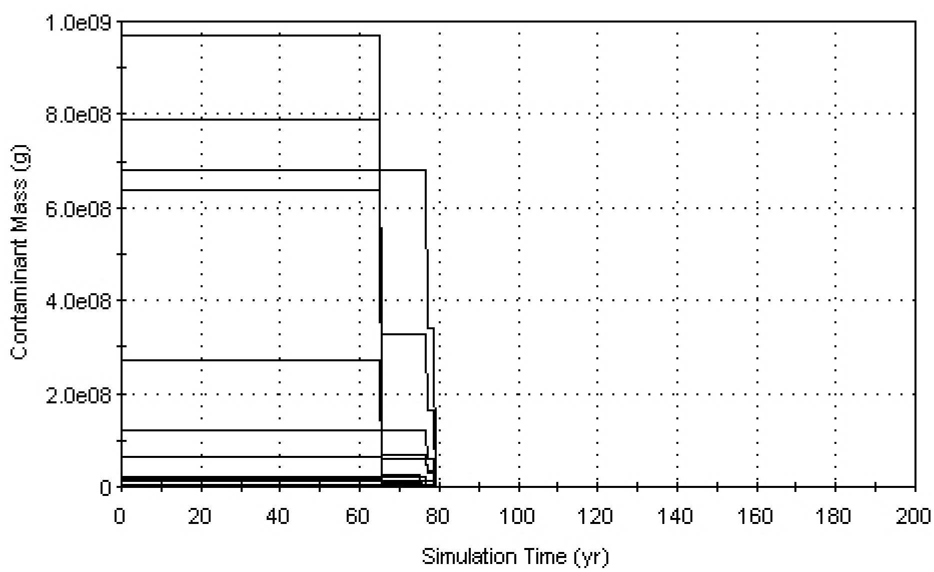

Figure 180. Material Balance for the SDA Waste Areas for the First 200 Years (Retrieval Operations begin around Year 65 and *In Situ* Grouting for Immobilization)

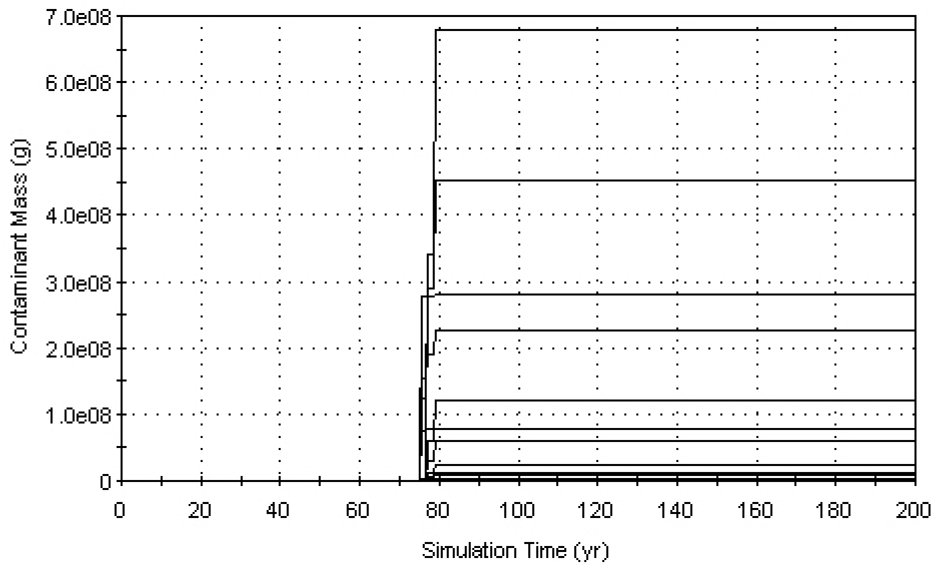

Figure 181. Material Balance for the SDA Disposal Areas (Disposal Operations begin around Year 80 and *In Situ* Grouting for Immobilization)

