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Disclaimer:

1. INTRODUCTION

This report documents the revised Performance Assessment (PA) analysis for the E-Area Low-Level Waste Facility (ELLWF) at the United States (U.S.) Department of Energy (DOE) Savannah River Site (SRS). A PA analysis is required for DOE-operated facilities that dispose of low-level radioactive waste. PA analyses simulate (1) the release of radionuclides from the disposal site after facility closure, (2) transport of those contaminants through the environment, and (3) exposure/impacts to potential receptors. The purpose of the PA analysis is to demonstrate that the facility is operated in a manner that ensures long-term environmental protection after facility closure, thereby providing for the protection of public health and safety in limiting doses to a hypothetical member of the public (MOP) or an inadvertent human intruder (IHI). DOE Manual (M) 435.1-1, Chg. 3, *Radioactive Waste Management* (U.S. DOE, 2021b) establishes quantitative post-closure environmental impact limits and requires a facility-specific PA analysis to demonstrate compliance with these limits for DOE low-level waste (LLW) disposed of after September 26, 1988. These limits are defined in terms of human health (e.g., dose limits) with respect to radioactive constituents in the waste.

In accordance with the requirements in DOE Order (O) 5820.2A (U.S. DOE, 1988), prior to the issuance of DOE O 435.1 (U.S. DOE, 2021a), a PA for the ELLWF was completed in 1994 (Cook and Hunt, 1994). Reviews of the ELLWF PA have been conducted annually since Fiscal Year (FY) 1999. The ELLWF began accepting waste in 1994 and is expected to continue accepting waste from across SRS operations and cleanup through 2065. The results of these PA annual reviews have been presented at the DOE Low-Level Waste Disposal Facilities Federal Review Group (LFRG) business meeting and transmitted to the South Carolina Department of Health and Environmental Control (SCDHEC) and the United States Environmental Protection Agency (U.S. EPA) Region IV for information following DOE approval. DOE M 435.1-1,

KEY TAKEAWAYS

- ✓ A single PA for ELLWF was prepared to comply with Chapter IV, DOE M 435.1-1, Chg. 3.
- ✓ Three previous ELLWF PAs have been prepared (1994, 2000, 2008).
- ✓ Separate inventory limits are established for GW, air, radon, and IHI pathways to ensure DOE O 435.1 POs are met.
- ✓ Five types of low-level waste disposal units are located in ELLWF.
- ✓ Implementation of ELLWF Waste Acceptance Criteria provides assurance that inventories in disposal units comply with POs.
- ✓ ELLWF comprises 200 acres for waste disposal with a surrounding 100-meter POA; operations began 9/28/1994 with placement of the first LLW box in the LAWV.
- ✓ The distance from ELLWF to the nearest SRS boundary is roughly 7 miles west.
- ✓ It has been determined that a quantitative ALARA analysis is not necessary for the ELLWF PA.
- ✓ ELLWF and surrounding lands will remain under DOE control and within DOE SRS boundaries for the foreseeable future.
- ✓ A 1993 Federal Facility Agreement for SRS between U.S. DOE, U.S. EPA, and SCDHEC, integrates CERCLA and RCRA requirements to achieve a comprehensive remediation strategy and to coordinate administrative and public participation requirements.

Chg. 3 *Radioactive Waste Management Manual,* (U.S. DOE, 2021b) requires that PA maintenance plans be prepared annually to support the continued adequacy of the PA and to increase confidence in results. PA maintenance plans also identify planning activities, work control documents, and conceptual approaches along with PA production estimates for out-year revisions to the PA baseline. To date, subsequent revisions to the initial ELLWF PA were issued in 2000 (McDowell-Boyer et al., 2000) and again in 2008 (WSRC, 2008). In the FY2016 ELLWF PA Maintenance Plan (SRNL, 2016), the next outyear ELLWF PA revision development was planned to begin in FY2018. DOE-Savannah River (DOE-SR) established a funding plan to start that next ELLWF PA revision in FY2018 with approval in FY2020; however, this revision effort start date was delayed by DOE until FY2019. The most recent ELLWF PA Maintenance Plan is for FY2021 (Crawford, 2021).

The ELLWF PA includes five different types of LLW disposal units located in E Area, which are described in Section 1.3. This PA revision has been prepared to address changes in the ELLWF footprint and operation, updates to the modeling and databases associated with the ELLWF, unresolved issues from the previous PA, new data from research testing and field studies, as well as changes in those assumptions from the previous PA, other SRS waste management PAs, or other new technical analyses such as Special Analyses (SAs).

The chapters and appendices comprising the PA report include:

Chapter 1	Introduction
Chapter 2	Site and Facility Characteristics
Chapter 3	Analysis of Performance
Chapter 4	Implementation of Groundwater Modeling
Chapter 5	Results of Analysis
Chapter 6	Sensitivity Analysis and Uncertainty Quantification
Chapter 7	Inadvertent Human Intruder Analysis
Chapter 8	Integration and Interpretation of Results
Chapter 9	Performance Evaluation
Chapter 10	Quality Assurance
Chapter 11	Contributions
Chapter 12	References
Appendix A	Performance Assessment Supporting Documents and Key Assumptions
Appendix B	Supporting Information: Inventory Uncertainty
Appendix C	Supporting Information: Analysis of Performance
Appendix D	Supplemental Transport Model Results for Slit and Engineered Trenches
Appendix E	Supplemental Transport Model Results for the Low-Activity Waste and Intermediate-Level Vaults
Appendix F	Supporting Information: Sensitivity Analysis and Uncertainty Quantification
Appendix G	Supporting Information: Inadvertent Human Intruder
Appendix H	Supporting Information: Integration and Interpretation of Results
Appendix I	Supporting Information: Performance Evaluation

This chapter is organized as follows:

- **Section 1.1** discusses the basis for this PA revision.
- **Section 1.2** presents an overview of the modeling process used in this PA.
- **Section 1.3** provides a high-level general facility description.
- **Section 1.4** briefly introduces ELLWF design features of the five types of disposal units, the final closure cap, and the barriers to water infiltration and inadvertent intrusion.
- **Section 1.5** discusses the ELLWF lifecycle and closure plan.
- **Section 1.6** describes other site documents related to this PA.
- **Section 1.7** provides the regulatory context for the PA including performance objectives, points of assessment, and timeline assumptions.
- **Section 1.8** briefly introduces the PA approach to the hypothetical inadvertent human intruder.
- **Section 1.9** summarizes the As Low As Reasonably Achievable (ALARA) process and analysis for this PA.
- **Section 1.10** describes the Federal Facility Agreement for SRS between U.S. DOE, U.S. EPA, and SCDHEC and how it integrates requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA).
- **Section 1.11** briefly touches on land use and institutional controls.
- **Section 1.12** provides a high-level summary of key assumptions made in this PA revision.

1.1. BASIS FOR PERFORMANCE ASSESSMENT

Operation of the ELLWF is authorized under the Disposal Authorization Statement (DAS) (similar to a Federal Permit) which collectively defines the design, construction, operation, monitoring, and closure of the facility. One PA for the ELLWF was prepared to meet requirements of Chapter IV of DOE M 435.1-1, Chg. 3 (U.S. DOE, 2021b). The Manual specifies that a PA should provide reasonable assurance that a LLW disposal facility will comply with the performance objectives (POs) of the Order.

Since the completion of the three previous PA iterations, and after 12 years of subsequent operation, several factors led to the decision to update the ELLWF PA. These factors include:

- Changes in the ELLWF footprint (i.e., increase of approximately 41 hectares or 100 acres).
- Changes in ELLWF monitoring activities by Savannah River Nuclear Solutions (SRNS) Solid Waste Management (SWM) [i.e., expanded vadose zone (VZ) monitoring lysimeter installations around trenches].
- Changes in ELLWF monitoring activities by Savannah River National Laboratory (SRNL) [i.e., provided review and technical oversight of VZ monitoring program; conducted annual PA monitoring validation; conducted PA model validation through geostatistical analysis of lysimeter data and analysis of alternative conceptual models].

- Completed updates to various models and property databases supporting this PA (see bulleted list below).
- Results of recently completed SRNL field studies [i.e., evaluated feasibility of bamboo as long-term cap vegetative cover; surveyed components-in-grout (CIG) grout test pour for potential cracking to validate PA assumptions; assessed data from B-25 box corrosion monitoring field site to validate PA assumptions; monitor SRNL Radionuclide Field Lysimeter Experiment (RadFLEx) for site-specific sorption coefficient (K_d) values].
- Information from other updated PAs at SRS since 2008, including the reprocessing storage tank and Saltstone PAs (Savannah River Remediation, 2009; 2012; 2020).

Table A-1, Table A-2, and Table A-3, respectively, in Appendix A list all special analyses, unreviewed disposal question evaluations, and other related analyses and assessments prepared in support of the ELLWF since the previous ELLWF PA was issued in early 2008.

Since the 2008 ELLWF PA (PA2008), updates to various models and property databases supporting this PA revision have included the following:

- Updated dose software and combined with intruder analysis application (Savannah River National Laboratory Dose Toolkit; Aleman, 2019)
- Updated air, radon, groundwater (GW), and IHI radionuclide screening models (Aleman and Hamm, 2020; 2021; Dyer, 2017a)
- Set up automation scheme for PA GW calculations
- Established PA network file system structure and upgraded the personal computer (PC) cluster
- Updated the General Separations Area (GSA) model mesh refinement application (Danielson, 2017)
- Generated new atmospheric dose release factors (Dixon and Jannik, 2021)
- Updated Atmospheric Release Model (ARM) in GoldSim® (Wohlwend, 2017)
- Updated the radionuclide property data package and report (Smith et al., 2015; Smith et al., 2019; SRNL, 2019b)
- Updated the geochemical property data package and report (Kaplan, 2016b; SRNL, 2018)
- Updated the hydraulic properties data package and report (Nichols and Butcher, 2020; SRNL, 2020)
- Updated infiltration data package and report (Dyer, 2019b; SRNL, 2019a)
- Updated the GSA hydrostratigraphic surfaces data package and report (Bagwell et al., 2017; SRNL, 2017)
- Updated Software Quality Assurance Plans (SQAPs) and Standard Testing Procedures (STPs) for existing PA software and standardized pre- and post-processing scripts (see Chapter 10 for the complete listing of SQAPs)
- Produced new estimated inventories at closure and best estimate closure date

In addition, two significant changes to the existing ELLWF closure plan (Phifer et al., 2009) have been made that are addressed in this PA revision.

1. A single final closure cap will be installed over the currently developed, elbow-shaped, 100-acre ELLWF operations area with the closure cap crestline running lengthwise down the overall ELLWF (i.e., essentially perpendicular to the 2008 PA and 2009 closure plan assumptions).
2. The alternate closure system concept presented in Section 4.4.2 of the 2009 ELLWF closure plan (Phifer et al., 2009) has been adopted. This concept adds a high-density polyethylene (HDPE) geomembrane over the existing planned geosynthetic clay liner (GCL) to provide a composite hydraulic barrier that conforms to best closure cap design practices.

Following their review of PA2008 (LFRG, 2008), the LFRG identified several secondary issues contained in that report, most of which have been tracked and resolved through the annual PA maintenance activities. The following two remaining secondary issues are considered in this PA revision:

1. Additional sensitivity analysis and uncertainty quantification work to increase confidence in the waste concentration limits for trench disposal units (DUs) (Flach, 2017a).
2. An update of the GSA GW flow model (Bagwell and Flach, 2016; Flach, 2019; Flach et al., 2017).

Lastly, separate inventory limits have been established for the GW, air, radon, and IHI pathways to ensure DOE M 435.1-1.IV.P. (U.S. DOE, 2021b) POs and requirements are protected. The approved set of radionuclide inventory limits are maintained in the PA limits database (Butcher et al., 2017).

Key assumptions, when applicable, are protected in operational procedures and on-site drawings. Table A-4 in Appendix A lists key assumptions made in the PA analysis of the various transport pathways. The table is organized by topical area or specific pathway and disposal unit. Assumptions that need to be protected by ELLWF Operations to maintain the radioactive waste management basis for the facility are identified. The table also contains key assumptions that define disposal system or model properties that are outside of operational controls (e.g., hydraulic properties of the subsurface soil zones) but which are important to the PA analysis. A database listing the key assumptions and associated SWM controls and/or implementing documents is maintained on the SRNL computer network (Hamm et al., 2018).

As required by DOE O 435.1 (U.S. DOE, 2021a), the following annual reviews are conducted: waste receipts; monitoring; research and development (R&D) work; and other evaluations and investigations performed in the preceding calendar year to ensure that these changes do not alter the conclusions of the ELLWF PA. The FY2020 and FY2021 PA annual reviews are provided by LaBone et al. (2021) and LaBone et al. (2022), respectively.

1.2. PERFORMANCE ASSESSMENT MODELING PROCESS OVERVIEW

In developing this ELLWF PA revision, an improved, systematic model development approach is applied that builds upon post-2008 ELLWF modeling efforts, LFRG recommendations from PA2008, and the 2016 *Strategic Plan for Next E-Area Low-Level Waste Facility Performance Assessment* (Butcher and Phifer, 2016a; 2016b). An overview of the PA modeling process is shown in Figure 1-1.

Safety Functions and FEPs Screening

- ✓ A blended top-down, safety-functions-based and bottom-up, FEPs-based approach identifies the relevant PA scenarios (Sections 3.2 and 3.3).

Conceptual Model Development

- ✓ FEPs relevant to the ELLWF and having a detrimental impact on the effectiveness of a given safety function are used to inform development of conceptual models for the final closure cap (Section 3.4); aquifer zone flow and transport (Section 3.5); air and radon flux pathways (Section 3.6); exposure pathways (Section 3.7); and vadose zone groundwater flow and transport for slit and engineered trenches (Sections 4.1 and 4.4), simple (Section 4.2) and complex (Section 4.3) special waste forms in trenches, low-activity waste vault (Section 4.5), intermediate-level vault (Section 4.6), and naval reactor component disposal areas (Section 4.7).

Mathematical Model Development

- ✓ Equations and formulas are developed to quantify the conditions and processes within the conceptual models in the same sections outlined above.

Submodel Implementation

- ✓ Submodels are developed by defining the necessary input values and implementing them in specific modeling programs and other computational tools (Section 3.9) for purposes of calculating intermediate results from the mathematical models. Radiological; geochemical; material and hydraulic; infiltration; and hydrostratigraphic properties data packages are developed and tested (Section 3.8).

Submodel Integration

- ✓ Interfaces between the various submodels are identified and used to integrate the submodels into a single, integrated PA model for each disposal unit type (slit and engineered trenches, low-activity waste vault, intermediate-level vault, and naval reactor component disposal areas).

Figure 1-1. E-Area Low-Level Waste Facility Performance Assessment Modeling Process Overview

1.3. GENERAL FACILITY DESCRIPTION

Located in the central region of SRS within the GSA, the ELLWF comprises 200 acres for waste disposal coupled with a surrounding 100-meter point of assessment (POA). The ELLWF began radiological waste disposal operations on September 28, 1994, with the placement of the first LLW box within the Low-Activity Waste Vault (LAWV). At present, approximately 100 acres have been cleared and developed for disposal. The active 100-acre disposal area is elbow-shaped, curving to the northwest, and is situated immediately north of the Mixed Waste Management

Facility (MWMF) and the Old Radioactive Waste Burial Ground (ORWBG). Figure 1-2 shows the location of all individual DUs within the current and proposed future ELLWF footprint being evaluated in this PA.

