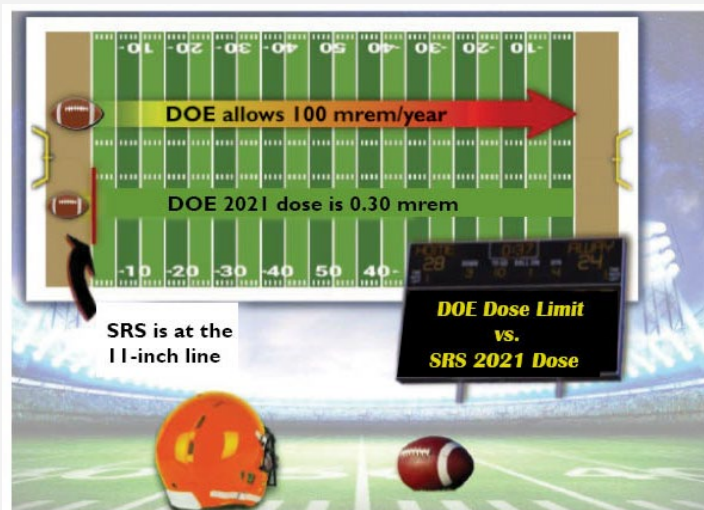


Chapter 6: Radiological Dose Assessment

Department of Energy (DOE) Order 458.1, “Radiation Protection of the Public and the Environment,” establishes dose limits for the public and plants and animals that are onsite. DOE establishes these dose limits to protect the public and environment from the potential effects of radiation released during radiological operations. To document that radiation exposure does not exceed the DOE public dose limit of 100 millirem (mrem)/year (yr), the Savannah River Site (SRS) calculates the potential dose to the public from radioactive releases in air and water through all reasonable exposure pathways. SRS also considers and quantifies exposure pathways that are nontypical and not included in the standard dose calculations to the representative person. These apply to conservative and unlikely scenarios, such as a member of the public eating fish caught only from the mouths of SRS streams, or to special scenarios, such as hunters who participate in onsite hunts. In addition, DOE Order 458.1 establishes authorized surface contamination limits, which allow SRS to release personal and real property unconditionally. SRS performs radiological surveys on all equipment considered for release and follows applicable procedures.

2021 Highlights

Dose to the Offsite Representative Person—To comply with the DOE all-pathway dose limit of 100 mrem/yr, SRS conservatively adds the doses to the offsite representative person from both Site liquid and air pathways. In 2021, the dose to the offsite representative person was 0.28 mrem from liquid releases and 0.017 mrem from air releases. The total representative person dose was 0.30 mrem, which is 0.30% of the 100 mrem/yr DOE dose limit.



Comparison of DOE's 100 mrem/yr Dose Limit to SRS's 2021 All-Pathway Dose of 0.30 mrem

2021 Highlights (continued)

Sportsman Doses

- **Onsite Hunter**—SRS conducts annual hunts to control onsite deer and wild hog populations. SRS determines the estimated potential dose from eating harvested deer or hog meat for every onsite hunter. Due to pandemic restrictions, the Site did not hold a hunt in 2021. However, SRS collected flesh samples from feral hogs that had been trapped in various hunt compartments onsite and analyzed them for radionuclides. The results were used to calculate dose to sportsman in the vicinity of the Site.
- **Creek Mouth Fisherman**—SRS estimated the maximum potential dose from fish consumption from bass collected at the mouth of Steel Creek at 0.43 mrem. This dose is 0.43% of the 100 mrem/yr DOE dose limit. SRS bases this hypothetical dose on the low probability that, during 2021, a fisherman consumed 53 pounds (lbs) of bass caught exclusively from the mouth of Steel Creek.

Release of Material Containing Residual Radioactivity—SRS did not release any real property (land or buildings) in 2021. SRS unconditionally released 12,158 items of personal property (such as tools) from radiological areas. Most of these items did not leave SRS but were reused elsewhere on the Site. Therefore, these items required no additional radiological controls postsurvey, as they met DOE Order 458.1 release criteria.

Radiation Dose to Aquatic and Terrestrial Biota—SRS evaluates plant and animal doses for water and land systems using the RESidual RADioactivity (RESRAD) Biota model (version 1.8) (SRS EDAM 2017). This model is a graded approach for evaluating radiation doses to aquatic and terrestrial biota to comply with DOE Order 458.1. For 2021, all SRS water, sediment, and soil locations passed the Level 1 (using maximum measured concentrations) screenings and did not require further assessments.

