Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

We put science to work.™

Savannah River National Laboratory®

OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

A U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORY • SAVANNAH RIVER SITE • AIKEN, SC

Exposure Pathways and Scenarios for the E-Area Low-Level Waste Facility Performance Assessment

B. H. Stagich

G. T. Jannik

January 2020

SRNL-STI-2020-00007, Revision 0

SRNL.DOE.GOV

DISCLAIMER

Printed in the United States of America

Prepared for
U.S. Department of Energy

SRNL-STI-2020-00007
Revision 0

Keywords: *Example keywords*

Retention: *Permanent*

Exposure Pathways and Scenarios for the E-Area Low-Level Waste Facility Performance Assessment

B. H. Stagich
G. T. Jannik

January 2020

Prepared for the U.S. Department of Energy under contract number DE-AC09-08SR22470.

REVIEWS AND APPROVALS

AUTHORS:

B. H. Stagich, Environmental Sciences and Biotechnology Date

G. T. Jannik, Environmental Sciences and Biotechnology Date

TECHNICAL REVIEW:

B. T. Butcher, Environmental Modeling Date

APPROVAL:

J. J. Mayer, Manager Date
Environmental Sciences and Biotechnology

EXECUTIVE SUMMARY

In support of the Savannah River Site (SRS) Performance Assessment (PA), the member of the public (MOP) and intruder exposure pathways must be defined to calculate receptor doses. The primary mechanism for transport of radionuclides from the SRS E-Area Low-Level Waste Facility (LLWF) to the MOP is expected to be leaching to the groundwater, groundwater transport to the well at 100-m, and subsequent internal or external human exposure. The main transport mechanism for the inadvertent intruder is direct intrusion into the waste zone or excavation of areas near the waste zone. Leaching to the groundwater and use of the contaminated groundwater are not calculated for the inadvertent intruder in accordance with the DOE position (U.S. DOE 2007). Intrusion scenarios are not assumed to occur, and the DOE All-Pathways performance objective does not apply, until the 100-year institutional control period ends, after which time it is assumed that no active E-Area LLWF facility maintenance will be conducted.

All the potential pathways to the MOP and intruder were evaluated after excluding all pathways related to surface water and recreational activities. Surface water and recreational related pathways are evaluated in the 2010 SRS CA (SRNL 2010). A combination of past studies and calculations using numerical information provided evidence justifying the elimination of pathways from further consideration.

TABLE OF CONTENTS

LIST OF TABLES vii
LIST OF FIGURES vii
LIST OF ABBREVIATIONS viii
1.0 Introduction 1
2.0 Member of the Public (MOP) Exposure Pathways 7
2.1 Scenario with Well Water as Primary Water Source 7
2.2 Basis for Public Release Pathways 7
3.0 Intruder Exposure Pathways 8
3.1 Intruder Release Scenarios 9
3.2 Acute Intruder – Basement Construction Scenario 9
3.3 Acute Intruder – Discovery Scenario 9
3.4 Acute Intruder – Drilling Scenario 9
3.5 Chronic Intruder – Agriculture Scenario 9
3.6 Chronic Intruder – Resident Scenario 10
3.7 Chronic Intruder – Post-drilling Scenario 10
3.8 Bio-intrusion Scenario 10
3.9 Basis for Intruder Pathways 12
4.0 References 13

LIST OF TABLES

Table 1-1. Potential MOP Contaminant Exposure Pathways 3

Table 1-2. Potential Intruder Contaminant Exposure Pathways 4

Table 3-1. Total volume of waste material brought to surface through bio-intrusion and basement construction. 11

LIST OF FIGURES

Figure 1-1. Potential Pathways to Human Exposure for Undisturbed Disposed Low-Level Waste............ 2

LIST OF ABBREVIATIONS

ELLWF	E-Area Low-Level Waste Facility
CA	Composite Analysis
DU	Disposal Units
MOP	Member of the Public
PA	Performance Assessment
SRNL	Savannah River National Laboratory
SRS	Savannah River Site

1.0 Introduction

In support of the Savannah River Site (SRS) Performance Assessment (PA), the member of the public (MOP) and intruder exposure pathways must be defined to calculate receptor doses. The primary mechanism for transport of radionuclides from the SRS E-Area Low-Level Waste Facility (ELLWF) to the MOP is expected to be leaching to the groundwater, groundwater transport to the well at 100-m, and subsequent internal or external human exposure. The main transport mechanism for the inadvertent intruder is direct intrusion into the waste zone or excavation of areas near the waste zone. Leaching to the groundwater and use of the contaminated groundwater are not calculated for the inadvertent intruder in accordance with the DOE position (U.S. DOE 2007). Intrusion scenarios are not assumed to occur, and the DOE All-Pathways performance objective does not apply, until the 100-year institutional control period ends, after which time it is assumed that no active ELLWF facility maintenance will be conducted. Surface water and recreational related pathways are evaluated in the 2010 SRS CA (SRNL 2010) and not considered in the SRS PA analyses.