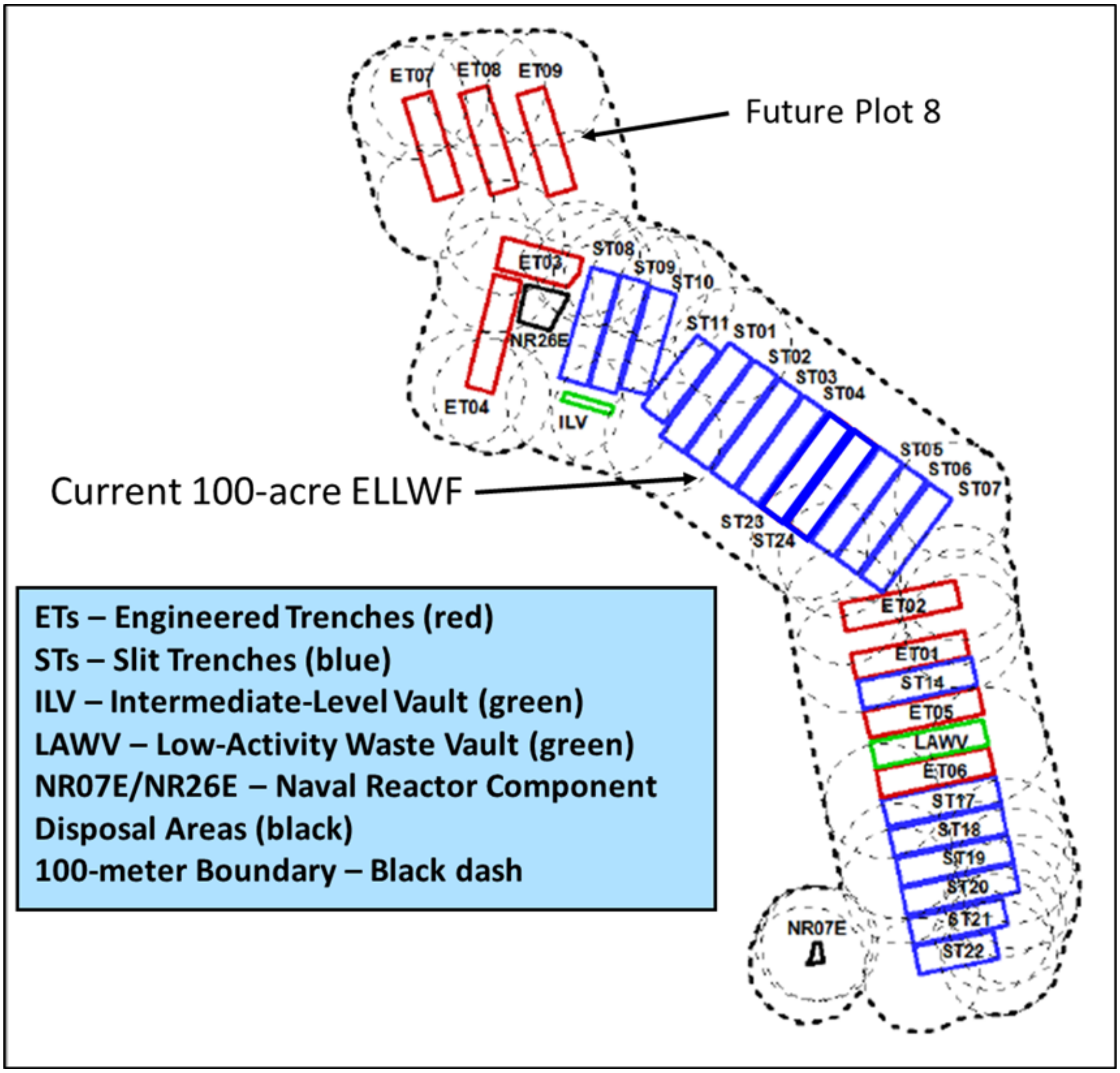

Figure 1-2. Location of Existing and Future E-Area Low-Level Waste Facility Disposal Units and 100-meter POA (modified from Hang and Hamm, 2022)

Existing types of DUs include the below-grade Slit Trenches (STs), Engineered Trenches (ETs), and Intermediate-Level Vault (ILV), and the above-grade LAWV and Naval Reactor Component Disposal Areas (NRCDAs). The undeveloped "second 100 acres," which include Plot 8, consist of nine distinct plots of varying size (hereafter referred to as Plots 1 through 9) surrounding the current ELLWF operations area as will be detailed in Chapter 2. Brief descriptions of the different types of DUs are provided in Section 1.4.

1.3.1. Waste Acceptance Criteria

Implementation of the ELLWF Waste Acceptance Criteria (WAC) provides assurance that inventories in DUs comply with POs. WAC implementation serves as the principal means of communicating PA assumptions, radionuclide limits, and waste form and waste packaging requirements to waste generators. The WAC also incorporate criteria derived from DOE O 435.1, Chg. 2 (U.S. DOE, 2021a), facility safety documentation, and operational constraints (e.g., compatibility with waste handling equipment). In accordance with site procedures, the WAC are revised and updated as needed to incorporate new information or facility operational changes (SRS, 2021d). The WAC also allow for generator submitted deviation requests, which if approved, allow generators to deviate from specific criteria. All WAC revisions and deviation requests require documented technical reviews to ensure compliance with source documents (i.e., PA, safety, U.S. DOE Orders).

The radionuclide inventory limits calculated in the PA and implemented via the WAC are managed through a computerized Consolidated Waste Tracking System (CWTS).[1] Before containers are shipped for emplacement in the various vaults or trenches, the descriptions of the specific contents are entered into CWTS by the generators. CWTS compares the package contents with the WAC container limits, calculates the cell/facility inventory (to ensure compliance with the cell criticality and safety-based limits), and calculates the total inventory for each radionuclide to ensure compliance with the limits derived from all pathways.

1.3.2. General Land Use Patterns

Land use at the SRS is currently managed and operated by DOE-SR (Savannah River Operations Office) and its prime contractors for government-controlled industrial use. The primary use of SRS land is to support facility and program operations dedicated to waste management, environmental restoration, technology development and transfer, and economic development. A security force limits access to approved personnel and visitors. The distance from ELLWF to the nearest SRS boundary (outer perimeter fence line of the SRS reservation) is roughly 7 miles to the west at the outer edge of the Crackerneck Wildlife Management Area. Agricultural and forested land is located just beyond the outer perimeter fence line of the SRS reservation. DOE/EIS-0217F, *Savannah River Site Waste Management Final Environmental Impact Statement* (U.S. DOE, 1995b); DOE/EIS-0288F, *Final Environmental Impact Statement for the Production of Tritium in a Commercial Light Water Reactor* (U.S. DOE, 1999b); DOE/EIS-0303F, *Savannah River Site High-Level Waste Tank Closure Final Environmental Impact Statement* (U.S. DOE, 2002b); NUREG-1767, *Environmental Impact Statement on the Construction and Operation of a Proposed Mixed Oxide Fuel Fabrication Facility at the Savannah River Site, South Carolina* (U.S. NRC, 2005); and DOE/EIS-0541F, *Final Environmental Impact Statement for Plutonium Pit Production at the Savannah River Site in South Carolina* (U.S. DOE, 2020a) collectively describe the land use

[1] CWTS (SRS, 2021c) is a site database that performs tracking of low-level waste, hazardous waste, mixed waste, PCB waste, and transuranic waste. The functions tracked include packaging, overpacking, shipping, receiving, and relocation of waste containers from generating facilities to destination facilities. CWTS performs limit checks at each of the primary waste operation stages (SRS, 2021d). SRS recently migrated to CWTS from the legacy Waste Inventory Tracking System (WITS) database beginning in 2021 (SRS, 2019c).

for the SRS and ELLWF in greater detail. For nearer term land-use planning, the most recent Record of Decision (66 FR 34431) for DOE/EIS-0217F (U.S. DOE, 1995b) prescribes land use in the area in and around the ELLWF as exclusively industrial (primarily waste management). As part of efforts related to the end-state vision, planning assumptions for land use within and adjacent to the SRS indicate that much of the site could remain under government control in perpetuity (SRS, 2014a).

1.4. DESIGN FEATURES

The disposal concept at the ELLWF entails both the above- and below-grade disposal of LLW. Closure of the various units involves installation of a final closure cap. To that end, six different disposal technologies are employed at the ELLWF (Figure 1-3), which include the following: STs, CIG trench segments, ETs, LAWV, ILV, and NRCDAs. Design, operational, and closure details for these different disposal facilities are briefly described below and in detail in Section 2.2.

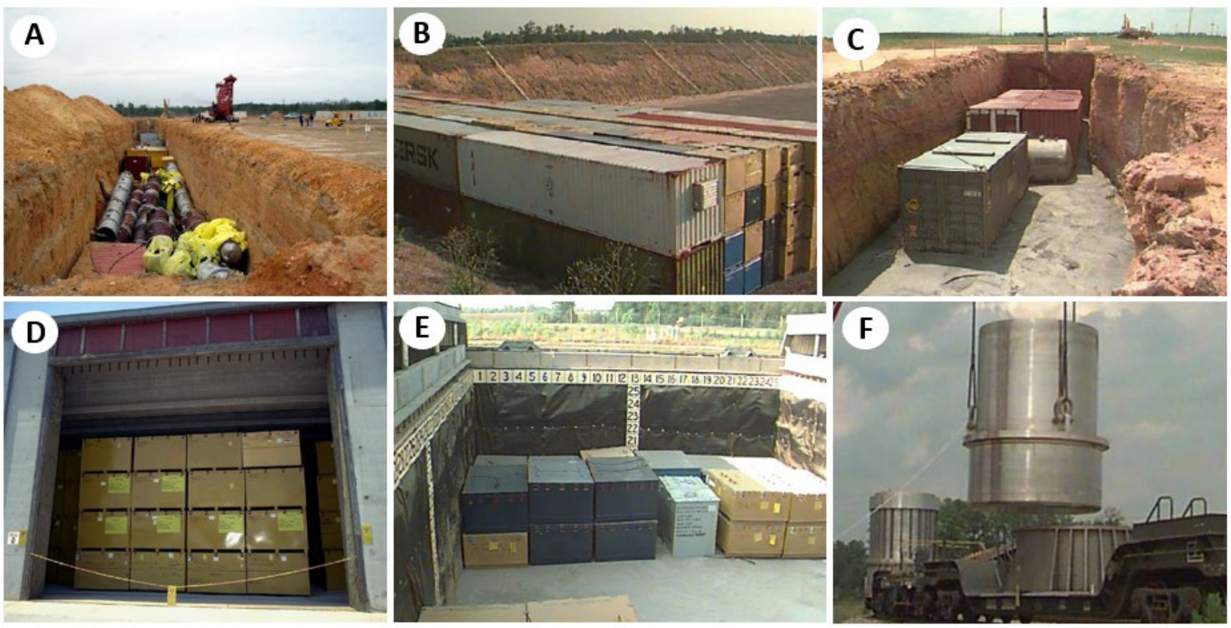

Figure 1-3. Operational Photographs of E-Area Low-Level Waste Facility Units: A) Slit Trench; B) Engineered Trench; C) Components-in-Grout Trench Segment; D) Low-Activity Waste Vault; E) Intermediate-Level Vault; F) Naval Reactor Component Disposal Area

1.4.1. Slit Trenches

STs are below-grade earthen DUs with vertical side slopes, making them inaccessible by vehicle. There are currently five closed, six open, and nine future STs. LLW consisting of soil, debris, rubble, wood, concrete, equipment, and job control waste is disposed within the STs. Job control waste consists of potentially contaminated personal protective equipment (PPE), plastic sheeting, and other slightly contaminated wastes. ST waste may be disposed in bulk form (e.g., demolition waste delivered in roll-off pans) or containerized (B-25 boxes, B-12 boxes, 55-gallon drums, SeaLand containers, and other metal containers). A section of a trench row (referred to as a trench "unit") is typically opened at one end to meet near-term disposal needs with operations proceeding toward the opposite end of the trench as the excavated space is filled. The excavated soil from trench construction is stockpiled for later placement over disposed waste. Additional units of trench space are not excavated until they are needed to minimize open trench area and the time that a trench unit remains open. Bulk waste is bulldozed into the trench unit while containerized waste and large equipment items are typically crane-lifted into place. Eventually, containerized waste areas of the trench unit are filled in with either bulk waste or clean soil to fill the voids between adjacent containers and the trench wall. Trench units are typically filled to within 4 feet of the ground surface with waste and daily cover, if required.

Operational closure of STs is conducted in stages. Once an individual ST trench unit is filled with waste, stockpiled clean soil is bulldozed in a single lift over that section of the trench unit to produce a minimum 4-foot-thick, clean, soil layer over the waste [i.e., operational soil cover (OSC)]. The OSC is graded to provide positive drainage off and away from the disposal operation and vegetated with a shallow-rooted grass to minimize erosion. Subsequent trench units are filled with waste, covered with an OSC, graded to promote positive drainage, and vegetated with a shallow-rooted grass until the entire ST is filled and covered. The only mechanical compaction that the soil and waste in the trench receive is from the bulldozer and other heavy equipment moving over the top of a completely backfilled trench.

When an entire ST (i.e., the 157-foot wide by 656-foot-long footprint comprised of five parallel trench rows) is filled with waste and completely covered by a minimum 4-foot-thick OSC and a vegetative cover of shallow-rooted grass, the ST is set for the installation of a low-permeability stormwater runoff cover. The low-permeability high-density polyethylene (HDPE) cover is installed over the entire ST to promote runoff and to minimize infiltration into the underlying waste zone (Collard and Hamm, 2008). A single operational stormwater runoff cover with a lengthwise crest may cover a single or multiple STs.

At the end of the operational period, which is currently projected to occur in 2065 (Sink, 2016c), a low-permeability interim runoff cover will be installed and maintained during the 100-year institutional control (IC) period (i.e., interim closure). The interim runoff cover will entail the surface application of an HDPE geomembrane (or other appropriate material with comparable performance) to maximize runoff.

Final closure of STs and the entire ELLWF will commence at the end of the 100-year IC period, which is projected to occur in 2165. Static surcharging and/or dynamic compaction of STs will be conducted at this time when the effectiveness of the subsidence treatment will be greater due to corrosion and loss of structural integrity of metal containers. Following subsidence treatment, a final multilayer soil-geomembrane closure cap, designed to minimize moisture contact with the waste and to provide an IHI deterrent, will be installed over all E-Area DUs and integrated with a common drainage system.

1.4.2. Components-in-Grout Trench Segments

Since approval of PA2008, CIG trench segments have been underutilized and have no waste forecasted through the end of ELLWF operations. Consequently, the remaining unused portion of the CIG01 DU and the future location of the CIG02 DU has been repurposed as ST23 and ST24, respectively, in the new PA baseline (Hamm, 2019). Therefore, CIG trench segments are no longer considered a unique type of DU but instead are treated as a special waste form (SWF) within a ST. CIG trench segments were designed to accept large radioactively contaminated equipment and other smaller waste forms, such as B-25 boxes, to fill in the space around and above the large equipment. Grout was subsequently poured around, between, and over the CIG component(s) to encapsulate them as shown in Figure 1-3(C). The nine existing CIG trench segments (CIG-1 through CIG-9) have already received operational stormwater runoff covers that will be maintained, including the repair of subsidence-induced damage, and will protect the operational soil covers from physical erosion. The operational stormwater runoff covers may transition to the interim runoff cover if their continued performance and serviceability are demonstrated following a technical assessment.