6.1 INTRODUCTION

Routine SRS operations release controlled amounts of radioactive materials to the environment through air and water. These releases could expose people offsite to radiation. To confirm that this exposure is below public dose limits, SRS calculates annual dose estimates using environmental monitoring and surveillance data, combined with relevant Site-specific data (such as weather conditions, population characteristics, and river flow). SRS also confirms that the potential doses to plants and animals (biota) living onsite remain below the DOE biota dose limits. This chapter explains radiation doses, describes how SRS calculates doses, and presents the estimated doses from SRS activities for 2021.

Radiological Impact of 2021 Operations at the Savannah River Site (Stagich, Dixon, and LaBone 2022) details SRS dose calculation methods and results. SRS used the data from the monitoring programs described in Chapter 5, *Radiological Environmental Monitoring Program*, to calculate the potential doses to the public.

6.2 WHAT IS RADIATION DOSE?

Radiation dose to a person is the amount of energy the human body absorbs from a radiation source located either inside or outside of the body. SRS typically reports dose in millirem, which is one-thousandth of a rem. A rem is a standard unit used to measure the amount of radiation deposited in human tissue.

Humans, plants, and animals potentially receive radiation doses from natural and manmade sources. The average annual background dose for all people living in the United States is 625 mrem (NCRP 2009). This includes an average background dose of 311 mrem from naturally occurring radionuclides found in our bodies, in the earth, and from cosmic radiation, such as from the sun. Manmade sources and their doses include medical procedures (300 mrem), consumer products (13 mrem), and industrial and occupational exposures from facilities such as SRS (less than 1 mrem).

DOE has established dose limits to the public so that DOE operations will not contribute significantly to this average annual exposure. DOE Order 458.1 (DOE 2013) establishes 100 mrem/yr (1 millisievert [mSv]/yr) as the annual dose limit to a member of the public. Exposure to radiation primarily occurs through the following pathways, which Figure 6-1 illustrates:

- Inhaling air
- Ingesting water and food
- Absorbing through skin
- Direct (external) exposure to radionuclides in soil, air, and water

6.3 CALCULATING DOSE

To comply with DOE Order 458.1, SRS can calculate dose to the maximally exposed individual (MEI) or to a representative person. The MEI is usually assumed to be an adult male, and the representative person is representative of all ages and genders of the highly exposed individuals in the population. Since 2012, SRS has used the representative person concept to determine whether the Site is complying with the DOE public dose limit. SRS calculates the representative person dose using Site-specific reference person parameters. The SRS representative person falls at the 95th percentile of national and regional data. The

Chapter 6—Key Terms

Exposure pathway is the way that releases of radionuclides into the water and air could impact a person.

Maximally exposed individual is a hypothetical member of the public (typically an adult male) who lives near the SRS boundary and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest possible equivalent dose.

Reference person is a hypothetical person with average physical and physiological characteristics—including factors such as age and gender—used internationally to standardize radiation dose calculations.

Representative person is a hypothetical individual receiving a dose that is representative of highly exposed individuals in the population. The calculations incorporate age, gender, food and water consumption, and breathing rate. At SRS, the representative person equates to the 95th percentile of applicable national human-use radiation exposure data.