A general overview of the potential exposure pathways from the undisturbed disposed low-level waste is provided in Figure 1-1. Table 1-1 and Table 1-2 identify the individual assumed pathways and whether quantified dose calculations are required for the individual pathways, for the MOP and intruders, respectively. Table 1-1 and Table 1-2 also identify the individual pathways that are not assumed to occur. The intake and exposure rate factors are provided in *Dose Calculation Methodology and Data for Solid Waste Performance Assessment and Composite Analysis at the Savannah River Site* (Smith et al. 2019).

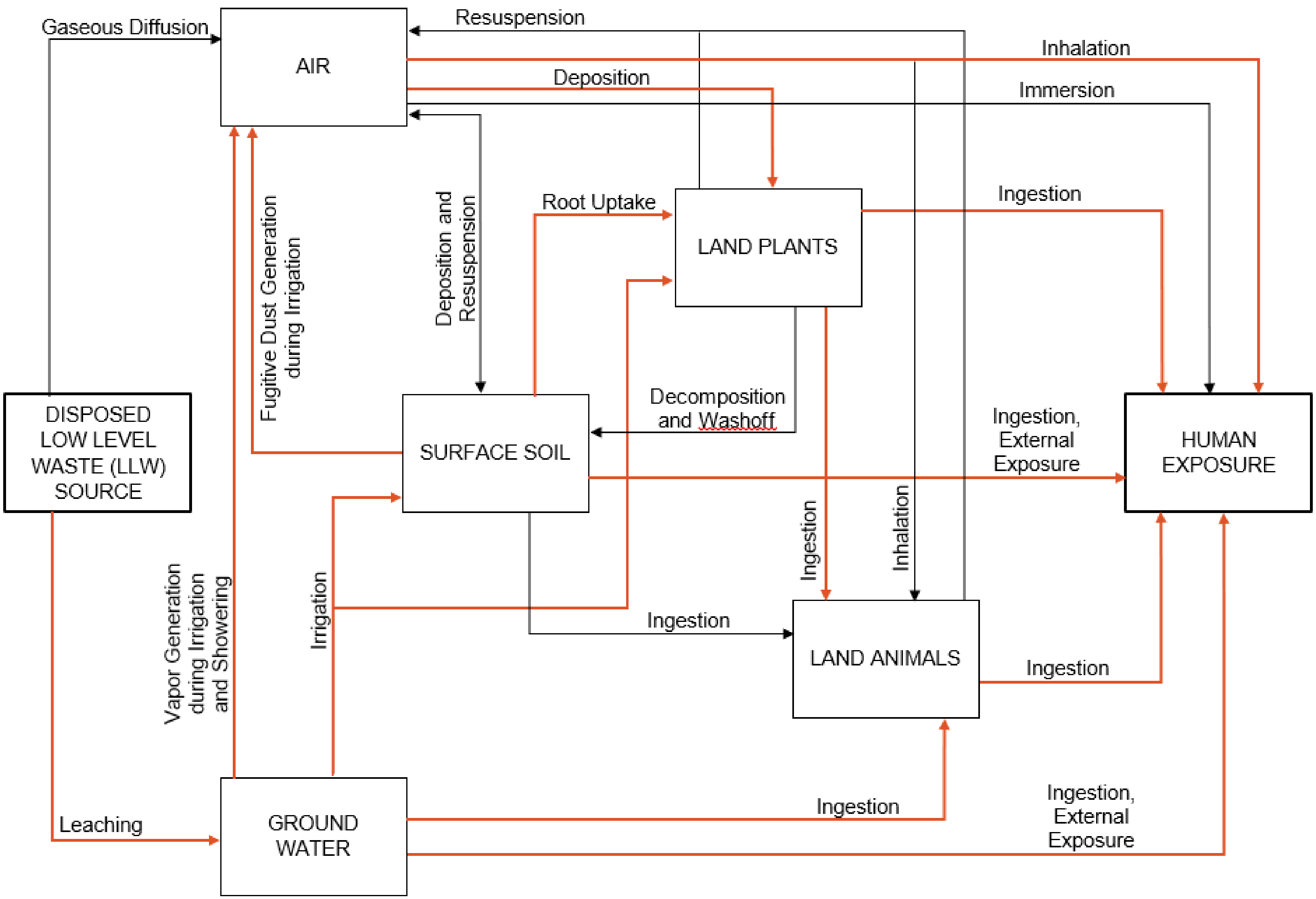

Figure 1-1. Potential Pathways to Human Exposure for Undisturbed Disposed Low-Level Waste (the red arrows indicate the pathways that require a quantified dose calculation for the MOP)