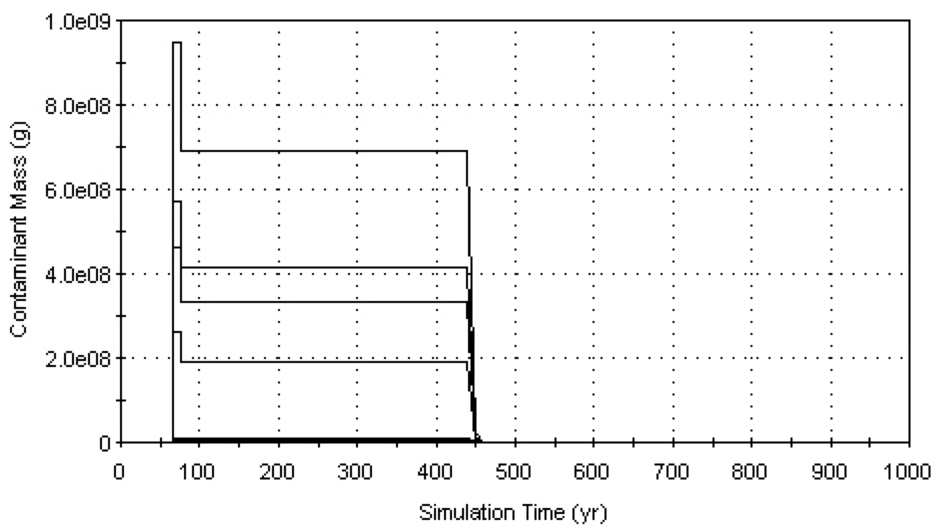

Figure 182. Material Balance for the SDA Remedial Areas (Retrieval Operations begin around Year 65, and No *In Situ* Grouting for Immobilization)

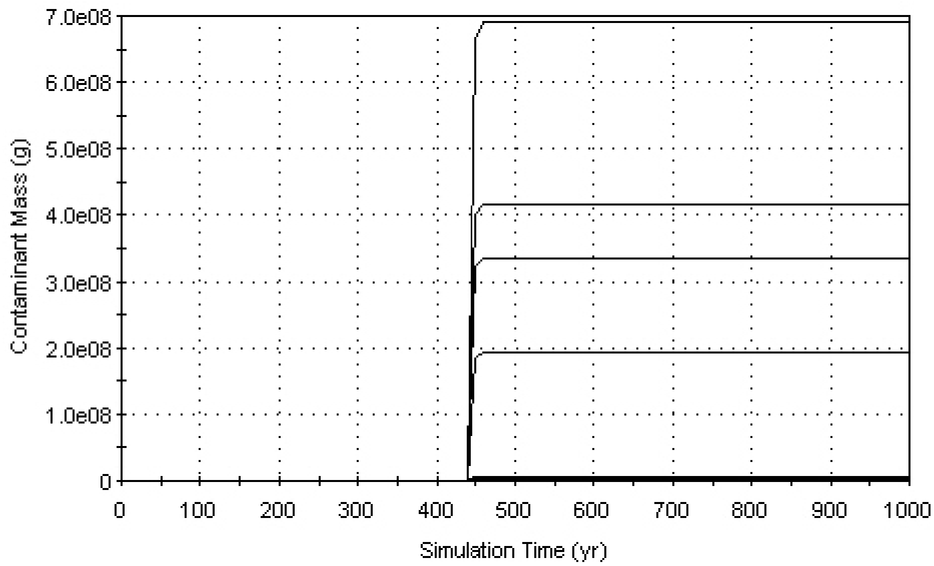

Figure 183. Material Balance for the Off-Site Disposal Areas (Retrieval Operations begin around Year 65, WIPP Disposal end around Year 450, and No *In Situ* Grouting for Immobilization)

The worker injury and fatality risks for the RTD remedial option when *in situ* grouting (ISG) is used to immobilize contaminants are illustrated in Figure 184 through Figure 186, respectively. In these and subsequent figures, only the direct worker risks are presented as they tend to dominate the corresponding support worker risks and both are computed in very similar fashions. For the RTD case with ISG for immobilization, the direct worker injury risks are significantly larger than those representing the background risks. As illustrated in Figure 184, the injury risks associated with WIPP operations are also large when compared to the background worker risks. However, the fatality risks associated with WIPP operations are orders of magnitude higher than those associated with remedial operations as illustrated in Figure 185 and Figure 186 (where the scale is expanded in Figure 186 to better show the risks).