Based on waste zone structural stability considerations (i.e., the presence of voids and waste container types), minimum 20-inch-thick reinforced-concrete mats were considered for placement over each CIG trench segment to provide structural support for a period lasting 300 years (Peregoy, 2006a). Trench segments CIG-1, CIG-2, and CIG-3 have zero subsidence potential and do not require reinforced-concrete mats. Reinforced-concrete mats have been installed over trench segments CIG-8 and CIG-9; however, based on the supporting analyses provided in Chapters 5 and 8, reinforced-concrete mats are also not required for trench segments CIG-4 through CIG-7.

Final closure of the CIG trench segments and the entire ELLWF will commence at the end of the 100-year IC period, which is projected to occur in 2165. A final multilayer soil-geomembrane closure cap, designed to minimize moisture contact with the waste and to provide an IHI deterrent, will be installed over all ELLWF DUs and integrated with a common drainage system.

1.4.3. Engineered Trenches

ETs are below-grade, earthen, drive-in DUs. The existing 100-acre ELLWF disposal area contains three ETs (one closed unit, ET01, and two open units, ET02 and ET03); a fourth ET (ET04) just received its first waste package in January 2022 but is treated as a future unit in this PA.[2] Two future ETs (ET05, ET06) are sited in the existing 100-acre disposal area, while another three future ETs (ET07, ET08, and ET09) will be sited in a section of the second 100 acres known as Plot 8. Figure 1-2 shows the location and layout of the existing and future ETs relative to other ELLWF DUs. Each ET is a vehicle-accessible, open-trench design that allows stacking of containerized waste packaged in mostly B-25 boxes and SeaLand containers, and to a lesser extent B-12 boxes, 55-gallon drums, components, and other metal containers. Upon digging a trench, the excavated soil is stockpiled for later placement over disposed waste.

During the operational period, LLW contained within the metal boxes, containers, and drums are stacked by forklift or placed by crane within the ET. B-25 boxes are the predominant disposal containers utilized, representing approximately 90% of ET waste volume. The B-25 boxes are stacked in rows four high (approximately 17-foot high) with a forklift, typically beginning at the

[2] ET04 became operational in January 2022; however, at the time the PA conceptual models and timelines were frozen in 1Q2021, ET04 had not yet received its first waste package and is therefore treated as a future unit in this PA.

end of the trench opposite the access ramp. The stacks of B-25 boxes are usually placed immediately adjacent to one another with as little void space as possible between the stacks.

Operational closure of ETs is conducted in stages. Excavated soil from trench construction is stockpiled for later placement over disposed waste. When enough B-25 rows are placed, the stockpiled clean soil is bulldozed in a single lift over some of the completed rows to produce a minimum 4-foot-thick, clean, soil layer on top (i.e., an OSC). The OSC is graded away from the working face to provide positive drainage away from the trench. Placement of containerized waste continues until the trench is filled. When full, a minimum 4-foot-thick OSC is placed over the remaining portion of uncovered trench and the entire area is graded to provide positive drainage off and away from the ET. Once a vegetative cover of shallow rooted grass is established, the ET is operationally closed.

At the end of the operational period, [3] a low-permeability interim runoff cover will be installed and maintained during the 100-year IC period (i.e., interim closure). The interim runoff cover will entail placement of up to an additional 24 inches of soil above the ET, which will be graded to promote even greater drainage away from the trench. The interim runoff cover will consist of the surface application of an HDPE geomembrane or other appropriate material with comparable performance.

Final closure of ETs and the entire ELLWF will commence at the end of the 100-year IC period. Static surcharging and/or dynamic compaction of ETs will also be conducted at this time when the effectiveness of subsidence treatment will be greater due to corrosion and the loss of structural integrity of the metal containers. Following subsidence treatment, a final multilayer soil-geomembrane closure cap, designed to minimize moisture contact with the waste and to provide an IHI deterrent, will be installed over all E-Area DUs and integrated with a common drainage system.

1.4.4. Low-Activity Waste Vault

The LAWV is an above-grade reinforced-concrete vault structure containing waste in B-25 boxes, 55-gallon drums and other containers. The vault is approximately 643-foot long, 145-foot wide, and 27 feet high at the roof crest and is divided along its length into three modules that contain four cells each. The LAWV is designed for the disposal of low-activity waste containers that exceed the radiological dose and radionuclide concentration limits of the STs and ETs. The existing LAWV is the only one anticipated to be needed over the lifetime of the ELLWF.

During the operational period, low-activity containerized waste (predominately B-25 boxes and B-12 boxes) are stacked by forklift within the vault. B-25 boxes and/or equivalent pairs of B-12 boxes are stacked four high. The waste within the containers typically includes job control waste, scrap metal, and contaminated soil and rubble. Job control waste consists of potentially contaminated protective clothing (e.g., plastic suits, shoe covers, lab coats), plastic sheeting, and

[3] ETs that are operationally closed by Year 2040 will receive a low-permeability interim runoff cover at that time. ETs in operation in Year 2040 or later will receive the interim cover in Year 2065.

similar items. The scrap metal consists of contaminated tools, process equipment and piping, and laboratory equipment. Soil and rubble are generated from demolition activities. Operational closure of the LAWV will occur in stages whereby individual cells will be closed as they are filled with stacks of containerized waste and the entire vault will be closed after it is full. Closure actions consist of sealing vault openings and sumps. No additional closure actions beyond operational closure are anticipated for the LAWV during the 100-year IC period (i.e., interim closure).

Final closure of the LAWV and the entire ELLWF will commence at the end of the 100-year IC period. A final multilayer soil-geomembrane closure cap, designed to minimize moisture contact with the waste and to provide an IHI deterrent, will be installed over all E-Area DUs and integrated with a common drainage system. The crest lines of the final closure cap will be approximately centered over the long and short axes of the LAWV and sloped away from the apex to minimize the overburden loads on the vault and maximize runoff and lateral drainage from the overlying closure cap.

Carey (2005) predicts that structural failure of the LAWV roof will occur after 2,805 years. Upon failure, the concrete roof is assumed to collapse into the vault and the overlying closure cap subsides. Closure cap subsidence results in the cap losing its runoff and drainage layer functionality together with a decrease in evapotranspiration in the subsided area.

1.4.5. Intermediate-Level Vault

The ILV is a predominantly below-grade reinforced concrete vault containing grout-encapsulated waste containers. The ILV has two modules: Intermediate-Level Tritium (ILT) module containing two cells and Intermediate-Level Non-Tritium (ILNT) module containing seven cells. The original need for separate tritium and non-tritium modules no longer exists as the site's tritium mission and resulting waste forms have evolved since the early 1990s. Tritiated waste has been placed in all LAWV cells. The ILV is used to dispose of waste containers that exceed the radiological dose and radionuclide concentration limits of the STs, ETs, and LAWV.

ILT Cell #1 is fitted with an array of 144 vertical silos originally designed to receive overpacked cylindrical crucibles containing spent reactor targets formerly used in the extraction of tritium for Defense Programs. A total of 35 crucibles were disposed in the ILT Cell #1 silos before a new tritium extraction process became operational resulting in a different spent tritium target waste form. The other 109 silos are currently used for disposing of tritium job control waste and small equipment in 10-gallon drums. The packaged waste is placed in individual silos and a shielding plug is then installed over each silo containing waste. The remaining eight cells, ILT Cell #2 and ILNT Cells #1 through #7, have open interiors suitable for disposal of large equipment and containers of intermediate-activity waste. The disposal sequence for operation of these cells is as follows:

- The first layer of waste is placed within each cell directly on top of the graded stone drainage layer.
- The first layer of waste is encapsulated in grout which forms the surface for the placement of the next layer of waste.

- Subsequent layers of waste are placed directly on top of the previous encapsulated waste and may be encapsulated with a controlled low-strength material (CLSM) rather than grout.

The waste placed within ILT Cell #2 and ILNT Cells #1 through #7 typically consists of job control waste, scrap hardware, and containerized contaminated soil and rubble. Containers predominately include B-25 boxes, B-12 boxes, drums, and other metal containers.

Operational closure of the ILV will occur in stages. ILT Cell #1 will be operationally closed by placing a 37-inch-thick final layer of grout level with the top of the interior ILV wall. The installed silo shielding plugs will remain in place within the final grout layer. ILT Cell #2 and ILNT Cells #1 through #7 will be operationally closed as they are filled with waste by removing any shielding tees and placing a 17-inch-thick final layer of grout level with the top of the interior ILV walls. After the entire ILT module has been filled, it will be operationally closed by installing a 42-inch to 54-inch permanent reinforced-concrete roof slab and overlying bonded-in-place fiberboard insulation and waterproof membrane roofing over the entire module. After the entire ILNT module has been filled, it will be operationally closed by installing a 27-inch to 39-inch permanent reinforced-concrete roof slab and overlying bonded-in-place fiberboard insulation and waterproof membrane roofing over the entire module. The rain covers, shielding tees, and unused shielding plugs will no longer be required after installation of the permanent roof slab. No additional closure actions beyond operational closure are anticipated for the ILV during the 100-year IC period (i.e., interim closure).

Final closure of the ILV will take place at final closure of the entire ELLWF which will occur at the end of the 100-year IC period. Final closure will consist of installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an IHI deterrent. The integrated closure system will consist of a multilayer soil-geomembrane closure cap installed over all the DUs as well as a run-off drainage system. The closure cap will have a 2% slope perpendicular to the long axis of the ILV to minimize the overburden loads on the vault and maximize runoff and lateral drainage from the overlying closure cap. In addition, the average closure cap thickness above the ILV will be maintained at 9 feet or less to satisfy differential settlement and maximum seismic load considerations.

Following installation of the final closure cap, but before structural failure of the vault after an estimated mean time of 6,703 years (Peregoy, 2006b), the final closure cap and the structurally intact concrete vault will minimize infiltration into the vault. During this period, the hydraulic performance of the closure cap is assumed to degrade, resulting in increased infiltration through the closure cap over time (Dyer, 2019b). In addition, cracks are assumed to develop in the roof slab upon placement of the closure cap load, resulting in increased infiltration through the vault roof (Jones and Phifer, 2007).

1.4.6. Naval Reactor Component Disposal Areas

Reactor components from the U.S. Navy have been disposed in two areas associated with the ELLWF at SRS. The two areas are the currently operating at-grade gravel disposal pad, NR26E (643-26E), located inside the original 100-acre ELLWF, and the operationally closed at-grade gravel disposal pad, NR07E (643-7E), located in the old burial ground adjacent to the ELLWF. These units are formally designated as NRCDAs. The disposed waste forms consist of NR waste shipping and disposal casks containing waste NR components and less robust bolted containers of other auxiliary equipment. The NR07E disposal pad is a trapezoidal area of approximately 0.13 acres containing 41 casks up to 10.5 feet in diameter by 17.7 feet tall that is closed to future receipts. Structural fill has been placed around and over the NR07E disposal pad for radiation shielding. NR26E is an irregularly shaped area of approximately 1.1 acres that is currently open. Current NR waste projections for NR26E are substantially different from the original estimates due to a change in reactor maintenance (Wohlwend and Butcher, 2018). The original estimate was for 50 heavily shielded, welded casks and 50 thinner-walled bolted containers through the year 2025. Currently, NR Programs projects 33 heavily shielded, welded casks (31 are already in place on the NR26E pad) and 400+ thinner-walled, bolted containers by 2065.

The reactor components arrive by rail and are moved by crane to the at-grade gravel disposal pads (currently NR26E and formerly NR07E). NR waste consists of highly radioactive components comprising activated corrosion-resistant metal alloy contained within thick-walled (13.8-inch minimum thickness), welded, carbon-steel casks, and auxiliary equipment primarily contaminated with activated corrosion products (ACP) at low levels and contained within thinner-walled (2.75-inch minimum thickness), bolted, gasket-sealed, steel containers. NR components have historically consisted of various waste types including core barrels, thermal shields, shear blocks, adapter flanges, closure heads, cover plates, pumps, and other similar equipment from the Navy.

No additional operational closure or interim closure actions beyond simply placing containers on the NRCDA pads are necessary due to the water- and air-tight nature of the casks and bolted containers. However, to provide additional radiation shielding for personnel beyond operational closure, the casks will be surrounded with a structurally suitable material capable of supporting the final closure cap without resulting in differential subsidence at the time of cap installation.

Final closure of the NRCDAs will take place during final closure of the entire ELLWF at the end of the 100-year IC period. Before final closure, the space around, between, and over the casks will be filled with a structurally suitable material that will support the final closure cap without resulting in differential subsidence. Dynamic compaction of the NRCDAs will not be conducted. Final closure will consist of installation of an integrated multilayer closure cap system designed to minimize moisture contact with the waste and to provide an IHI deterrent.

1.4.7. E-Area Low-Level Waste Facility Water Infiltration

Water infiltration rates through the operational, interim, and final cover systems proposed in this PA for the ELLWF DUs are calculated using the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994a; Schroeder et al., 1994b). Design features included to minimize water infiltration through the waste zone are briefly introduced below and described in detail in Section 2.2.2.3.

For STs, ETs, and CIG trench segments, water infiltration through the waste zone is limited during the operational period by controlling the area of open trench. In addition, an OSC that is graded to provide positive drainage, an HDPE stormwater runoff cover, containerized or encapsulated waste, berms to prevent stormwater run-on, and sumps are variously used with these DUs to limit water infiltration through the waste zone. The interim runoff cover for trenches limits water infiltration through the waste zone during the 100-year IC period. The final soil-geomembrane multilayer closure cap over the DUs further limits infiltration through the waste zone during the post-IC period.

For the LAWV, water leakage into the vault during the operational period is limited by the crushed stone sub-drainage system, the waterproof membrane roofing, and the gutter/downspout system. Water that does enter the LAWV during operation is collected in a sump that is appropriately monitored, sampled, and pumped out as necessary. During the 100-year IC period after the LAWV has been operationally closed, water infiltration into the vault is minimized through the crushed stone sub-drainage system, gutter/downspout system, continuous concrete walls to seal all openings, and the waterproof membrane roofing. Following the 100-year IC period but before the vault's structural failure after 2,805 years, the final integrated closure cap system over all ELLWF DUs, along with the structurally intact concrete vault structure, will serve as a hydraulic barrier to water flow into the waste zone.

Likewise, for the ILV, water leakage into the vault during the operational period is limited by the crushed stone sub-drainage system, exterior wall surfaces coated with a tar-based waterproofing material, interior walls with drainage net attached, continuous water-stop seals at all construction joints, and removable sloped metal rain cover. Water that does enter the ILV during operation is collected in a sump that is appropriately monitored, sampled, and pumped out as necessary. During the 100-year IC period after the ILV has been operationally closed, the sloped metal rain covers will be replaced with a permanent reinforced-concrete roof slab with overlying bonded-in-place fiberboard insulation and waterproof membrane roofing. Following the 100-year IC period but before the vault's structural failure after a mean time of 6,703 years, the final integrated closure cap system over all E-Area DUs, along with the structurally intact concrete vault structure, will serve as a hydraulic barrier to water flow into the waste zone.