Table 1-1. Potential MOP Contaminant Exposure Pathways

Human Receptor	Scenario	Exposure Route	Primary Pathway	Secondary Pathway	Tertiary Pathway	Quantified Dose Calculations Needed?
Member of Public	Resident Farmer (Groundwater 100 m Well)	Ingestion	Domestic Use of Well Water	Drinking Water	N/A	Yes
				Showering (incidental)	N/A	No
			Well Water to Livestock	Livestock Biotic Uptake	Meat	Yes
					Milk	Yes
			Well Water Irrigation	Garden Vegetables Biotic Uptake	Vegetables	Yes
				Fodder Biotic Uptake	Livestock Biotic Uptake – Meat	Yes
					Livestock Biotic Uptake – Milk	Yes
				Direct Garden Soil Contact	N/A	Yes
					Livestock Biotic Uptake – Meat	No
					Livestock Biotic Uptake – Milk	No
		Inhalation	Domestic Use of Well Water	Showering	N/A	No
			Well Water Irrigation	Fugitive Dust Generation during Irrigation	Ambient Air (particulates)	Yes
				Vapor Generation during Irrigation	Ambient Air (vapors)	Yes
		External Exposure	Domestic Use of Well Water	Showering	N/A	Yes
			Well Water Irrigation	Direct Rad Emission from Soil	N/A	Yes
			Deposition and Resuspension of Garden Soil		N/A	No
			Decomposition and Washoff of Plants		N/A	No

Table 1-2. Potential Intruder Contaminant Exposure Pathways

Human Receptor	Scenario	Exposure Route	Primary Pathway	Secondary Pathway	Tertiary Pathway	Quantified Dose Calculations Needed?
Acute Intruder	Basement Construction	Ingestion	Exhumed Waste mixed in Clean Soil	Direct Soil Contact	N/A	Yes
		External Exposure		Direct Rad Emissions from Soil	N/A	Yes
		Inhalation	Fugitive Dust Generation during Construction activities	Ambient Air (particulates)	N/A	Yes
	Well Drilling	Ingestion	Exhumed Waste mixed in Clean Soil	Direct Soil Contact	N/A	Yes
		External Exposure		Direct Rad Emissions from Soil	N/A	Yes
		Inhalation	Fugitive Dust Generation during Drilling activities	Ambient Air (particulates)	N/A	Yes
	Discovery	External Exposure	Exhumed Waste mixed in Clean Soil	Direct Rad Emissions from Soil	N/A	Yes
Chronic Intruder	Agriculture	Ingestion	Exhumed Waste mixed in Garden Soil	Garden Vegetables Biotic Uptake	Vegetables	Yes
				Direct Soil Contact	N/A	Yes
		Inhalation		Fugitive Dust Generation while working in Garden	Ambient Air (particulates)	Yes
				Fugitive Dust Generation while residing in Home		Yes
		External Exposure		Direct Rad Emissions from Soil	N/A	Yes
			Residential building built on Soil mixed with Exhumed Waste			Yes
	Post-Drilling	Ingestion	Exhumed Waste mixed in Garden Soil	Garden Vegetables Biotic Uptake	Vegetables	Yes
				Direct Soil Contact	N/A	Yes
		Inhalation		Fugitive Dust Generation while working in Garden	Ambient Air (particulates)	Yes
				Fugitive Dust Generation while residing in Home		No
		External Exposure		Direct Rad Emissions from Soil	N/A	Yes
			Residential building built on Soil mixed with Exhumed Waste			No

Table 1-2. Potential Intruder Contaminant Exposure Pathways (continued)

Human Receptor	Scenario	Exposure Route	Primary Pathway	Secondary Pathway	Tertiary Pathway	Quantified Dose Calculations Needed?
Chronic Intruder	Residential	Ingestion	Exhumed Waste mixed in Garden Soil	Garden Vegetables Biotic Uptake	Vegetables	No
				Direct Soil Contact	N/A	No
		Inhalation		Fugitive Dust Generation while working in Garden	Ambient Air (particulates)	No
				Fugitive Dust Generation while residing in Home		No
		External Exposure	Residential building built above Waste	Direct Rad Emissions	N/A	Yes
Acute/Chronic Intruder	Bio-intrusion by Burrowing Animal	Ingestion	Waste is brought to Surface by Burrowing Animal	Exhumed Waste mixed in Soil	Direct Soil Contact	No
					Garden Vegetables Biotic Uptake - Vegetables	No
		Inhalation			Fugitive Dust Generation while working in Garden – Ambient Air (particulates)	No
					Fugitive Dust Generation while residing in Home – Ambient Air (particulates)	No
		External Exposure			Direct Rad Emissions from Soil	No

Table 1-2. Potential Intruder Contaminant Exposure Pathways (continued)