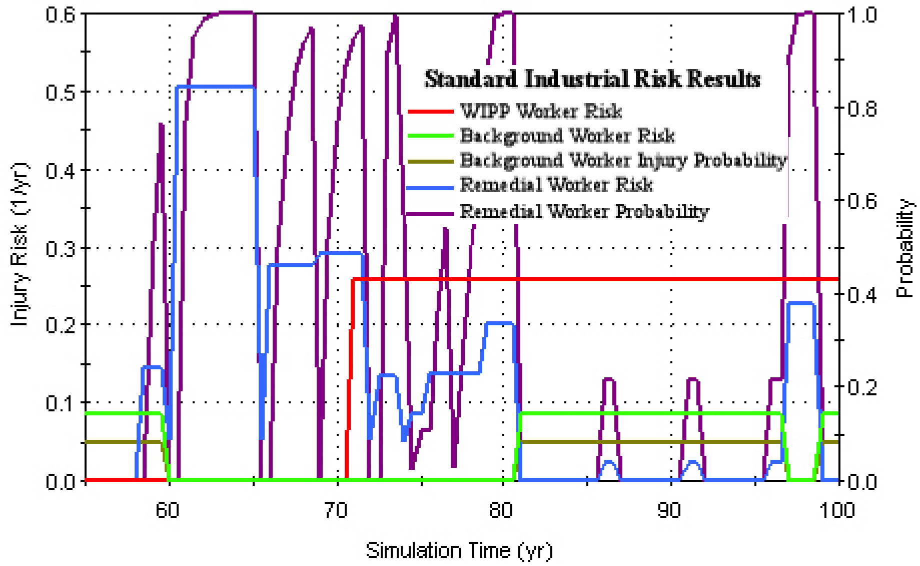

Figure 184. SDA Direct Worker Injury Risks and Probabilities for the Retrieve, Treat, and Dispose (RTD) Scenario with ISG for Immobilization (55 to 100 Years).

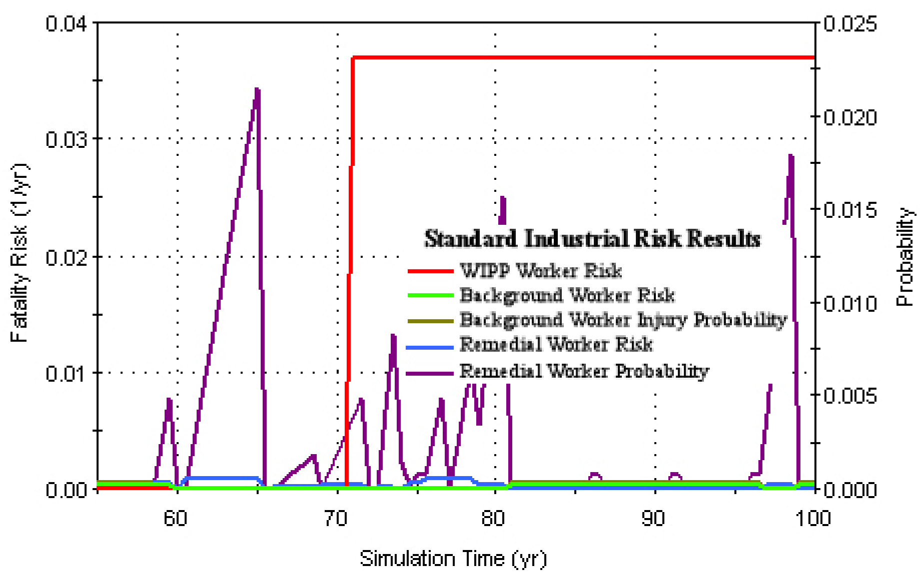

Figure 185. SDA Direct Worker Fatality Risks and Probabilities for the Retrieve, Treat, and Dispose (RTD) Scenario with ISG for Immobilization (55 to 100 Years). The WIPP Fatality Risks Are much Larger than Others Predicted.