For the NRCDAs, welded casks and bolted containers are considered hydraulically intact until buried. Corrosion calculations detailed in Section 4.7.1.1 estimate that the carbon-steel welded casks will remain watertight for at least 750 years (bounding and pessimistic) after placement on the NRCDA pads (Wohlwend and Butcher, 2018). For bolted containers, the time to hydraulic failure of the gasketed seal is not known (see Section 4.7.1.4); therefore, as a bounding and pessimistic case, the bolted, gasket-sealed containers are assumed to fail hydraulically and to instantaneously release contaminants to surrounding soil after burial. Additionally, as a less pessimistic sensitivity case, bolted containers are also assumed to fail hydraulically 750 years after placement on the NRCDA pad. Therefore, for both container types, negligible water infiltration is anticipated during the operational period. Based on the specific hydraulic failure scenario assumed, bolted, gasket-sealed containers will either fail immediately upon burial or remain hydraulically intact throughout the IC and post-closure periods until the time of welded cask hydraulic failure at 750 years. The final closure cap installed at the end of IC will also limit water contact with the casks and bolted containers.

1.4.8. E-Area Low-Level Waste Facility Barriers to Inadvertent Human and Biotic Intrusion

Inadvertent human intrusion into DU waste zones is not considered possible during the operational and IC periods because of the presence of facility security. During the post-closure period, institutional controls and institutional memory are assumed to be lost, and inadvertent human and biotic intrusion is possible. Engineered features of the final closure cap, including cover thickness over the waste and engineered barriers, are designed to limit or deter intrusion. The final closure cap includes an erosion barrier designed to halt the progression of erosion above the waste zone. Intrusion into the waste layer by burrowing animals is precluded based on the depth of the waste zone relative to typical burrowing depths, the population densities of burrowing species likely to reside on the SRS, and the inclusion of a robust erosion barrier in the closure cap design. Biointrusion of pine tree tap roots into the waste zone because of pine tree succession of the grass cover will be deterred by an HDPE geomembrane which sheds infiltrating water through the LDL before reaching the waste zone. Evidence indicates that the presence of the geomembrane redirects a vertical tap root preventing penetration into the waste zone (Benson and Benavides, 2018).

On the other hand, for STs and ETs, the collective set of engineered barriers in the final closure cap design will not prevent penetration into the trench waste zone when using typical drilling techniques. In addition, as the final closure cap slopes from crest to toe, the minimum distance from the top of the erosion barrier to the top of the waste zone drops below the minimum 10 feet necessary for typical residential basement construction for portions of some DUs.

For the LAWV, the reinforced-concrete vault alone provides a significant barrier to intrusion from well drilling and basement excavation activities. Normal residential construction and well-drilling equipment used in the vicinity of SRS is not capable of penetrating the concrete roof structure (Smith et al., 2019). While the reinforced-concrete roof slab and precast beams remain intact (mean time to failure estimated to be 2,805 years), the vault structure will be an effective physical barrier against inadvertent excavation and drilling.

The ILV concrete roof similarly provides a barrier against biotic and inadvertent human intrusion with one exception. Because the ILV is positioned near the bottom of the closure cap slope, after erosion of the cap to the top of the erosion barrier and absent the concrete roof, the minimum distance from the top of the erosion barrier to the top of the waste zone drops below the minimum 10 feet necessary for typical residential basement construction. Still, an inadvertent human intruder attempting to excavate a basement will encounter obvious barriers in the closure cap (e.g., HDPE layer in cover and erosion barrier) that are distinguishable from the backfill and cover soils that are normally expected.

Because the welded steel casks are assumed to be structurally stable for 8,000 years after placement on the pads, they also provide a barrier to intrusion for this time period. Bolted containers are also assumed to remain structurally intact and distinguishable from native soil throughout the 1,000-year compliance period. Normal residential construction and well-drilling equipment used in the vicinity of the SRS is not capable of penetrating a structurally intact welded cask (minimum wall thickness is 13.8 inches) or bolted container (minimum wall thickness is 2.75 inches).

1.4.9. E-Area Low-Level Waste Facility Final Closure Cap

Final closure of all DUs in the ELLWF will occur in 2165 at the end of the 100-year IC period (SRS, 2016). Final closure will consist of site preparation and construction of an integrated closure system designed to minimize moisture contact with the waste zone and to provide an IHI deterrent (Phifer et al., 2009). The integrated closure system is described in detail in Section 2.2.2. Final closure will carefully consider the waste types and forms, unit location, disposition of non-disposal structures and utilities, site hydrogeology, potential exposure scenarios, and lessons learned from implementing closure systems at other SRS facilities.

Following installation, maintenance of the final closure cap will not be performed beyond that required to establish a vegetative cover. As discussed in Section 3.4, a bounding assumption in this PA is that the hydraulic performance of the closure cap begins to degrade immediately upon installation because of the following long-term natural degradation mechanisms, resulting in increased infiltration through the cap over time (Dyer, 2019b):

- Formation of holes in the HDPE geomembrane layer due to oxidative degradation of the polymer.
- As a result of pine forest succession, the subsequent formation of holes in the GCL caused by pine tree tap roots penetrating through holes in the degraded HDPE geomembrane.
- Reduction in the saturated hydraulic conductivity of the lateral drainage layer (LDL) due to colloidal clay migration from the upper backfill layer above.
- Erosion of the topsoil layer that provides water storage to facilitate evapotranspiration.

1.5. E-AREA LOW-LEVEL WASTE FACILITY LIFECYCLE AND CLOSURE PLAN

The overall ELLWF lifecycle timeline developed for the current PA revision is summarized below.

09/28/1994	**Start of burial in LAWV**
09/28/1994	**Start of burial in ILV**
09/28/1994 to 09/30/2021	**Opening and, in some cases, closing of various DUs (e.g., ST01 opened and closed; ET03 opened and still in operation)**
09/30/2021	**Opening of all new (future) DUs**
09/30/2040	**Application of an interim cover over all ST and ET DUs that are closed by this date**
09/30/2065	**Closure of ELLWF and application of another interim cover over the remaining ST and ET DUs (start of IC period)**
09/30/2065 to 09/30/2165	**100-year period of IC where the interim covers are actively maintained**
09/30/2165	**End of IC period**
09/30/2165 to 09/30/3165	**1,000-year period of performance**
09/30/3165	**Post-compliance period to identify potential peak doses that occur beyond the 1,000-year compliance period.**

The timeline in terms of relative time from the start of ELLWF operations is as follows:

Years 0 – 71	**Operational period**
Years 71 – 171	**IC period**
Years 171 – 1,171	**Period of performance**
Years 0 – 1,171	**Total compliance period**

Hamm et al. (2018) developed individual timelines for filling each DU based upon waste volume and/or radionuclide activity to establish DU-specific inventory limits that provide a high level of confidence in meeting the POs. Based upon information provided/projected by current and future waste generator inventories, Hamm et al. (2018) created three DU lifecycles:

- Best Estimate Case
- Most Probable and Defensible (MPAD) Case
- Upper Bound Case

A composite of these three lifecycle cases was chosen for application in this PA. The chosen DU timelines place 100% of the inventory in each DU at the time of first package burial. For closed and existing DUs this point in time is known. For future DUs, all units are assumed to open on 09/30/2021.

The alignment of most burials, as described above, should result in a total sum-of-fractions (SOFs) at the 100-meter POA that is higher than realized during the entire compliance period. In addition, the choice to assume burial of all inventory at the start of a DU's operation versus distributing the inventory over time or burying it at the end of operations, yields higher estimated SOFs for mobile radionuclides, such as H-3, Tc-99, I-129, and C-14, because of the longer duration without a geomembrane cover. There are two exceptions: ST10 and ET04. ST10 and ET04 are assumed to receive their first waste packages on 12/18/2020; however, their planned openings did not occur on this date and therefore are considered future units in this PA.[4] Two competing aspects are at play:

1. The assumed earlier burial date (12/18/2020) provides these two DUs more uncovered operational time wherein increased migration toward the 100-meter POA occurs.
2. Not being aligned with other neighboring DUs yields less plume overlap at the 100-meter POA. However, the plume interaction factor (PIF) approach is based on a steady-state concept mitigating this impact.

The ELLWF closure plan (Phifer et al., 2009) was originally developed in 2009 according to the specifications of the *Format and Content Guide for U.S. Department of Energy Low- Level Waste Disposal Facility Closure Plans* (U.S. DOE, 1999c). The closure plan will be updated following revision of the ELLWF PA per the *Disposal Authorization Statement and Tank Closure Documentation* (U.S. DOE, 2017) to reflect the current status of the facility and to ensure

[4] ET04 became operational in January 2022; however, at the time the PA conceptual models and timelines were frozen in 1Q2021, ET04 had not yet received its first waste package and is therefore treated as a future unit in this PA.

compliance with applicable orders and regulations. The closure plan describes the technical approach to closure, and includes operational, interim, and final closure details, as well as the schedule of closure as these elements apply to each of the ELLWF DUs.

The operational timeline for the ELLWF comprises three closure phases to accommodate ongoing operations, limit infiltration into the underlying buried waste, and optimize future waste stabilization measures. The three phases are: operational closure, interim closure, and final closure. Operational closure will be conducted as DUs are filled. Operational closure is specific to each type of DU and is primarily intended to limit infiltration, facilitate operations, promote worker safety, and prepare the facility to transition to interim closure. Environmental Management (EM) operations are anticipated to conclude in the year 2065 in alignment with the SRS Nuclear Materials Management Plan FY 2016-2030 (SRS, 2016). STs will have operational stormwater runoff covers installed at operational closure to optimize stormwater runoff and limit infiltration into the underlying waste zone. The operational stormwater runoff covers will be maintained, including the repair of subsidence-induced damage, and will protect the OSCs from physical erosion. The operational stormwater runoff covers may transition to the interim runoff cover if their continued performance and serviceability are demonstrated following a technical assessment. ETs will utilize soil covers for operational closure to optimize stormwater runoff and minimize infiltration into the underlying waste zone. The soil covers are permanent and will be an integral part of the interim and final cover systems. Operational closure of the two vaults will entail sealing exterior vault openings and sumps with concrete for the LAWV and grouting the headspace in each cell and installing a reinforced concrete roof slab and waterproof membrane for the ILV. Due to the water- and air-tight nature of the stainless-steel casks, operational closure of the NRCDAs simply entails carefully placing the casks on the gravel pads and backfilling around casks as needed for radiation shielding.

Interim closure begins a nominal 100-year period of IC when close to 100% of the ELLWF is filled with waste and is specific for each type of DU. The primary objectives of interim closure are to limit infiltration during the 100-year IC period, and to prepare the facility for transition to final closure by allowing time for waste container corrosion. The 100-year interim closure period is assumed to commence on September 30, 2065, with a subset of trenches being closed on September 30, 2040 (all STs and ETs filled by that date). STs and CIG trench segments will have interim runoff covers installed for interim closure to optimize stormwater runoff as was done previously for operational closure. No additional interim closure actions are anticipated for the LAWV, ILV, and NRCDAs beyond those for operational closure.

Static surcharging and/or dynamic compaction of STs and ETs will be performed at the end of the 100-year IC period when the efficiency of subsidence treatment is greater due to container corrosion and a corresponding loss of structural strength. The interim runoff covers will be removed before performing the subsidence treatment and installing the final closure cap system. Dynamic compaction will not be performed in sections of STs and ETs designated as exempt from compaction, such as those containing M-Area glass and Effluent Treatment Facility (ETF) carbon columns (Nichols and Butcher, 2020). The stabilization measures taken are assumed to sufficiently consolidate the underlying waste layer and eliminate subsidence except in the presence of "non-crushable" containers.

Final closure of all DUs in the ELLWF will take place in 2165 at the end of the 100-year IC period (SRS, 2016). Final closure will consist of site preparation and construction of an integrated closure system designed to minimize moisture contact with the waste zone and to provide an IHI deterrent. The integrated closure system will consist of one or more multilayer soil-geomembrane closure caps installed over all the DUs coupled with an integrated drainage system. Before final closure of the NRCDA pads, the space around, between, and over the stainless-steel casks will be filled with a structurally suitable material capable of supporting the final closure cap without resulting in differential subsidence. Final closure will carefully consider the waste types and forms, unit location, disposition of non-disposal structures and utilities, site hydrogeology, potential exposure scenarios, and lessons learned from implementing closure systems at other SRS facilities.

Closure phases and associated closure actions are presented in greater detail in Sections 2.2.1 and 2.2.2.

1.6. RELATED DOCUMENTS

The ELLWF PA is influenced by, and has an influence on, other related site documents that are discussed in the following sections.

1.6.1. Groundwater Protection Management Program

The plan for protection of GW at SRS is documented in the *SRS Groundwater Protection Program* (SRNS, 2018b). The hydrogeologic information utilized in this revision of the ELLWF PA is consistent with that in the GW protection program. The GW protection program at SRS is focused on those activities regulated by external agencies (i.e., the State of South Carolina and the U.S. EPA). The ELLWF is not regulated by the State of South Carolina or the U.S. EPA but is instead regulated by U.S. DOE through DOE O 435.1, Chg. 2 (U.S. DOE, 2021a). Additionally, the SRS has not entered into a formal agreement applicable to GW protection with respect to the ELLWF. However, consistent with guidance for preparing this PA (U.S. DOE, 2021b), the requirement of DOE O 435.1, Chg. 2 to assess impacts to water resources has been addressed by assessing the concentrations of radioactive or chemical contaminants against standards for public drinking water supplies established by the U.S. EPA and SCDHEC. This interpretation is consistent with the *SRS Groundwater Protection Program* (SRNS, 2018b).

1.6.2. Savannah River Site End State Vision

The *Savannah River Site End State Vision* (SRS, 2005) focuses on site facilities and areas that are the responsibility of the DOE Office of Environmental Management, which includes the ELLWF. The end state vision includes the following components:

- The entire site will be owned and controlled by the federal government in perpetuity
- The property will be used only for industrial purposes
- Site boundaries will remain unchanged
- Residential use will not be allowed on-site

The U.S. DOE solicited public input in developing the *Savannah River Site End State Vision* (SRS, 2005) which contains an appendix that addresses public comments received, including recommendations and endorsement from the SRS Citizens Advisory Board.

1.6.3. Savannah River Site Land Use Plan

Savannah River Site Land Use Plan (SRS, 2014a) provides the framework for integrating the SRS mission and vision with ecological, economic, cultural, and social factors in a regional context and to support decision-making for near-term and long-term use of the site, including the ELLWF. The SRS land use plan describes the current site conditions, defines a vision for the evolution of the site, outlines actions to achieve the vision, and guides the allocation of resources toward attainment of that vision. The plan provides guidance and direction for the future physical development of the site and a framework within which detailed analyses will be conducted to determine the courses of action required to reach optimum site configuration. The plan is based on specific assumptions. If these assumptions were to change, the plan would be updated to reflect the changed conditions. Guidelines on which SRS land use is based include:

- Giving priority to protection of workers and the public
- Maintaining site security
- Maintaining other appropriate institutional controls
- Considering worker, public, and environmental risks, benefits, and costs
- Restricted use programs for units regulated under CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) or RCRA (Resource Conservation and Recovery Act)
- Maintaining existing SRS boundaries
- Continuing federal ownership of the land
- Prohibiting residential use of SRS land

Because the SRS land use plan states that the current site boundaries will remain unchanged and under the ownership of the federal government, no MOP will have unrestricted access to the ELLWF. Nonetheless, per the requirements of DOE O 435.1, Chg. 2, the revised ELLWF PA has used the point of maximum calculated dose or concentration, outside a 100-meter POA surrounding the disposed waste, as the POA. For the IHI calculations, the assumed period of active IC was limited to 100 years.