Human Receptor	Scenario	Exposure Route	Primary Pathway	Secondary Pathway	Tertiary Pathway	Quantified Dose Calculations Needed?
Acute/Chronic Intruder	Bio-intrusion by Pine Tree Root Penetration	Ingestion	Decomposition of Fallen Contaminated Pine Needles	Decomposed Needles mixed in Soil	Direct Soil Contact	No
					Garden Vegetables Biotic Uptake - Vegetables	No
		Inhalation			Fugitive Dust Generation while working in Garden – Ambient Air (particulates)	No
					Fugitive Dust Generation while residing in Home – Ambient Air (particulates)	No
		External Exposure			Direct Rad Emissions from Soil	No

2.0 Member of the Public (MOP) Exposure Pathways

Table 1-1 presents, and this section discusses, MOP exposure pathways that should be considered in the next E-Area PA revision. Table 1-1 also identifies those pathways that are recommended for quantitative dose calculations in the next E-Area PA. The assumption is that these scenarios occur after the end of the 100-year institutional control period and discontinuation of active E-Area LLWF facility maintenance.

Table 1-1 also identifies which pathways are recommended for exclusion from the quantitative dose calculations in the next PA revision. The discussion in this section provides the justification for these recommendations.

2.1 Scenario with Well Water as Primary Water Source

The primary water source for MOP exposure pathways is a well drilled into the groundwater aquifers contaminated by the E-Area LLWF. In the groundwater well-dose analyses, doses are calculated using water from a well for domestic purposes (e.g., drinking water, irrigation). The following exposure pathways involving the use of contaminated well water are assumed to occur as presented in Table 1-1 and Figure 1-1.

- Direct ingestion of well water
- Ingestion of milk and meat from livestock (e.g., dairy and beef cattle, chickens, and hogs) that drink well water
- Ingestion of vegetables grown in garden soil irrigated with well water
- Ingestion of milk and meat from livestock (e.g., dairy and beef cattle, chickens, and hogs) that eat fodder from pasture irrigated with well water
- Ingestion and inhalation of well water while showering
- External exposure to irrigation water and irrigated garden soil

Additional exposure pathways could involve releases of radionuclides into the air from the water taken from the well (i.e., volatile radionuclides such as H-3, C-14, I-129). Exposure from the air pathway may include:

- Direct plume shine
- Inhalation

There are other secondary and indirect pathways that contribute relatively minor doses to a receptor when compared to direct pathways such as ingestion of milk and meat. These pathways include:

- Inhalation of well water used for irrigation
- Inhalation of dust from the soil that was irrigated with well water
- Ingestion of soil that was irrigated with well water
- Direct radiation exposure from radionuclides deposited on the soil that was irrigated with well water

2.2 Basis for Public Release Pathways

Table 1-1 was prepared to provide a list of the E-Area LLWF exposure pathways identified as candidates for detailed analyses. The list of candidates was developed based on a review of SRS PA analysis documents. [Savannah River Remediation (2009), Savannah River Remediation (2012), (Butcher and Phifer 2016)] Those activities at SRS that could bring humans in contact with stabilized contaminants (e.g., water use, hunting, fishing, recreational activities such as swimming and boating, habitation in dwellings, other unique activities that involve water use or ground disturbance) were considered (with emphasis on local practices), to ensure that any pathways unique to SRS were taken into account. Surface water and recreational related pathways are evaluated in the 2010 SRS CA (SRNL 2010) and not considered in the SRS PA analyses. The *SRS Ecology Environmental Information Document* (2006) was used as a source of relevant environmental information and conditions at SRS. For example, Wike et al. (2006) was used to identify potential wild game available onsite, potential bio-intrusion candidates (flora and fauna), and the potential for the presence of fish and/or shellfish in the creeks bordering the ELLWF.

Based on this screening analysis, if a pathway has a negligible contribution to human exposure, the pathway may be removed from consideration in the dose analysis (U.S. DOE 2017).

Pathways related to MOP resident scenario using water from a well had the following assumptions made:

- The release mechanism to the MOP for contaminants in a stabilized system that have not been disturbed through intrusion, is leaching of stabilized contaminants to the groundwater. Well drilling is not a release mechanism since any well drilling associated with the MOP scenarios would be outside of the ELLWF buffer zone and therefore stabilized contaminants remain undisturbed.
- In the "well water as primary water source" scenario, well water will be used as a primary potable water source for a resident near the well (e.g., drinking water, showering) and will be used by the resident as a primary water source for agriculture (e.g., irrigation, livestock water).
- Any wild game ingested (deer, wild pigs) would merely offset ingested livestock, and would result in a lower total dose since the livestock raised near ELLWF would be more affected by E-Area LLWF stabilized contaminants than transient wild game.
- A local trend has developed in recent years where farmers and suburban residents are raising free-range chickens and pigs rather than using commercial food. Thus, the determination of "meat" production and consumption includes all meats (Stone and Jannik 2013).
- Since there is no substantial water source at the well site, there was no consideration for pathways connected to water-related commercial activities. Based on the relative proximity of a large, natural water source (i.e., the Savannah River), there is no assumption that a man-made body of water would be created at the MOP resident site.
- The consideration for the dose associated with dermal absorption of radionuclides is insignificant because, unlike some organic chemicals, the expected radionuclide particulate compounds generally absorb poorly into the body. For tritium oxide (half-life of 12.3 y), the estimated residual concentrations in groundwater are relatively small and in combination with the short exposure time during showering (10 min/d), renders this pathway an insignificant contributor to dose.
- The quantities of water ingested during the relatively short activity of showering (10 min/d) are negligible and not addressed independently. The impact of this activity is addressed with the "direct ingestion of well water" pathway (i.e., they are included in the 300 liters of water that is assumed to be ingested every year) (Jannik and Stagich 2017).

3.0 Intruder Exposure Pathways

The stabilized contaminant materials after E-Area LLWF closure will be located beneath a multi-layer, soil-geomembrane closure cap. The higher activity fraction of waste will be contained in concrete vaults or sealed in robust casks or containers that are clearly distinguishable from the surrounding native soil. Regional drilling practices would preclude drilling through the E-Area reinforced concrete vaults (i.e., the Low Activity Waste Vault and Intermediate Level Vault), causing drillers to stop operations and move drilling locations; therefore, the drilling intruder scenarios are analyzed for trench units only and not for the reinforced concrete vaults.

Table 1-2 presents the dose pathways for an inadvertent intruder based on intruder scenarios described in the PA Methodology document (Smith et al. 2019) with the addition of a Bio-intrusion scenario. Additionally, Table 1-2 indicates if detailed dose calculations are required. The assumption is that intruder release scenarios will occur after the 100-year institutional control period ends (after which active ELLWF facility maintenance has concluded).

3.1 Intruder Release Scenarios

The following intruder scenarios were considered for the calculation of the dose to an inadvertent intruder.

- Acute Intruder – Basement Construction Scenario
- Acute Intruder – Discovery Scenario
- Acute Intruder – Drilling Scenario
- Chronic Intruder – Agriculture Scenario
- Chronic Intruder – Resident Scenario
- Chronic Intruder – Post-Drilling Scenario
- Bio-intrusion Scenario

3.2 Acute Intruder – Basement Construction Scenario

In this scenario, it is assumed that after the end of active institutional controls, a construction project begins at the site with associated earthmoving activities. The intruder-construction scenario involves an inadvertent intruder who chooses to excavate or construct a residence on the closure site. The intruder is assumed to excavate a basement to a depth of approximately 10 feet. Due to surface erosion of the cap by time of intrusion, some portion of the excavation is assumed to reach the waste zone. It is assumed that the waste material bought to the surface is indistinguishable from native soil such that the intruder does not recognize the hazardous nature of the material excavated.

The exposure pathways for this acute basement construction scenario include:

- Inadvertent ingestion of contaminated soil from the waste zone
- Inhalation of re-suspended contaminated soil from the waste zone
- External exposure to contaminated soil from the waste zone

3.3 Acute Intruder – Discovery Scenario

The intruder-discovery scenario is a modification of the intruder-construction scenario. The basis for the intruder-discovery scenario is the same as the intruder-construction scenario except that the exposure time is reduced. The scenario involves the intruder excavating a basement to a depth of approximately 10 feet. The intruder is assumed to recognize that he or she is digging into very unusual soil immediately upon encountering the waste and leaves the site. The discovery scenario can occur at any time after loss of institutional control whereas the basement construction scenario cannot occur until the thickness of the overlying cover material is eroded to a depth less than that of a typical basement.

3.4 Acute Intruder – Drilling Scenario

The assumption in this scenario is that a well is drilled into the waste disposal unit (DU) sometime after the end of active institutional controls. The intention of the well is assumed to be for domestic water and irrigation. Lacking identification of additional natural resources in the ELLWF, additional drilling scenarios are not considered. The person or persons who perform the well installation are the acute intruder in a drilling scenario and exposure to drill cuttings during installation is anticipated.

The assumption is that a drilling borehole will penetrate the closure site. This scenario involves stabilized contaminants being disturbed and brought to the surface as drill cuttings. The acute drilling scenario assumes that an inadvertent intruder drills a well through the trench units, but not through the reinforced concrete vaults. The intruder is exposed to well cuttings containing waste material that have been brought to the surface and mixed with clean soil; therefore, the exposure pathways for the acute drilling scenario are the same as the pathways described for the acute basement construction scenario.