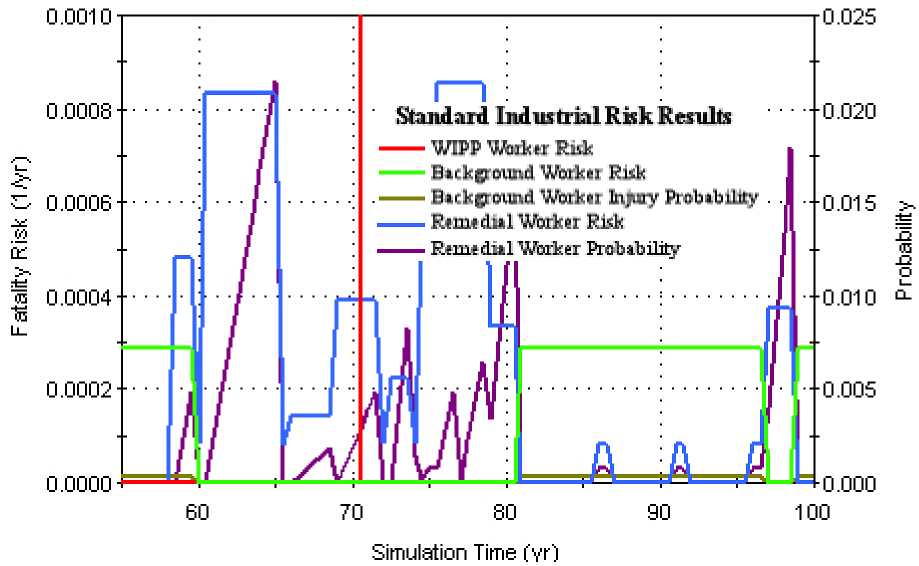

Figure 186. SDA Direct Worker Fatality Risks and Probabilities for the Retrieve, Treat, and Dispose (RTD) Scenario with ISG for Immobilization (55 to 100 Years). The scale is expanded from Figure 185 to better show the risks.

Results similar to those illustrated in this appendix for the SDA were generated for the various manage-in-place and retrieval alternatives for the Bear Creek Burial Grounds (BCBG). The types of waste and contaminants, areas and transport pathways, and potential receptors involved differ between these two sites, but the manner in which worker risks are computed and the results obtained tend to be very similar.

The primary difference between how worker risks are estimated for the BCBG involves estimating risks when working with unstable and pyrophoric materials. As described in Chapter VI, injury and fatality risks are assumed to be much higher because of the highly hazardous nature of materials buried in various areas in the BCBG. The predicted injury and fatality risk results for the BCBG retrieval case with immobilization using *in situ* grouting (ISG) are illustrated in Figure 187 and Figure 188, respectively.