1.6.4. Other SRS Performance Analyses

In addition to the ELLWF PA, Savannah River Remediation LLC (SRR) manages SRS PAs for the Saltstone Disposal Facility (Savannah River Remediation, 2020), F-Area Tank Farm

(Savannah River Remediation, 2010), and H-Area Tank Farm (Savannah River Remediation, 2012). As required by DOE O 435.1, Chg. 2 (U.S. DOE, 2021a), these PAs assess the calculated dose impact on a future, hypothetical MOP and an IHI, as well as the environmental impacts from the respective facilities after final closure. The analyses presented in this revised ELLWF PA are consistent with the other SRS PAs.

1.6.5. Composite Analysis

The 2010 SRS Composite Analysis (CA) (SRNL, 2010) assessed the potential impacts to hypothetical members of the public from residual radioactive material that may be left at the SRS when operations are complete. The 2010 CA concluded that the impacts of the operating LLW disposal facilities—the ELLWF and Saltstone Disposal Facility—are negligible contributors to calculated doses; therefore, the CA will not influence the WAC for the ELLWF. Based on the assessments performed in the annual reviews and collective engineering judgement, the conclusions of the 2010 SRS CA remain valid and there is reasonable assurance that SRS will meet the performance objectives delineated in DOE O 435.1, Chg. 2. The 2010 SRS CA will be updated subsequent to the revision of the ELLWF PA to incorporate SRS PA changes and to address the number of proposed changes to inventories and sources and model improvements accumulated since the 2010 CA.

1.6.6. Savannah River Site Waste Management Environmental Impact Statement

SRS has prepared an environmental impact statement (EIS) for waste management activities on the site (U.S. DOE, 1995b). The EIS considered continued disposal of LLW in the 643-7E disposal facility (i.e., the former LLW burial site; disposal at this site has since ceased) and the ELLWF. Three records of decision (RODs) have been issued for this EIS (U.S. DOE, 1995a; 1997b; 2001). The analyses presented in this revised PA are consistent with the EIS and the associated RODs.

1.7. REGULATORY CONTEXT

This revised PA has been prepared within the regulatory context of ELLWF management per DOE O 435.1, Chg. 2 (U.S. DOE, 2021a) and under the guidance of DOE M 435.1-1, Chg. 3 *Radioactive Waste Management Manual* (U.S. DOE, 2021b) and the DOE *Standard for Disposal Authorization Statement and Tank Closure Documentation* (U.S. DOE, 2017).

On September 28, 1999, U.S. DOE Headquarters issued the disposal authorization statement (DAS) for LLW disposal in the ELLWF and Saltstone disposal facilities. The DAS serves as the "federal permit" under which SRS may dispose of low-level waste at the two disposal facilities. The PAs for the two facilities, the CA, and the information developed during and subsequent to the review of these documents (e.g., addenda to the PAs and CA) form the basis for the DAS. Changes in disposal operations, such as the development of new disposal technologies, are appropriate if these changes conform to the PA and CA maintenance requirements.

1.7.1. Performance Objectives

The POs for U.S. DOE LLW disposal facilities are stated in DOE M 435.1-1.IV.P. (1) (U.S. DOE, 2021b) as follows:

"Low-level waste disposal facilities shall be sited, designed, operated, maintained, and closed so that a reasonable expectation exists that the following performance objectives will be met for waste disposed of after September 26, 1988:

> *(a) Dose to representative members of the public shall not exceed 25 mrem [millirem] (0.25 mSv) [millisievert] in a year total effective dose equivalent from all exposure pathways, excluding the dose from radon and its progeny in air.*
>
> *(b) Dose to representative members of the public via the air pathway shall not exceed 10 mrem (0.10 mSv) in a year total effective dose equivalent, excluding the dose from radon and its progeny.*
>
> *(c) Release of radon shall be less than an average flux of 20 pCi/m^2/s [picocurie per square meter per second] (0.74 Bq/m^2/s) [becquerel per square meter per second] at the surface of the disposal facility. Alternatively, a limit of 0.5 pCi/L [picocurie per liter] (0.0185 Bq/L) of air may be applied at the boundary of the facility."*

The DOE M 435.1-1.IV.P. (2). (g) requires assessment of the protection of water resources (U.S. DOE, 2021b) as follows:

> *"(g) For purposes of establishing limits on radionuclides that may be disposed of near-surface, the performance assessment shall include an assessment of impacts to water resources."*

The format and content guide (U.S. DOE, 2007) for DOE O 435.1 states that

> *"DOE M 435.1-1 does not contain a specific performance objective (e.g., dose or concentration standard) for water resource impact…. For water resources protection, impacts should be assessed on a site-specific basis in accordance with a hierarchical set of criteria. This approach recognizes that there are no Federal requirements for protection of water resources for a radioactive waste disposal facility. The site-specific hierarchical approach, rather than mandating specific performance measures for all sites, is consistent with the Environmental Protection Agency strategy for groundwater protection, which recognizes that groundwater protection is a regional and local matter. Rather, a site-specific approach, in accordance with a hierarchical set of criteria should be followed."*

At SRS, the appropriate measure for protection of water resources is determined to be the Safe Drinking Water Act maximum contaminant levels (MCLs) The MCLs (U.S. EPA, 2000; 2002) are listed in Table 1-1.

Table 1-1. Safe Drinking Water Act Maximum Contaminant Levels

Component	Maximum Contaminant Level
Beta-Gamma Dose	4 mrem/year
Gross Alpha	15 pCi/L
Radium	5 pCi/L
Uranium	30 µg/L

µg/L = micrograms per liter

The DOE O 435.1, Chg. 2 requirement for assessment of the IHI analysis is found in DOE M 435.1-1.IV.P. (2). (h) (U.S. DOE, 2021b), which states that

> *"(h) For purposes of establishing limits on the concentration of radionuclides that may be disposed of near-surface, the performance assessment shall include an assessment of impacts calculated for a hypothetical person assumed to inadvertently intrude for a temporary period into the low-level waste disposal facility. For IHI analyses, institutional controls shall be assumed to be effective in deterring intrusion for at least 100 years following closure. The IHI analyses shall use performance measures for chronic and acute exposure scenarios, respectively, of 100 mrem (1 mSv) in a year and 500 mrem (5 mSv) total effective dose equivalent excluding radon in air."*

The Manual specifies that the PA shall include calculations for a 1,000-year period after closure of potential doses to representative future members of the public and potential releases from the facility to provide a reasonable expectation that the POs identified are not exceeded (U.S. DOE, 2021b). The point of compliance must correspond to the point of highest projected dose or concentration beyond a 100-meter POA surrounding the disposed waste.

The POs employed in this PA to calculate individual inventory limits and corresponding SOF values are listed in Table 1-2. The chosen POs are specifically defined for a future MOP. SCDHEC and U.S. EPA drinking water standards are included based on published MCLs, where available, or are derived based on dose coefficient factors and the typical person drinking water consumption rate.

Table 1-2. Exposure Scenarios, Performance Objectives and Measures, and Points of Assessment for the E-Area Low-Level Waste Facility Performance Assessment

Exposure Scenario	Performance Objective or Measure	Point of Assessment	Compliance Period
Air Pathway	10 mrem/yr [a]	1) Atmospheric "at and beyond" the SRS boundary	1) 71 yr to 171 yr (during IC period)
		2) Atmospheric "at and beyond" the ELLWF 100-meter boundary based on waste footprints	2) 171 yr to 1,171 yr (period of performance following IC period)
Radon Pathway	20 pCi/m^2/s	ELLWF waste footprint flux at ground surface	71 yr to 1,171 yr (entire post-closure period)
All-Pathways	25 mrem/yr	GW "at and beyond" the ELLWF 100-meter boundary based on waste footprints	171 yr to 1,171 yr (end of IC to end of period of performance)
Water Resources: • Ra-226 + Ra-228 • Gross alpha [b] • Beta-gamma • Uranium (total)	 5 pCi/L 15 pCi/L 4 mrem/yr 30 µg/L	GW "at and beyond" the ELLWF 100-meter boundary based on waste footprints	0 yr to 1,171 yr (start of ELLWF operations to end of period of performance)
Inadvertent Human Intruder • Chronic exposure • Acute exposure	 100 mrem/yr 500 mrem	ELLWF waste footprints at ground surface	171 yr to 1,171 yr (end of IC to end of period of performance)

Notes:

[a] Excluding radon in air.

[b] Including Ra-226 but excluding radon and uranium.

For the air pathway, two separate POAs exist as follows:

- Atmospheric "at and beyond" the SRS boundary during the 100-year IC period when site access is restricted.
- Atmospheric "at and beyond" the 100-meter boundary that surrounds the ELLWF DU footprints, where unrestricted access is assumed for the remainder of the period of performance.

The two separate air pathway POAs do not overlap in time, so only a single pathway is required. All POs listed in Table 1-2 represent separate dose pathways to a MOP. Thus, inventory limits are required for nine unique pathways as follows:

- Air pathway
- Radon pathway
- IHI chronic pathway
- IHI acute pathway
- All-pathways
- Beta-gamma pathway
- Gross-alpha pathway
- Radium pathway
- Uranium pathway

The beta-gamma, gross-alpha, radium, and uranium pathways address GW protection of the aquifer water resource beneath the ELLWF out to its surface seepage faces [i.e., Upper Three Runs (UTR) Creek and its tributaries]. For the IHI, two separate pathways are considered.

1.7.2. Points of Assessment and Compliance Periods

POAs are provided for each exposure scenario shown in Table 1-2. For the ELLWF PA, the POAs are identical to DOE M 435.1-1, Chg. 3 (U.S. DOE, 2021b) requirements and consistent with the *Disposal Authorization Statement and Tank Closure Documentation* standard (U.S. DOE, 2017). The POAs do not vary with the post-closure period, even though expected future land use and institutional controls (refer to Section 1.11) would preclude public exposure at the 100-meter POA boundary for as long as waste remains above unrestricted use criteria in the area (as required under CERCLA). Institutional controls limiting site access are assumed to be effective for 100 years following closure. These assumptions are pessimistic given that U.S. DOE is required to maintain control over land containing radionuclide sources until the land can be safely released pursuant to DOE O 458.1, *Radiation Protection of the Public and the Environment* (U.S. DOE, 2020b), and CERCLA. Additional consideration of land use and institutional controls are provided in Section 1.11 below.

The compliance period for each exposure scenario pathway is presented in Table 1-2. The specific time periods listed are relative time with respect to the start of the ELLWF (i.e., burial of the first package on September 28, 1994). Most of the models and subsequent results presented in this PA employ a relative time scale. The timeline employed in this PA for the ELLWF is consistent with the one used in the 2008 PA and subsequent SAs. Figure 1-4 presents an overview of the ELLWF PA timeline in both absolute and relative time.

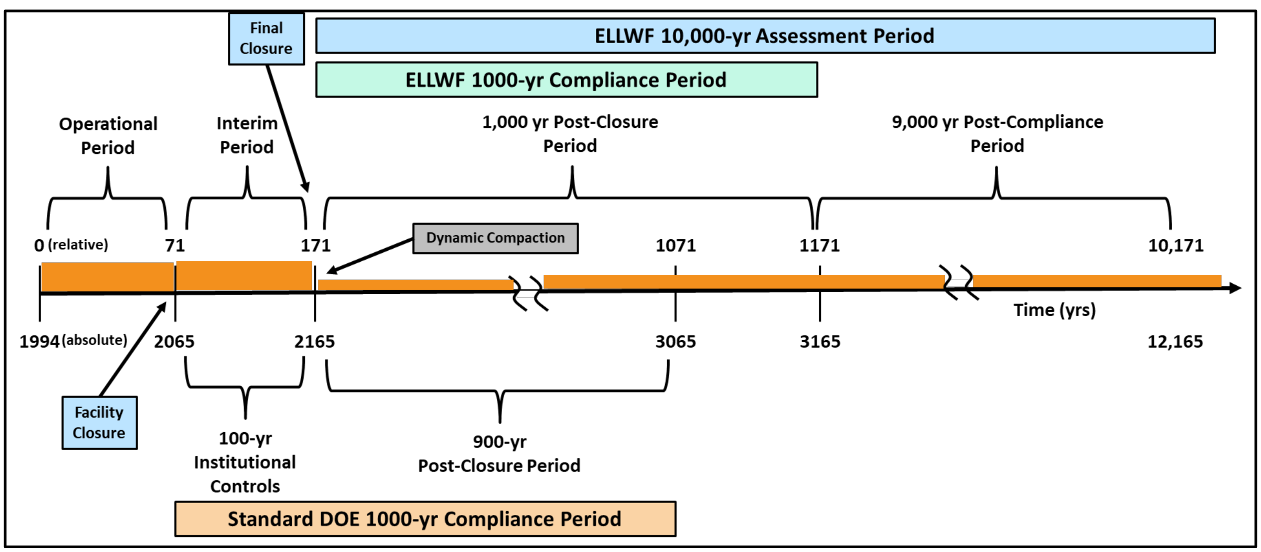

Figure 1-4. Overview of E-Area Low-Level Waste Facility Timeline for This Performance Assessment Highlighting Key Assessment Periods

The key time periods presented in Figure 1-4 are as follows:

- **Operational Period:** The initial 71-year period when the ELLWF is authorized to receive waste packages. At the end of this period, all ELLWF DUs are closed for waste receipts, and the facility is also considered closed. This period is part of the overall compliance period.
- **Interim Period:** A 100-year period where the facility is maintained within its initially closed state and is closed to the public. At the beginning of this period, an interim cover is placed over the entire facility. At the end to this period (i.e., end of institutional controls), the facility is dynamically compacted, where appropriate, and the final closure cap is placed. A state of final closure is established. This period is part of the overall compliance period.
- **1,000-Year Compliance Period:** A 1,000-year period, beginning at the end of IC, when facility maintenance no longer occurs. This period is part of the overall compliance period.
- **9,000-Year Post-Compliance Period:** A 9,000-year period, commencing at the end of the 1,000-year compliance period, when facility maintenance does not occur. This period is not part of the overall compliance period but is included to help identify potential peak doses occurring beyond the overall regulatory compliance period.

The overall compliance period encompasses all of the compliance periods listed in Table 1-2 and highlighted in the bulleted list above. Specifically, the overall compliance period in relative time spans from Year 0 through Year 1,171. For assessment purposes, facility performance is considered for an additional 9,000-year period beyond Year 1,171. The decision to compute, and then present, facility performance for 10,000 years beyond the end of IC (Year 171) is based on the following reasoning:

1. The majority of the radionuclides peak during the 10,000-year period.
2. Some facilities in the U.S. DOE complex have assessed performance for 10,000 years.
3. A 10,000-year assessment period facilitates comparison to NRC-regulated facilities.

A 2015 update of the SRS 10-year plan (SRNS, 2015) estimates that the SRS EM cleanup mission will continue for another approximately 50 years until Year 2065, at which time a traditional 100-year IC period commences. Dynamic compaction of crushable containers is not performed during operations or IC.

During the 2000 to 2004 timeframe, Cook et al. (2004) concluded that dynamic compaction of ETs and portions of STs containing containerized waste would at best reduce the subsidence potential by 50% if dynamic compaction was attempted at the time of burial. Instead, Cook et al. (2004) determined that dynamic compaction will be significantly more efficient (~95% or greater) if delayed until the end of IC. Based on this information, SRNL, SWM, and DOE-SR agreed to delay dynamic compaction until the end of IC.