3.5 Chronic Intruder – Agriculture Scenario

The agriculture scenario assumes that the intruder comes onto the site after the end of active institutional controls and establishes a permanent homestead. Waste in the disposal facility is assumed to be accessed when an intruder constructs a home directly on top of a disposal facility and the basement of the home extends into the waste itself. Waste exhumed from the disposal facility is assumed to be mixed with native soil in the intruder's vegetable garden.

The following exposure pathways involving exhumed waste or waste remaining in the exposed disposal facility on which the intruder's home is located then are assumed to occur:

- Ingestion of vegetables grown in contaminated garden soil
- Direct ingestion of contaminated soil, primarily in conjunction with intakes of vegetables from the garden
- External exposure to contaminated soil while working in the garden or residing in the home on top of the disposal facility
- Inhalation of radionuclides attached to soil particles resuspended into the air from contaminated soil while working in the garden or residing in the home

3.6 Chronic Intruder – Resident Scenario

In this scenario, it is assumed that after the end of active institutional controls, an intruder lives in a home with a basement located directly above the disposal facility. The resident is shielded from exposure to radionuclides in the waste by the concrete floor slab and the soil remaining between the basement and the top of the waste zone. The exposure pathway for this scenario is therefore external exposure to photon-emitting radionuclides in the disposal facility while residing in a home located on top of the facility. Because the intruder does not excavate into the waste it is assumed that there is no significant inhalation or ingestion exposure.

3.7 Chronic Intruder – Post-drilling Scenario

The post-drilling scenario assumes that an intruder who resides permanently near the disposal facility drills through the disposal facility while constructing a well for a domestic water supply. Contaminated waste material brought to the surface during drilling operations, which is assumed to be indistinguishable from native soil, is mixed with native soil in the intruder's vegetable garden. The chronic post-drilling scenario assumes that the well is drilled through a trench unit, but not through a reinforced concrete vault.

The exposure pathways involving ingestion of contaminated vegetables, ingestion of contaminated soil, and external and inhalation exposures while working in the garden are the same as the pathways described previously for the agriculture scenario. In the post-drilling scenario, however, external and inhalation exposures are limited to time spent in the garden and do not include pathways for time residing in the home.

3.8 Bio-intrusion Scenario

The bio-intrusion scenario assumes that an intruder moves onto the site but does not excavate into the stabilized contaminants. Rather, radioactivity is brought to the surface by plants through root uptake and by burrowing animals. Bio-intrusion is not considered a credible mechanism for significant stabilized contaminant disturbance until after erosion of the cap down to the erosion barrier, based on burrowing species characteristics and the stabilized contaminant depth. Of the likely burrowing animal residents at SRS, two burrowers, the Florida Harvester Ant and the gopher tortoise, are expected to burrow only 2 meters. Although only 5% of the harvester ant's burrows and 10% of the gopher tortoises' are expected to be that deep (McKenzie et al. 1986).

The Florida Harvester Ant has a population density of approximately 27 colonies per hectare and is estimated to bring a volume of 0.05 m^3/ha of soil to the surface each year (McKenzie et al. 1986). Provided below is an estimated total volume of waste brought to the surface by the Florida Harvester Ant. This calculation assumes that the area of focus is not 1 hectare, but the area above the trench disposal units and includes a dilution factor to account for the ratio of waste material to the total amount of soil brought to the surface. Since only 5% of the burrows are expected to penetrate the waste, only 5% of the total volume brought to the surface was used in the calculation. The waste material is considered indistinguishable from the soil. Because only the edges of closed trench units will erode sufficiently to allow burrowing into the waste zone (i.e., zones close to the toe of the slope on the closure cap) only the last 50 feet on either end of a nominal trench footprint need be considered. Thus, a nominal trench unit is 157 feet wide resulting in 157,000 ft2 of surface area available to the burrowing harvester ant as shown below.

$$(50\ \mathrm{ft}\ \times 157\ \mathrm{ft}) \times 2 = 15700\ \mathrm{ft}^2 \times \frac{1\ \mathrm{ha}}{107639.104\ \mathrm{ft}^2} = \frac{0.146\ \mathrm{ha}}{\text{trench disposal units (DU)}}$$

$$\frac{27\ \text{ant colonies}}{\mathrm{ha}} \times \frac{0.146\ \mathrm{ha}}{\mathrm{DU}} = \frac{4\ \text{colonies}}{\mathrm{DU}}$$

$$0.05\left(\frac{0.05\ \mathrm{m}^3}{\mathrm{ha}\cdot\mathrm{yr}}\right) \times \frac{(4\ \text{colonies})(0.146\ \mathrm{ha})}{\mathrm{DU}\cdot\mathrm{yr}} = \frac{0.00146\ \mathrm{m}^3}{\mathrm{DU}\cdot\mathrm{yr}}$$

$$\frac{0.00146\ \mathrm{m}^3}{\mathrm{DU}\cdot\mathrm{yr}} \times \frac{1\ \text{ft of waste material}}{10\ \text{ft of total soil column brought to the surface}} = \frac{1.46\ \times 10^{-4}\ \mathrm{m}^3}{\mathrm{DU}\cdot\mathrm{yr}}$$