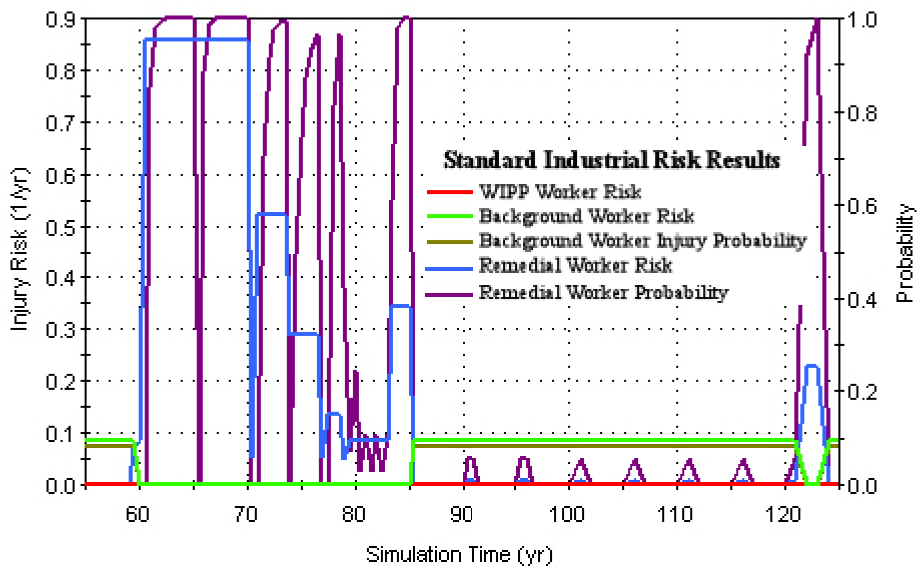

Figure 187. BCBG Direct Worker Injury Risks and Probabilities for the Retrieve, Treat, and Dispose (RTD) Scenario with ISG for Immobilization (55 to 125 Years).

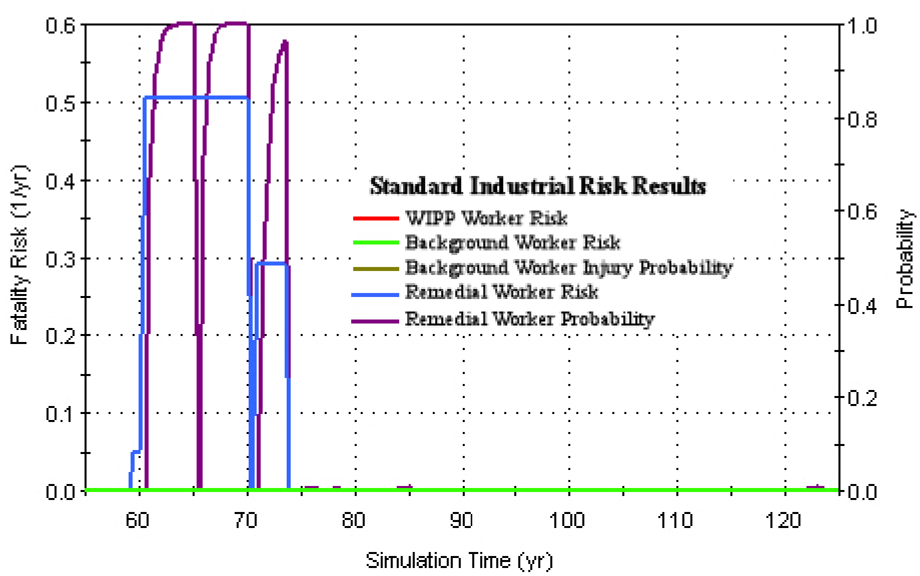

Figure 188. BCBG Direct Worker Fatality Risks and Probabilities for the Retrieve, Treat, and Dispose (RTD) Scenario with ISG for Immobilization (55 to 125 Years). The WIPP Fatality Risks Are much Larger than Others Predicted.

The injury risks associated with those operations involving potential interactions with pyrophoric materials (in Figure 187) are approximately twice those for similar operations in the SDA (in Figure 184). However, the largest impacts are on the predicted fatality risks as illustrated in Figure 188 where remedial fatality risks are much higher than the background risks as well as those for WIPP operations (in Figure 185). These results agree with expectations based on how injury and fatality risks are predicted for BCBG operations.

Other Verification Tests

A series of other tests were performed to assure that the values computed in the screening risk tool are verifiable. Some tests were performed in Microsoft Excel®; however, the majority of the tests were performed using MathCad®. The tests included:

- Barometric pumping
- Plant- and animal-induced transport
- Colloidal transport
- Diffusion for source release
- Barrier failure rates
- Inundation and flooding
- Organic degradation
- Exposure dose and risk
- Standard industrial risks

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