As highlighted in Figure 1-4, the receipt of the last package (i.e., *facility* closure) occurs after 71 years of operation, while *final* closure occurs 171 years after the start of operations. Dynamic compaction is delayed until the end of IC, at which time the post-closure period begins and lasts for an assumed additional 1,000 years (labeled "ELLWF 1000-yr Compliance Period" in Figure 1-4). The standard U.S. DOE 1,000-year compliance period is extended for the ELLWF PA because the final closure cap will not be placed over the facility until the end of IC as indicated in Figure 1-4 (labeled "Standard DOE 1000-yr Compliance Period"). The overall benefit (i.e., lower maintenance costs for the final closure cap because of ongoing subsidence) significantly exceeds the modest reduced activity capacity of the ELLWF.

1.8. INADVERTENT HUMAN INTRUSION

Analysis of performance relative to a future, hypothetical IHI at the ELLWF is based on the performance measures for acute and chronic exposures specified in DOE M 435.1-1, Chg. 3 (U.S. DOE, 2021b). The ELLWF PA considers three acute exposure scenarios (basement construction, discovery, and well drilling) and three chronic exposure scenarios (agriculture, post-drilling, and residential) consistent with the guidance in *Disposal Authorization Statement and Tank Closure Documentation* (U.S. DOE, 2017). An IHI is assumed to occur 100 years after facility closure because of a temporary loss of IC at the SRS site. An IHI at ELLWF is highly unlikely given that U.S. DOE is required to maintain control over land containing radionuclide sources until the land can be safely released pursuant to DOE O 458.1 (U.S. DOE, 2020b) and that CERCLA requires remediated sites to be monitored until shown to be acceptable for unrestricted use. A 1,000-year post-closure compliance period is considered for purposes of assessing ELLWF performance relative to IHI performance measures.

1.9. ALARA PROCESS AND ANALYSIS

U.S. DOE's approach to radiation protection for LLW disposal is based on the POs listed in DOE M 435.1-1.IV.P (1) (U.S. DOE, 2021b), which specify maximum doses for various pathways, and on the ALARA principle, which requires doses to be maintained as low as reasonably achievable. The requirement as stated in DOE M 435.1-1.IV.P (2) (f) (U.S. DOE, 2021b) is:

> *"Performance assessments shall include a demonstration that projected releases of radionuclide to the environment shall be maintained as low as reasonably achievable (ALARA)."*

Therefore, in addition to providing a reasonable expectation that the POs will be met, the goal of ALARA is attainment of the lowest practical dose level after accounting for social, technical, economic, and public policy considerations.

1.9.1. Process

The U.S. DOE ALARA process[5] helps to ensure that optimization techniques will be integrated into the design and analyses of programmatic options necessary for the protection of the public

[5] As applied by U.S. DOE, ALARA is not a level or limit to be achieved in controlling radiation exposures or doses, but rather a process used to ensure that appropriate factors are considered in making decisions that can affect protection against radiation. The ALARA process must be applied to DOE activities and the design or modification of facilities that expose the public or the environment, no matter how small the dose (U.S. DOE, 2014).

and the environment in accordance with the requirements of DOE O 458.1 (U.S. DOE, 2020b). As much as possible, U.S. DOE sites should consider using existing processes, programs, or documentation for addressing the provisions of DOE O 458.1 (which are also applicable for DOE O 435.1, Chg. 2) in the development and implementation of the ALARA requirements.

DOE O 458.1 (U.S. DOE, 2020b) requires that the ALARA process use a graded level of control and oversight to ensure that doses to the public are low and decisions made as a result of the process are both beneficial and cost-effective. DOE has defined the graded approach for nuclear safety management (10 CFR § 830.3) as the process of ensuring that the level of analysis, documentation, and actions used to comply with a requirement are commensurate with the relative importance to safety, safeguards, and security, the magnitude of any hazard involved, the life cycle stage of a facility, the programmatic mission and characteristics of a facility, the relative importance of radiological and non-radiological hazards, and any other relevant factor. ALARA is a self-limiting system and thus the level of analysis should be commensurate with the estimated collective dose to the exposed population; higher estimated collective doses require more rigor in the analysis (U.S. DOE, 2014).

1.9.2. Analysis

SRS has a well-established ALARA policy and program (SRS, 2018) that is fully integrated into Solid Waste Management Facility (SWMF) procedures and activities as described in the *Savannah River Site Solid Waste Management Facility Documented Safety Analysis* (SWM, 2021). The ALARA analysis for the ELLWF PA revision assesses the hazards associated with the ELLWF relative to other nuclear operations when considering the need for design or modification of disposal facilities or other closure activities (U.S. DOE, 2017). Per DOE O 458.1 (U.S. DOE, 2020b) and as described in *DOE Handbook: Optimizing Radiation Protection of the Public and the Environment for Use with DOE O 458.1, ALARA Requirements* (U.S. DOE, 2014), the ALARA process has been implemented for the ELLWF by applying a graded approach that optimizes control and management of the LLW DUs so that doses to members of the public (both individual and collective) and releases to the environment are maintained as low as reasonably achievable. Several factors suggest that further ALARA optimization analysis is not necessary for the ELLWF PA.

First, SRS prepared an EIS for waste management activities on the site (U.S. DOE, 1995b) that considered social, technical, economic, and public policy aspects. Therefore, the design and operation of the ELLWF address key considerations in an ALARA analysis. The options considered and conclusions drawn from the EIS serve as part of the basis for demonstrating adherence to the ALARA requirement.

Second, the ALARA concept is integrated into all SWMF activities involving radioactive materials. SWMF is committed to maintaining external and internal exposures to radiation from site processes to ALARA levels in accordance with SCD-6, the *SRS ALARA Manual* (SRS, 2018). In addition, Manual 5Q (SRS, 2022a) establishes procedures, limits, and requirements for radiological protection training, radiation exposure control (administrative limits, radiological practices, dosimetry, and respiratory protection), radiological monitoring, radiological protection instrumentation, and radiological protection recordkeeping. Training is provided to all site personnel commensurate with the work to be performed according to Chapter 6 of SCD-6 (SRS, 2018) and Chapter 6 of Manual 5Q (SRS, 2022b). The establishment of goals, their periodic review, and comparison with actual data are methods used for tracking progress toward the ultimate purpose of the ALARA program, reducing exposures to as low as reasonably achievable. The radiological work permit program visual survey data system and associated ALARA reviews provide a base of historical information. Manual 5Q (SRS, 2022a) and SCD-6 (SRS, 2018) describe ALARA methods incorporated into the preplanning of tasks and development of procedures. To establish a rigorous and frequent review of the radiological protection program's performance against challenging goals, a network of review and approval committees is used to ensure adequate oversight by senior management (SWM, 2021). More detail is provided in the *Savannah River Site Solid Waste Management Facility Documented Safety Analysis* (SWM, 2021).

Third, the point of compliance for the ELLWF PA is chosen to be the point of highest calculated dose or concentration occurring after the IC period at a distance outside the 100-meter POA surrounding the DUs. GW and air dispersion modeling results indicate that the location of highest dose or concentration is near the outer edge of the 100-meter POA. However, the SRS Land Use Plan (SRS, 2014a) states that the current SRS boundaries will remain unchanged, meaning that no MOP will have unrestricted access to the ELLWF. Because the ELLWF is located approximately 7 miles east of the nearest SRS boundary (far beyond the 100-meter POA), and GW potentially impacted by ELLWF releases is completely intercepted by UTR Creek, the PA results are substantially more protective of a MOP than is required under the SRS Land Use Plan. ELLWF radionuclide releases to GW and air will undergo considerably more dispersion when the nearest access point to the ELLWF is the site boundary, rather than the 100-meter POA.

Fourth, results presented in Section 9.1 for all exposure pathways reveal that peak doses and concentrations for the deterministic compliance case fall comfortably below the POs during the compliance periods. Table 9-1 reports a maximum, deterministic, all-pathways peak dose of 1.35 mrem/year, which is only 5.4% of the PO of 25 mrem/year. Similarly, Table 9-1 reports a maximum, deterministic peak dose of 0.0266 mrem/year for the air pathway, which is 0.27% of the PO of 10 mrem/year. Finally, the maximum, deterministic peak radon flux is only 0.00793 pCi/m^2/sec compared to a PO of 20 pCi/m^2/sec. Stochastic analyses, based on a Monte Carlo simulation with 10,000 realizations, project that the exceedance probability is only 2.9%, which is a reasonably low likelihood of exceeding any POs during the compliance periods.

In conclusion, the ELLWF PA performs a variety of deterministic, sensitivity, and stochastic analyses to evaluate the impacts of various disposal unit designs and engineered barrier assumptions, in addition to considering peaks well beyond the 1,000-year compliance period. Given the breadth of deterministic and sensitivity cases considered, the inclusion of biases and uncertainties in projected inventories at facility closure, and the fact that peak doses and concentrations for all exposure pathways during the compliance period are comfortably below POs, it is concluded that a quantitative ALARA analysis is not necessary for the ELLWF PA.

1.10. OTHER REQUIREMENTS

The 1993 Federal Facility Agreement (FFA) for SRS (U.S. DOE, 1993a), a tri-party agreement between U.S. DOE, U.S. EPA, and SCDHEC, integrates CERCLA and RCRA requirements to achieve a comprehensive remediation strategy and to coordinate administrative and public participation requirements. The FFA governs remedial actions, sets annual work priorities, and establishes milestones for cleanup. SRS conducts remediation and closure activities identified in the FFA in accordance with applicable regulations (ASER, 2021).

During FY2000, the Parties approved the Land Use Control Assurance Plan (LUCAP) for SRS and signed its associated Memorandum of Agreement. The LUCAP is updated periodically to include additional approved unit-specific Land Use Control Implementation Plans (LUCIPs). The unit-specific LUCIPs detail how SRS will implement, maintain, and monitor the land use control (LUC) elements of the selected remedy to ensure that the remedy remains protective of human health and the environment (SRNS, 2020b).

A unit-specific LUC was not part of the interim remedy at the ELLWF (ST01 to ST05) Operable Unit (OU). The ELLWF OU is currently in the operational phase, and an OU-specific LUC is deferred until final closure of the entire ELLWF OU. SRS facility security and administrative controls that restrict unauthorized access to this operating facility were not previously recognized as part of the interim remedies. The FFA Annual Progress Report list of LUC Units at SRS was revised (SRNS, 2017b) to include the ELLWF OU to recognize SRS facility security and administrative controls that restrict unauthorized access as long-term protective of human health and the environment (SRNS, 2020b).

In September 2007, U.S. DOE submitted a revised version of Appendix C, "RCRA/CERCLA Units," of the FFA for FY2008 that included ELLWF. Conditions of the U.S. EPA acceptance of the use of the CERCLA Off-Site Rule (40 CFR § 300.440) included the following:

- U.S. DOE will provide a milestone date for submittal of an Interim Record of Decision (IROD) that will address interim cover requirements for an operationally closed ST (i.e., group of five individual STs).
- Additional closure milestones will be included in future revisions of Appendix E of the FFA as additional groups of five STs are operationally closed.
- Detailed design requirements for the interim cover, which will consist of an adequate amount of soil and a high-density plastic cover to promote runoff and limit water infiltration, will be presented in the Remedial Action Implementation Plan (RAIP).
- It is anticipated that each subsequent ST interim closure will refer to the same IROD and RAIP.
- As each interim closure is completed, an Interim Remedial Action Completion Report describing construction details will be prepared and submitted.

At the conclusion of the operational period for the ELLWF, a ROD will be issued that addresses the final closure of the facility (U.S. EPA, 2008).

1.11. LAND USE AND INSTITUTIONAL CONTROLS

The ELLWF is located near existing DOE waste disposal facilities and mission-critical operational facilities at SRS. The ELLWF site and surrounding lands will remain under DOE control and within DOE SRS boundaries for the foreseeable future (SRS, 2014a). Assumed POAs for the ELLWF PA assume a 100-year IC period and do not take credit for the existence of land use or other ICs beyond 100 years post-closure. As such, the likelihood that U.S. DOE or successor federal agencies will maintain control of closed waste management facilities within SRS lands is considered as an aspect of defense-in-depth for the ELLWF disposal system.

1.12. SUMMARY OF KEY ASSUMPTIONS

This section summarizes the key assumptions in the PA that are important to the projected performance of the ELLWF with specific emphasis on assumptions related to key uncertainties or data gaps that will be addressed as part of the maintenance process or will need to be protected in design, operating, or closure documents. Assumptions related to design, operations, and closure that need to be protected by SWM Operations and transferred to the closure and IC authority are identified and will be communicated to SWM and captured in their designs and operating procedures, as appropriate. Where specific key assumptions are associated with uncertainties or data gaps that will be addressed as part of the PA maintenance process, the implications of the uncertainty, the approach for managing the uncertainty, and the required actions are explained. The significance of key assumptions to the controlling pathways or scenarios analyzed is also explained, where applicable.

Table A-4 in Appendix A provides a complete detailed listing of key assumptions relevant to this PA.

1.12.1. Land Use

Active Institutional Control Period (Sections 2.1.1.3 and 2.2.1.2)

Inadvertent human intrusion is not considered possible during the operational and IC periods because of the presence of facility security. After the 100-year IC period, however, IHIs are assumed to drill wells for water or to build a home with a 10-foot-deep basement within the ELLWF footprint. The *Savannah River Site Land Use Plan* (SRS, 2014a) assumes that the entire site will be owned and controlled by the federal government for periods of time longer than the assessment period. However, for the purpose of this ELLWF PA, no federal protection is assumed beyond a 100-year period of IC. The 100-year IC period in this PA is assumed to commence in calendar year 2065 at interim closure.

Post-Institutional Control Period (Sections 2.2.2.10.2 and 2.2.3.7)

After the IC period ends and the final closure cap is installed in calendar year 2165 (final closure), institutional controls and memory are lost, and inadvertent human and biotic intrusions are possible for some ELLWF DUs. For example, in the IHI basement construction scenario, an individual is exposed to waste by building a home over the disposal site with a 10-foot-deep basement extending into the waste zone (Smith et al., 2019). The IHI well drilling scenario is credible for some ELLWF DUs because of the absence of engineered barriers that will preclude penetration using typical site-specific drilling techniques (Smith et al., 2019). On the contrary, it is assumed that exposure pathways caused by bio-intrusion into the waste layer by burrowing animals bringing contaminated soil to the surface are precluded because of the presence of an erosion barrier in the final closure cap design, the depth of the waste layer relative to typical burrow depths, and the population densities of burrowing species likely to reside on the SRS.

1.12.2. Climate (Sections 3.3.2 and 3.5.2.10 and Table 3-1)

The PA model parameters most likely to be impacted by changes in the long-term climate are infiltration, GW flow, and depth to the water table. These parameters will reflect natural variation over long periods as a function of the prevailing climate conditions. Leigh (2008) describes a study of the long-term climate of the Atlantic Coastal Plain of the Southeastern United States based on pollen and paleochannel records. Leigh (2008) determined that approximately 8,200 years ago the local climate transitioned from a cooler, dryer period to the current state, which has remained relatively unchanged ever since. Based on this long period (8,200 years) of relatively steady climate conditions and to be consistent with the recent Saltstone Disposal Facility PA (Savannah River Remediation, 2020), the ELLWF PA also assumes that local climate conditions will continue to remain relatively unchanged throughout the compliance period. However, infiltration rates and GW conditions associated with alternative climate conditions are evaluated as part of the sensitivity and uncertainty analyses for each type of DU.

Short-term changes (e.g., seasonal, annual fluctuations) in infiltration or aquifer depth are not considered in the models due to the extended time ranges involved. Instead, steady-state modeling is used to approximate the infiltration rates into the system as well as the long-term GW conditions.