An estimated 7 tortoises reside in a hectare and bring approximately 1.05 m^3/ha of soil to the surface each year (McKenzie et al. 1986). Below is an estimated total volume of waste brought to the surface by the gopher tortoise following the same assumptions as the Florida Harvester Ant; however, 10% of the total volume is assumed to contain waste material.

$$\frac{7\ \text{tortoises}}{\mathrm{ha}} \times \frac{0.146\ \mathrm{ha}}{\mathrm{DU}} = \frac{1\ \text{tortoise}}{\mathrm{DU}}$$

$$0.10\left(\frac{1.05\ \mathrm{m}^3}{\mathrm{ha}\cdot\mathrm{yr}}\right) \times \frac{(1\ \text{tortoise})(0.146\ \mathrm{ha})}{\mathrm{DU}\cdot\mathrm{yr}} = \frac{0.0153\ \mathrm{m}^3}{\mathrm{DU}\cdot\mathrm{yr}}$$

$$\frac{0.0153\ \mathrm{m}^3}{\mathrm{DU}\cdot\mathrm{yr}} \times \frac{1\ \text{ft of waste material}}{10\ \text{ft of total soil column brought to the surface}} = \frac{1.53 \times 10^{-3}\ \mathrm{m}^3}{\mathrm{DU}\cdot\mathrm{yr}}$$

As shown in Table 3-1, the total volume of waste material brought to the surface through bio-intrusion is magnitudes less than the total volume brought up from the construction of a basement.

Table 3-1. Total volume of waste material brought to surface through bio-intrusion versus basement construction.

	Bio-intrusion (Florida Harvester Ant)	**Bio-intrusion (Gopher Tortoise)**	**Acute Intruder (Basement Construction)**
Total Volume of Waste Material brought to Surface (m^3/DU-yr)	1.46E-04	1.53E-03	1.00E+02

Assuming the E-Area LLWF cover reverts to pine forest in the future, the pine trees could also pose a bio-intrusion risk, with a mature pine having roots from 6-feet to 12-feet deep (Phifer and Nelson 2003). The closure cap includes a high-density polyethylene (HDPE) geomembrane liner that sheds infiltrating water through a lateral drainage layer before reaching the waste zone; therefore, forcing water to pool above and flow away from the cap. Roots from vegetation prefer areas where water is readily available, and therefore will accumulate above the essentially impervious HDPE liner rather than penetrating through it. Field evidence in support of this has been found during evaluations of similar covers (Benson and Benavides 2018).

3.9 Basis for Intruder Pathways

Table 1-2 was prepared to provide a list of the ELLWF exposure pathways identified as candidates for detailed analyses. The list of candidates was developed based on a review of SRS PA analysis documents. [Savannah River Remediation (2009), Savannah River Remediation (2012), (Butcher and Phifer 2016)] Those activities at SRS that could bring humans in contact with stabilized contaminants (e.g., water use, hunting, fishing, recreational activities such as swimming and boating, habitation in dwellings, other unique activities that involve water use or ground disturbance) were considered (with emphasis on local practices), to ensure that any pathways unique to SRS were taken into account. Surface water and recreational related pathways are evaluated in the 2010 SRS CA (SRNL 2010) and not considered in the SRS PA analyses.
Pathways that are found to make a negligible contribution to the overall exposure to humans may be removed from consideration (U.S. DOE 2017).

The following inputs and assumptions were made regarding the intruder release pathways scenario:

- The stabilized contaminant release mechanism to the intruder are inadvertent drilling into trench units. Leaching of stabilized contaminates to the groundwater and the use of the contaminated groundwater are credible release mechanisms; however, they are not calculated for the intruder, in accordance with the DOE position (U.S. DOE 2007).
- Once erosion of material above the erosion barrier occurs, the bio-intrusion scenario becomes a credible mechanism for contaminant transport. However, the total waste material brought to the surface through this scenario (1.46 x 10^{-4} m^3/DU-yr and 1.54 x 10^{-3} m^3/DU-yr) is estimated to be significantly less than the estimated volume brought up by the acute basement construction scenario (100 m^3/DU-yr).
- The high-density polyethylene geomembrane in the closure cap will force the water to pool and flow away from the barrier providing a readily available supply for roots above the cover. Evaluations of similar covers have not found evidence of root penetration into the area below these liners (Benson and Benavides 2018).

4.0 References

Benson, C. H. and J. M. Benavides (2018). Predicting Long-Term Percolation from the SDF Closure Cap, GENV-18-05, University of Virginia, Charlottesville, VA.