1.12.3. Radionuclide Screening

Groundwater and Inadvertent Human Intruder Pathways (Section 2.3.7)

A projected possible inventory of 1,252 radionuclides (ICRP, 2008; U.S. DOE, 2011a) is considered, which includes 177 radionuclides that are currently tracked by SWM plus 1,075 additional radionuclides that may or may not be disposed in the future. A tiered screening process is used based on simple, conservative modeling to rule out radionuclides that cannot reasonably contribute significant risk to receptors. The remaining radionuclides that are not ruled out undergo complete multi-dimensional modeling in the PA. Steps in the tiered screening process include: (1) a pre-screening step based on the projected 2065 inventories of 1,252 radionuclides; (2) Tier 0 eliminates radionuclides based on radiological aspects and process knowledge; (3) Tier 1 eliminates radionuclides based on GW and IHI screening (very conservative); (4) Tier 2 eliminates radionuclides with simple, but bounding, GW transport modeling (conservative).

Air Pathway Analysis (Section 2.3.8.1)

A four-step, tiered screening approach is employed that is similar to tiered approach for the GW and IHI pathways as follows:

- **Tier 0:** Eliminate radionuclides based on radiological aspects and process knowledge (Section 2.3.7.1)

- **Tier 1:** Eliminate radionuclides based on the Periodic Table of the Elements
- **Tier 2:** Eliminate radionuclides based on Henry's Law
- **Tier 3:** Eliminate radionuclides based on instantaneous release dose

Radon Flux Analysis (Section 2.3.8.2)
A three-step, tiered screening approach is used that is similar to the tiered approach for the GW and IHI pathways as follows:

- **Tier 0:** Eliminate radionuclides based on radiological aspects and process knowledge (Section 2.3.7.1).
- **Tier 1:** Eliminate radionuclides that are not within a decay chain with Rn-222 as a progeny.
- **Tier 2:** Eliminate radionuclides based on Rn-222 production and release.

1.12.4. Facility Timeline and Closure

Baselined Disposal Units (Section 2.2.1)
The total number of current and future DUs baselined for this PA is 33 (seven closed, 11 open, and 15 future). The 33 baselined DUs consist of 20 STs (five closed, six open, and nine future), nine ETs (one closed, two open, and six future[6]), one LAWV (open), one ILV (open), and two NRCDAs (one closed and one open).

E-Area Low-Level Waste Facility Timeline (Section 2.2.1)
The operational period in the current PA is assumed to be 71 years, with ELLWF radiological waste disposal operations commencing on September 28, 1994, following placement of the first low-level waste box inside the LAWV. The operational timeline for the ELLWF comprises three closure phases: operational, interim, and final. Operational closure dates vary by DU with the latest operational closure date being September 30, 2065. Interim closure dates are September 30, 2040, for those DUs that are closed by this date and September 30, 2065, for all remaining DUs. Final closure will occur on September 30, 2165, with installation of the final closure cap.

Operational Closure (Section 2.2.1.1)
Operational closure will be conducted as DUs are filled and is specific to each type of DU. EM operations are anticipated to conclude in the year 2065 in alignment with the SRS Nuclear Materials Management Plan FY2016-2030 (SRS, 2016). STs and the nine existing CIG trench segments have or will have operational stormwater runoff covers installed at operational closure to optimize stormwater runoff and limit infiltration into the underlying waste zone. ETs will utilize soil covers for operational closure to optimize stormwater runoff and minimize infiltration into the underlying waste zone. Operational closure of the two vaults will entail sealing exterior vault openings and sumps with concrete for the LAWV and grouting the headspace in each cell and installing a reinforced concrete roof slab and waterproof membrane for the ILV. Due to the water- and air-tight nature of the welded steel casks and bolted, gasketed steel containers,

[6] ET04 became operational in January 2022; however, at the time the PA conceptual models and timelines were frozen in 1Q2021, ET04 had not yet received its first waste package and is therefore treated as a future unit in this PA.

operational closure of the NRCDAs simply entails carefully placing the casks and containers on the gravel pads and backfilling around them with soil as needed for radiation shielding.

Interim Closure (Section 2.2.1.2)

Interim closure begins a nominal 100-year period of IC when close to 100% of the ELLWF is filled with waste and is specific for each type of DU. The primary objectives of interim closure are to limit infiltration during the 100-year IC period, and to prepare the facility for transition to final closure by allowing time for waste container corrosion. The 100-year interim closure period is assumed to commence on September 30, 2065, with a subset of trenches being closed on September 30, 2040 (all STs and ETs filled by that date). STs, CIG trench segments, and ETs will have interim runoff covers installed for interim closure to optimize stormwater runoff. No additional interim closure actions are anticipated for the LAWV, ILV, and NRCDAs beyond those for operational closure. Both the operational stormwater runoff and interim runoff covers will be maintained and subsidence-induced damage to the covers will be appropriately repaired.

Dynamic Compaction of Slit and Engineered Trenches (Section 2.2.1.2)

Dynamic compaction of STs and ETs will be performed at the end of the 100-year IC period when the efficiency of subsidence treatment is greater due to container corrosion and a corresponding loss of structural strength. The stabilization measures taken are assumed to sufficiently consolidate the underlying waste layer and eliminate subsidence except in the presence of "non-crushable" containers (i.e., containers that are not structurally stabilized after dynamic compaction but are assumed to catastrophically collapse immediately upon installation of the final closure cap, creating localized subsidence areas in the cap surface). Dynamic compaction is prohibited over SWF areas (such as those containing M-Area glass and ETF Carbon Columns) that have been specifically designated not to undergo active waste stabilization measures.

Final Closure (Section 2.2.1.3)

Final closure of all DUs in the ELLWF will take place in 2165 at the end of the 100-year IC period (SRS, 2016). Final closure will consist of site preparation and construction of an integrated closure system designed to minimize moisture contact with the waste zone and to provide an IHI deterrent. The integrated closure system will consist of one or more multilayer soil-geomembrane closure caps installed over all the DUs coupled with an integrated drainage system.

1.12.5. Final Closure Cap Degradation

Closure Cap Maintenance (Section 2.2.2.10.1)

Following installation of the final closure cap, no closure cap maintenance will be performed other than that required to establish the vegetative (Bahia grass) cover. A bounding assumption in this PA is that the hydraulic performance of the closure cap begins to degrade immediately upon installation because of long-term natural degradation mechanisms. Of these mechanisms, the formation of holes in the composite geomembrane/GCL barrier is the most consequential with respect to infiltration through the waste zone. The actual onset and rate, respectively, of HDPE geomembrane degradation is expected to be much later and slower than assumed in this PA. The total estimated service life of the HDPE geomembrane could range from roughly 2,000 to 3,500 years (Tian et al., 2017) as discussed in Section 3.4.1.7.3.

Waste Zone Subsidence (Section 3.4.1.2)

Waste zone subsidence as a closure cap degradation mechanism is central to the conceptual designs of the infiltration, flow, and transport models (both deterministic and stochastic) for all ELLWF DUs except the NRCDAs. For STs, ETs, and the CIG trench segments, waste zone subsidence will impact DU performance during the 1,000-year compliance period. For the LAWV and ILV, subsidence of the closure cap due to structural collapse of the concrete vault covers will occur beyond the compliance period.

Vegetative Cover (Section 3.4.1.3)

A vegetative cover will be established on the final closure cap to promote runoff, control soil erosion, prevent the initiation of gullying, and promote evapotranspiration. The initial vegetative cover will be a persistent turf grass consisting predominately of Bahia (*Paspalum notatum*). After installation of the interim cover in 2065, a 600-foot-wide treeless Bahia grass buffer zone will be actively maintained on all sides of the interim cover. For PA modeling purposes, it is assumed that at the end of IC in 2165, mature pine trees will exist at the outer edge of the 600-foot buffer zone; however, no pine trees will have become established within the ELLWF active maintenance area. This means that the nearest mature pine tree stand is at least 600 feet from the closure cap upon its installation in 2165. Once dynamic compaction of trenches is complete and the final closure cap is installed, the 1,000-year post-closure compliance period will begin, during which time no active facility maintenance will be performed.

Erosion (Section 3.4.1.4.1)

Erosion of the topsoil and upper backfill layers due to non-PMP (probable maximum precipitation) rainfall events and shallow animal burrowing is included as a closure-cap-wide degradation mechanism in the infiltration model for both a Bahia grass and pine forest vegetative cover. While limited erosion is expected to occur over the 10,000-year assessment period considered in this PA, it is not expected to significantly impact infiltration estimates. Acute erosion of the closure cap, caused by deep animal burrowing (e.g., feral hogs) or a PMP event that initiates gully formation, is expected to be localized such that the overall impact to closure cap performance will be minimal.

Erosion Barrier (Section 3.4.1.5)

Potential biological degradation mechanisms include tree root penetration and burrowing animals. Pine tree roots are assumed to freely penetrate the erosion barrier stone (upper bounding assumption). As such, root penetration is considered a viable closure cap degradation mechanism in the infiltration model for the erosion barrier as well as for the underlying LDL and GCL. The erosion barrier will be designed to act as a barrier to burrowing animals and feral hogs, which includes selection of the material used to fill the void space of the erosion barrier stone. For this reason, animals burrowing/rooting into and below the erosion barrier is not considered a viable closure cap degradation mechanism for the infiltration model.

Lateral Drainage Layer (Section 3.4.1.6)

Because pine tree roots are allowed to freely penetrate the erosion barrier and the presence of the geotextile filter fabric is ignored in the infiltration model (upper bounding assumptions), the LDL is assumed to progressively silt-in with colloidal clay that migrates from the overlying upper backfill layer, thereby steadily reducing its saturated hydraulic conductivity over time. Silting-in of the LDL is included as a closure cap degradation mechanism in the infiltration model.

HDPE Geomembrane (Section 3.4.1.7)

Antioxidant depletion of the HDPE geomembrane will occur via oxidation of the antioxidants and diffusion out of the polymer. Thermal oxidation of the geomembrane will occur after depletion of the antioxidants and it is assumed to occur in conjunction with tensile stress cracking, which will cause degradation of the geomembrane. The number of holes in the geomembrane over time is calculated based on methodologies developed by Mueller and Jakob (2003) for antioxidant depletion and by Needham et al. (2004) for turning the combined set of three degradation mechanisms into a defect (hole) generation rate. Intact HDPE geomembranes preclude root penetration and cause the roots to follow laterally atop the geomembrane surface; however, it is assumed that roots can penetrate the geomembrane in locations where holes have already formed due to other degradation mechanisms.

Geosynthetic Clay Liner (Section 3.4.1.8)

The GCL will be overlain by a HDPE geomembrane. Intact HDPE geomembranes preclude root penetration; however, it is assumed that roots can penetrate the GCL at locations where holes have already formed in the geomembrane due to other degradation mechanisms. The infiltration model also pessimistically assumes that sodium bentonite is converted to calcium and magnesium bentonite after only 100 years, resulting in an increase in the saturated hydraulic conductivity of the GCL from 5.0E-09 cm/s for the first 100 years to 5.0E-08 cm/s thereafter (Section 3.4.1.8.4).

1.12.6. Inventory

True Versus Reported Inventory (Section 2.3.5)

When there is no identifiable bias in reported values, the true inventory equals the reported inventory. However, when there is identifiable and quantifiable bias, the true inventory is equal to the reported inventory times a bias factor. For example, the true inventory of radionuclides in waste containers characterized by the Dose-to-Curie (DTC) method is approximately 50% of the reported inventory. When there is identifiable but <u>not</u> a quantifiable bias, the true inventory is equal to 90% of the reported inventory.

Bias Factor (Section 2.3.5)

A default bias factor is assigned to all calculation methods. The RAD weight or volume method has either a 100% bias factor if it is an underlying DTC measurement or 0% bias factor if it is a Smear-To-Curie (STC) measurement. The default bias for the Rad Weight (RAD) method is randomly selected using a weighting factor based on the distribution of DTC and STC measurements in CWTS. If possible, this bias factor is overridden for prioritized packages.

Measurement and Characterization Uncertainties (Section 2.3.5.3)

The reported inventory of an isotope is the product of the measured activity of each waste cut or container[7] and the fraction of activity associated with that isotope in the waste stream of that waste cut or container. It is assumed that the uncertainties in the measurement and characterization fractions are independent, random, and normally distributed; therefore, the uncertainty values can be added in quadrature. Default measurement and fraction characterization uncertainties are assigned. For prioritized waste packages, the default uncertainties are overridden and updated.

Total Inventory Uncertainty (Section 2.3.5.3)

The total inventory in a DU is the sum of the individual reported isotope inventories. The uncertainties in the individual reported inventory values are also assumed to be independent and random and may be added in quadrature. Inventory uncertainty at closure is assumed to be the same as at present.

Prioritization in Determining Inventory Uncertainties (Section 2.3.5)

H-3, C-14, Sr-90, Tc-99, I-129, and Np-237 are assumed to be the isotopes of most concern in this PA, and waste containers with the highest activity of these six isotopes are the most important for consideration of potential dose. Therefore, highest priority is given to determining the uncertainty and bias in the waste streams and waste cuts of these containers.

1.12.7. Slit and Engineered Trenches

Waste Forms (Section 2.2.3 and 2.2.4)

Most LLW in STs and ETs is treated in the PA flow and transport models as a generic waste form (e.g., job control waste in B-25 boxes), taking no credit for holdup of contaminants. There are also two general subcategories of special waste forms (SWFs) for specific ST and ET DUs where credit is taken for the waste form or disposal container: (1) those that rely on sorption properties alone (e.g., ion exchange resins) to control contaminant release; (2) those that rely on the hydraulic integrity of the container, other properties of the waste form, or a combination of both to control release. Examples include cementitious waste forms, reactor process heat exchangers, and the heavy water component test reactor. The PA models include SWFs for specific DUs to avoid consuming a large fraction of (or even exceeding) the allowable inventory for specific radionuclides.

Operational Covers (Sections 2.2.3.6 and 2.2.4)

During the operational period for STs, water infiltration through the waste is minimized by keeping the open ST area to a minimum and by adding a 4-foot-thick OSC, which is built up and graded to provide positive drainage off the trench and away from the working face. Upon closure of an individual ST or group of STs, an HDPE (or equivalent) operational stormwater runoff cover is installed at ground surface and integrated with a drainage system to remove surface runoff from

[7] Waste that comes from the same location, job, task, etc. and has been characterized using the same method is part of a *waste stream*. Individual bags of waste, items, or other components, such as soil or rubble, are called *waste cuts*. One or more waste cuts are placed in a *waste container* or *waste package*. These waste cuts may be from one or more waste streams, and the containers may have additional nested containers (Section 2.3.5.1)

the site. Operational closure of ETs is conducted in stages. When enough B-25 boxes are placed, stockpiled clean soil is bulldozed in a single lift over some of the completed rows to produce a minimum 4-foot-thick, clean, soil layer on top. Unlike for STs, a low-permeability stormwater runoff cover is not installed over the clean, 4-foot-thick ET soil cover at operational closure.[8]

Subsidence Potential (Sections 2.2.3.2, 2.2.4.2, and 4.4.8.1)

The subsidence potential for STs and ETs is estimated to be 4.9 feet[9] and 13.5 feet, respectively, after operational closure. To minimize future subsidence of the final closure cap, limits are imposed on the disposal of non-crushable containers with significant void space. Non-crushable packages account for less than 5% of the total ST and ET footprint area of open and closed units. Since PA2008, a limit of 2% non-crushable packages has been established for new STs and ETs and for open STs and ETs containing less than 2% non-crushable packages.

1.12.8. Low-Activity Waste Vault and Intermediate-Level Vault

Waste Forms (Sections 2.2.5.3 and 2.2.6.3)

All waste in the LAWV and most waste containers in the ILV are treated in the PA flow and transport models as a generic waste form. Generic waste form inventories are uniformly distributed throughout the waste zone. At present, only metal containers, primarily B-25 boxes, are disposed in the LAWV. No SWFs are disposed in the LAWV; however, there are two general subcategories of SWFs assumed for the ILV as described above for STs and ETs (Section 1.12.7). ILV SWFs include K- and L-Basin ion exchange resins (for retaining C-14, I-129, and Tc-99), ETF activated carbon, and tritium-producing burnable absorber rods (TPBAR) waste. In addition to the waste containers, the reinforced-concrete roofs, walls, and floors of the LAWV and ILV provide secondary containment, which delays contact of infiltrating water with the waste while the concrete is intact and limits water contact with the waste once cracks begin to form in the concrete.

Operational Timeline (Sections 4.5.3.2 and 4.6.3.1)

LAWV operations commence on September 28, 1994, when the ELLWF is opened. ILV operations begin one year later on September 28, 1995.

Degradation of Hydraulic Properties (Sections 4.5.3.6 and 4.6.3.5)

The vault roof and walls will experience limited non-through static cracking when the final closure cap is applied, resulting in increased infiltration through the vault roof (Jones and Phifer, 2007). The concrete hydraulic properties are assumed to fully degrade over a 500-year period following the end of the 100-year IC period when the final closure cap is placed.

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[8] Because STs receive offsite CERCLA waste, a regulatory agreement reached between SRS and SCDHEC requires a low-permeability stormwater runoff cover to be installed over the surface of the OSC at operational closure. ETs do not receive CERCLA waste; therefore, an additional low-permeability cover upon operational closure is not required.

[9] The waste zone height before dynamic compaction for STs (and ETs) is 16 feet. Wohlwend and Aleman (2020) assumed a thickness of 8.87 feet for the ST hybrid waste zone after dynamic compaction per PA2008. The thickness after dynamic compaction was subsequently revised to 11.1 feet for the final PORFLOW ST and ET VZ model production runs (Nichols and Butcher, 2020). Subsidence potential for ST = 16.0 feet – 11.1 feet = 4.9 feet.

Structural Stability (Sections 4.5.3.1 and 4.6.1)

Vault collapse occurs when the roof fails. LAWV and ILV structural failures are assumed to occur after 2,805 years (Carey, 2005) and 6,703 years (Peregoy, 2006b), respectively. The estimated maximum subsidence potentials for the LAWV and ILV are 21 feet and 17 feet, respectively (Nichols and Butcher, 2020). Increased infiltration will occur through the portions of the subsided closure cap overlying the collapsed vaults.

Inadvertent Human Intrusion (Sections 2.2.5.7 and 2.2.6.7)

During the post-closure period, the reinforced-concrete vault alone provides a significant barrier to intrusion from well drilling and basement excavation activities. The reinforced-concrete roofs are considered effective barriers against acute well drilling and basement construction IHI scenarios throughout the 1,000-year period of performance. Normal residential construction and well-drilling equipment used in the vicinity of SRS is not capable of penetrating the concrete roof structure (Smith et al., 2019).

1.12.9. Naval Reactor Component Disposal Areas

Waste Placement (Section 4.7.8.5.1)

The entire waste mass is assumed to be placed at the time of first burial for both NRCDAs. Radionuclide decay of waste and corrosion of the outer container are assumed to start from the date the pad receives waste.

Waste Forms and Corrosion (Section 4.7.8.5.1)

The NR casks are welded shut. Corrosion from inside the cask to the outside is expected to be insignificant due to the negligible amount of water present in the casks before being welded shut. Taking these disposal conditions into consideration, corrosion is estimated to penetrate the welds after 750 years of disposal allowing water to enter the disposal casks via small holes in the welds (i.e., hydraulic failure) and enabling radionuclides from inside the cask to be released to the surrounding waste zone. Conversely, the bolted NR containers are sealed hydraulically using gaskets and are assumed to potentially leak much earlier than the casks.

Interim Cover Material (Section 4.7.8.5.1)

Immediate NR waste burial is under an interim soil cover, ignoring the open-air period. This assumption is bounding in two respects. First, carbon-steel corrosion rates in air are at or below the low end of corrosion rates in soil for atmospheric conditions representative of SRS (Wohlwend and Butcher, 2018). Second, assuming soil instead of CLSM (a flowable soil-cement material used as backfill) for the interim cover material will lead to higher corrosion rates of carbon steel due to the impact of the slightly acidic soil moisture.

Hydraulic Failure (Section 4.7.8.5.1)

Hydraulic failures of bolted containers and welded casks are, in fact, distributed over time. However, to simplify the analysis, all casks and bolted containers are conservatively assumed to fail simultaneously at the times provided in the timelines for NR07E and NR26E in Table 4-77 and Table 4-78, respectively. Likewise, release of radionuclides from hydraulically failed casks and containers is assumed to occur at these same times.

Structural Stability (Section 4.7.8.5.1)

The robust, welded NR casks are assumed to be structurally stable for thousands of years after placement on the NRCDA pads based on estimated corrosion rates (Wohlwend and Butcher, 2018). Due to the robust nature of NR container and cask designs, and the density of the internal component/equipment they contain, significant subsidence is not considered feasible for the NRCDAs.

1.12.10. Special Waste Forms

Special Waste Form Model Implementation (Section 4.2)

SWFs are a category of waste that have the potential to consume a large fraction of or even exceed the allowable inventory for specific radionuclides if containment credit is not taken for the waste form or disposal container. For certain SWFs, deterministic PORFLOW models are created to explicitly account for container aspects associated with both simple and complex SWFs. Implementation methods for simple SWFs include effective K_d, delayed release, solubility-controlled/diffusion-controlled release, tall boxes, and CIG trench segments. The three complex SWFs include the heavy water components test reactor, the reactor process heat exchangers, and 232-F concrete rubble.

Inventory Placement (Section 4.2)

Placement of SWF inventory is assumed to occur on the date when each trench unit is first opened to waste, which is consistent with the modeling assumption for generic waste (i.e., instantaneous disposal of all inventory at the start of operations for each trench unit). Placement of future SWF inventory that is targeted for disposal in future trenches is assumed to be placed on September 30, 2021.

Components-in-Grout Trench Segments – Subsidence Potential (Section 4.2.1.2)

Four CIG trench segments, CIG-4 through CIG-7, contain components or low-density waste that are not filled with grout and are estimated to have a maximum of 7 feet of subsidence potential (Nichols and Butcher, 2020). Reinforced concrete mats were not placed over CIG-4 through CIG-7 after final waste placement. CIG-8 and CIG-9 also have subsidence potential; however, a reinforced concrete mat has been placed over these two segments. For CIG-4 through CIG-7, a bounding subsidence base case assumes that subsidence occurs immediately at the end of IC. For CIG-8 and CIG-9, the best estimate subsidence case assumes that subsidence occurs 200 years after the end of IC. As a sensitivity case, the best estimate subsidence scenario is explored for CIG-4 through CIG-7 as well, where a reinforced concrete mat is introduced in the models even though one is not currently in place.

Components-in-Grout Trench Segments – Cementitious Material Degradation (Section 4.2.1.3)

Physical degradation of the cementitious materials is represented by step-changes at predetermined times corresponding to the operational, interim closure, and final closure periods. Most notably, the CIG trench segments degrade from an intact CIG SWF to the degraded SWF at model Year 40, when the hydraulic conductivity increases by nine orders of magnitude. At model Year 371 (i.e., 200 years after the end of IC), the CIG SWF is considered fully degraded. In addition to degradation of physical properties, chemical degradation occurs as chemical constituents are leached from cementitious material zones, leading to a reduction in the K_d values for the radionuclide contaminants. The degradation of cementitious materials proceeds through four stages from young (Stage I) to old (Stage III) and is tracked through time using the number of pore volumes of water that have passed through the material. Beyond Stage III, the enhanced chemical attenuation of the cementitious materials is assumed to dissipate, and K_d values revert to those for the surrounding soil.

1.12.11. Groundwater Flow and Transport Model

PORFLOW Model (Table 3-1 and Appendix A)

Time-step and mesh sizes are adequate. Uncertainty introduced by model parameterization is not investigated. Numerical dispersion is not significant.

Radioactive Decay (Table 3-1 and Appendix A)

The time lag between characterization and disposal is typically short enough that decay of disposed radionuclides to potentially more problematic daughters during the time lag is ignored. Assuming secular equilibrium for decay chain members with half-lives of less than one year is considered adequate. Some short-lived daughters may not remain in secular equilibrium because they are transported at a different rate than the parent radionuclide.

Water Table (Table 3-1 and Appendix A)

Depths to the water table do not change from the base case values throughout the analysis period.

Flow Fields (Table 3-1 and Appendix A)

A series of steady-state flow fields is adequate in lieu of a transient flow analysis.

Infiltration Model (Table 3-1 and Appendix A)

A one-dimensional (1-D) infiltration analysis is adequate. Annual-average rainfall remains constant throughout the simulation period, and there is no impact from climate change.

1.12.12. Air Pathways Analysis

Atmospheric Release Model Simplifications (Section 3.6.1.1)

Zero-flux boundaries are assumed on the sides and base of the 1-D stack of GoldSim® computational elements. The water phase is assumed to be stationary, when in fact it is infiltrating slowly downward. Vapor-phase diffusion is assumed to occur only vertically to the ground surface while some diffusion will occur laterally and vertically downward. The flow field is assumed to be isobaric and isothermal. Short-term oscillations in temperature and pressure are thought to have a long-term net-zero effect.

Diffusion (Section 3.6.1.1)

Air is the medium through which all diffusion is assumed to occur. Diffusion in the aqueous phase is ignored because the diffusion rates in water are negligible compared to rates in air. Sorption to solid phases is considered.

Operational Period (Section 3.6.1.1)

Releases from the waste zone do not occur until operational closure. Radioactive source decay and diffusive air releases that occur during operations are not accounted for in the simulations; therefore, the initial source term is slightly larger than actual. Operational closure occurs on the same date for all DUs. Peaks in surface flux tend to occur simultaneously, which has a negative impact on plume overlap.

Closure Cap (Section 3.6.1.1)

The erosion barrier is assumed to be the top layer of the closure cap in the flux calculations. The 6-inch topsoil and 30-inch upper compacted backfill layers are assumed to have eroded, thereby reducing the diffusive length by 36 inches.

Dose Release Factors (Section 3.6.2.2.4)

Dose release factors (DRFs) are calculated for the maximally exposed individual (MEI) by representing DUs as a point source; adopting ground-level release of radionuclides above the DU; assuming radionuclide release over a period of one year; and assuming the receptor stands in the plume centerline and receives continuous exposure over the entire year.

Cementitious Materials (Section 3.6.2.3.1)

C-14 is saturation-limited in cementitious material. For systems involving cementitious materials, the ARM imposes a constant $^{14}CO_2$ concentration in the vapor-filled pore space of the cementitious medium.

Plume Overlap (Section 3.6.2.3.1)

100% spatial overlap of atmospheric plumes is assumed at the site boundary and 100-meter POAs.

1.12.13. Radon Flux Analysis Assumptions

Emanation Factor (Section 3.6.3.2.3)

Because the exact form of Ra-226 at a specific time is unknown, the radon flux analysis does not use an emanation factor and assumes all Rn-222 produced is released from soil to the gas phase.

Waste Placement (Section 3.6.3.2.1)

Waste is assumed to be uniformly placed in DUs both spatially and temporally and is introduced 25 years before radon release from the waste zone is assumed to commence. This bake time allows for decay of Rn-222-producing parents as well as the build-up of Rn-222 without accounting for diffusive air releases that will occur during operations.

Radon Parent Mobility (Section 3.6.3.2.1)

Radon parents are assumed to be stationary. In actuality, the parent radionuclides exist in the solid phase and therefore do not migrate upward through the air-filled pore space; however, they can leach and be transported downward from the waste zone by pore water movement. This potential downward migration of the parent radionuclides is neglected in the ARM.

1.12.14. Exposure Pathways and Dose

Human Receptor (Section 3.7.1)

At SRS, the representative person is based on an SRS-specific reference person at the 95th percentile of national usage and exposure data and is used as a replacement for the maximally exposed individual in compliance dose calculations. For the GW and IHI exposure pathways in this PA, usage and exposure parameters for a typical person at the 50th percentile are employed in the best estimate, deterministic, sensitivity, and stochastic calculations of limits and doses. The usage and exposure parameters are fixed at that their typical person settings for all dose calculations.

Dominant Exposure Pathways (Sections 3.7 and 3.7.2)

The primary mechanism for transport of radionuclides from the ELLWF to the MOP is expected to be leaching to GW, GW transport to the 100-meter POA, and subsequent internal or external human exposure. The primary water source for the MOP exposure pathways is a well drilled into aquifers contaminated by the ELLWF. In the GW well-dose analyses, doses are calculated using water from a well for domestic purposes (e.g., drinking water, irrigation). The main transport mechanism for the IHI is direct intrusion into the waste zone or excavation of areas near the waste zone. Intrusion scenarios are assumed to not occur (and the DOE all-pathways PO does not apply) until the end of the 100-year IC period. Surface water and recreational pathways were evaluated in the 2010 SRS CA (SRNL, 2010) and are not considered in SRS PA analyses.

Basis for Public-Release Pathways (Sections 3.7.2.2)

Table 3-49 provides a list of ELLWF exposure pathways identified as candidates for detailed analyses in this PA. The following key assumptions are made for pathways related to the MOP, "Resident Farmer" scenario with well water as the primary water source:

- For contaminants in a stabilized system that have not been disturbed through intrusion, the release mechanism to the MOP is leaching of stabilized contaminants to GW. Well drilling is not a release mechanism because any well drilling will occur outside the 100-meter POA.
- Because a substantial water source is absent at the well site, no consideration is given to pathways connected to water-related commercial activities. Based on the relative proximity of the Savannah River, a man-made body of water will not be created at the MOP resident site.
- The dose associated with dermal absorption of radionuclides is considered insignificant because the expected radionuclide particulate compounds generally absorb poorly into the body. For tritium oxide (12.3-year half-life), estimated residual concentrations in GW are

relatively small, which renders this pathway an insignificant contributor to dose when considered in combination with the short exposure time during showering.

- Water ingested during the relatively short activity of showering is negligible and is not addressed independently. Instead, the impact of showering is addressed with the "Direct Ingestion of Well Water" pathway.

Basis for Inadvertent Human Intruder Pathways (Section 3.7.3.8)

The stabilized contaminant release mechanism for the IHI is inadvertent drilling into trench units. Leaching of stabilized contaminants to GW and use of contaminated GW are credible release mechanisms; however, they are not calculated for the IHI in accordance with the DOE position (U.S. DOE, 2007).

Once erosion of material occurs above the erosion barrier, the bio-intrusion scenario becomes a credible mechanism for contaminant transport. However, the total volume of waste material brought to the surface via this scenario is estimated to be significantly less than the estimated volume brought to the surface by the acute basement construction scenario.

The HDPE geomembrane in the final cover system will cause infiltrating water to pool and flow laterally away from the barrier, providing a readily available water supply for roots above the geomembrane. Evaluations of similar covers by Benson and Benavides (2018) have found no evidence of root penetration into the layers situated below the geomembrane.

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