Butcher, B. T. and M. A. Phifer (2016). Strategic Plan for Next E-Area Low-Level Waste Facility Performance Assessment: Appendix 1.0 Topical Presentations and Team Deliberations, SRNL-STI-2015-00620, Savannah River National Laboratory, Aiken, SC.

Jannik, G. T. and B. H. Stagich (2017). Land and Water Use Characteristics and Human Health Input Parameters for use in Environmental Dosimetry and Risk Assessments at the Savannah River Site - 2017 Update, SRNL-STI-2016-00456, Savannah River Site, Aiken, SC.

McKenzie, D. H., L. L. Cadwell, J. W. E. Kennedy, L. A. Prohammer and M. A. Simmons (1986). Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal, NUREG/CR-2675, Pacific Northwest Laboratory, Richland, WA.

Phifer, M. A. and E. A. Nelson (2003). Saltstone Disposal Facility Closure Cap Configuration and Degredation Base Case: Institutional Control to Pine Forest Scenario (U), WSRC-TR-2003-00436, Savannah River SIte, Aiken, SC.

Savannah River Remediation (2009). Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site, LWO-RIP-2009-00011, Savannah River Remediation LLC, Aiken, SC.

Savannah River Remediation (2012). Performance Assessment for the H-Area Tank Farm at the Savannah River Site, SRR-CWDA-2010-00128, Savannah River Remediation LLC, Aiken, SC.

Smith, F. G., III, B. T. Butcher, L. L. Hamm and W. P. Kubilius (2019). Dose Calculation Methodology and Data for Solid Waste Performance Assessment and Composite Analysis at the Savannah River Site, SRNL-STI-2015-00056, Revision 1, Savannah River National Laboratory, Aiken, SC.

SRNL (2010). Savannah River DOE 435.1 Composite Analysis, SRNL-STI-2009-00512, Rev. 0, Savannah River National Laboratory, Aiken, SC.

Stone, D. K. and G. T. Jannik (2013). Site Specific Reference Person Parameters and Derived Concentration Standards for the Savannah River Site, SRNL-STI-2013-00115, Savannah River Site, Aiken, SC.

U.S. DOE (2007). Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Performance Assessments and Composite Analyses, U.S. Department of Energy, Washington, DC.

U.S. DOE (2017). Disposal Authorization Statement and Tank Closure Documentation, DOE-STD-5002-2017, U.S. Department of Energy, Washington, DC.

Wike, L. D., F. D. Martin, E. A. Nelson, N. V. Halverson, J. J. Mayer, M. H. Paller, R. S. Riley, M. G. Serrato and W. L. Specht (2006). SRS Ecology: Environmental Information Document, WSRC-TR-2005-00201, Savannah River Site, Aiken, SC.

WSRC (2008). E-Area Low-Level Waste Facility DOE 435.1 Performance Assessment, WSRC-STI-2007-00306, Westinghouse Savannah River Company, Aiken, SC.

Distribution:

timothy.brown@srnl.doe.gov
alex.cozzi@srnl.doe.gov
david.crowley@srnl.doe.gov
c.diprete@srnl.doe.gov
a.fellinger@srnl.doe.gov
samuel.fink@srnl.doe.gov
nancy.halverson@srnl.doe.gov
erich.hansen@srnl.doe.gov
connie.herman@srnl.doe.gov
patricia.lee@srnl.doe.gov
Joseph.Manna@srnl.doe.gov
john.mayer@srnl.doe.gov
daniel.mccabe@srnl.doe.gov
Gregg.Morgan@srnl.doe.gov
frank.pennebaker@srnl.doe.gov
Amy.Ramsey@srnl.doe.gov
William.Ramsey@SRNL.DOE.gov
michael.stone@srnl.doe.gov
Boyd.Wiedenman@srnl.doe.gov
bill.wilmarth@srnl.doe.gov
sebastian.aleman@srnl.doe.gov
paul.andrews@srs.gov
dan.burns@srs.gov
tom.butcher@srnl.doe.gov
kerri.crawford@srs.gov
Thomas.Danielson@srnl.doe.gov
kenneth.dixon@srnl.doe.gov
James.Dyer@srnl.doe.gov
peter.fairchild@srs.gov
gregory.flach@srs.gov
luther.hamm@srnl.doe.gov
thong.hang@srnl.doe.gov
tim.jannik@srnl.doe.gov
daniel.kaplan@srnl.doe.gov
steven.mentrup@srs.gov
verne.mooneyhan@srs.gov
ralph.nichols@srnl.doe.gov
Virgina.Rigsby@srs.gov
Jansen.Simmons@srs.gov
Frank.Smith@srnl.doe.gov
Brooke.Stagich@srnl.doe.gov
Ira.Stewart@srs.gov
Tad.Whiteside@srnl.doe.gov
Jennifer.Wohlwend@srnl.doe.gov
Records Administration (EDWS)