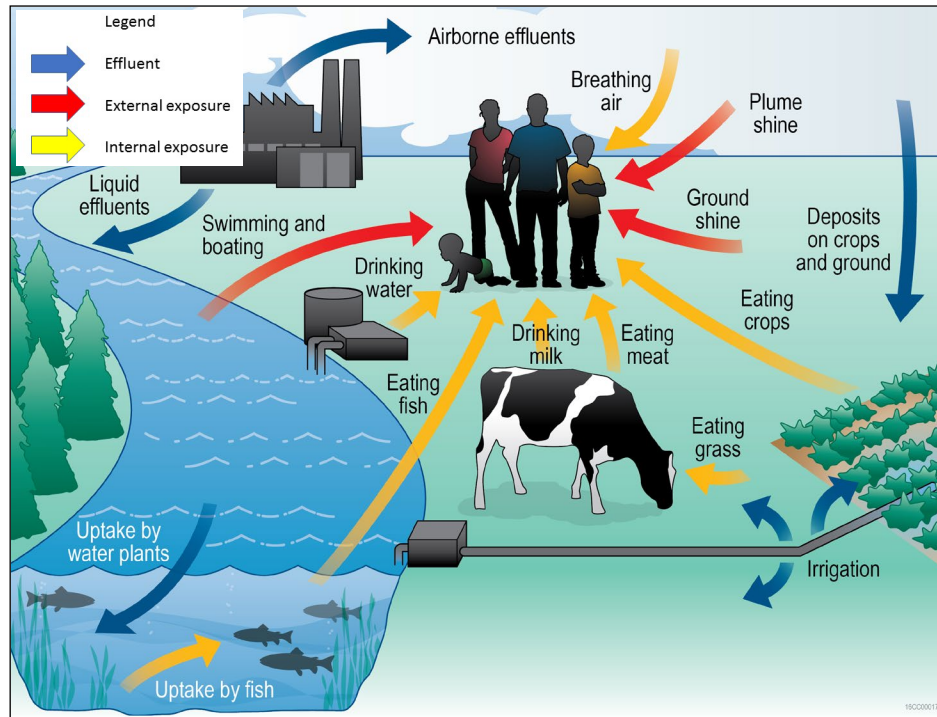


Figure 6-1 Exposure Pathways to Humans from Air and Liquid Effluents

applicable national and regional data used are from the U.S. Environmental Protection Agency's (EPA's) *Exposure Factors Handbook*, 2011 Edition (EPA 2011).

The reference person is weighted based on gender and age. The International Commission on Radiation Protection Publication 89, (ICRP 2002) groups these ages as: Infant (0 years), 1 year, 5 years, 10 years, 15 years, and Adult (17 years and older). The reference person accounts for the fact that younger people are generally more sensitive to radioactivity than older people. SRS also developed human usage parameters at the 50th percentile for calculating dose to a “typical” person when determining population doses. The SRS report *Site-Specific Reference Person Parameters and Derived Concentration Standards for SRS* (Stone and Jannik 2013) documents SRS-specific reference and typical person usage parameters. The SRS report *Land and Water Use Characteristics and Human Health Input Parameters for Use in Environmental Dosimetry and Risk Assessments at the Savannah River Site* (Jannik and Stagich 2017) documents all other applicable land- and water-use parameters in the dose calculations. These parameters include local characteristics of food production, river recreational activities, and other human usage parameters required in SRS models to calculate radiation dose exposure.

To determine whether the Site is complying with DOE public dose requirements, SRS calculates the potential doses to members of the public from Site effluent releases of radioactive materials (air and liquid) for the following scenarios:

- Representative person living near the SRS boundary
- Adult person working at the Three Rivers Landfill located on SRS (near B Area)
- Population living within a 50-mile (80-kilometer [km]) radius of SRS's H Area

For all routine environmental dose calculations, SRS uses environmental transport and dose models based on codes the Nuclear Regulatory Commission (NRC) developed (NRC 1977). The NRC-based transport models use DOE-accepted methods, consider all significant exposure pathways, and permit detailed analysis of the effects of routine operations. To demonstrate compliance with DOE Order 458.1, SRS uses the MAXDOSE-SR and POPDOSE-SR codes for air releases (representative person and population, respectively) and LAPTAP XL[®] for liquid releases. The SRS *Environmental Dose Assessment Manual* (Jannik 2017) describes these models.

At SRS, the dose to a representative person is based on the following:

- 1) SRS-specific reference person usage parameters at the 95th percentile of appropriate national or regional data (Stone and Jannik 2013).
- 2) Reference person (gender- and age-averaged) ingestion and inhalation dose coefficients from the *DOE Derived Concentration Technical Standard*, DOE-STD-1196-2011 (DOE 2011).
- 3) External dose coefficients derived from EPA's Federal Guidance Report (FGR) #15 (EPA 2019). FGR #15 is a revision to FGR #12 (EPA 1993), which incorporated age-specific external dose coefficients. SRS used these age-specific values to develop reference-person external dose coefficients in a method similar to what DOE 2011 documents. SRS started using these newly developed reference person external dose coefficients in 2019. The SRS report *Updated External Exposure Dose Coefficients*, SRNL-L3200-2020-00014 (Laird and Jannik 2020) documents the external dose coefficients used.

6.3.1 Weather Database

Complete and accurate weather (meteorological) data are important to determine offsite contamination levels. SRS calculated potential offsite doses from radioactive releases to the air with quality-assured weather data from 2014 to 2018 (Bell 2020).

Figure 6-2 presents the H-Area wind rose plot for 2014-2018 and shows the direction and frequency the wind blows. SRS bases its wind rose plot in H Area because it is where most of SRS's radiological air releases occur. As shown, the wind blows the most towards the East-Northeast sector (about 10% of the time), but there is no strongly prevalent wind direction.

6.3.2 Population Database and Distribution

SRS calculates the collective (population) doses from air releases for the population within a 50-mile radius of the H Area. Based on the U.S. Census Bureau's 2010 data, the

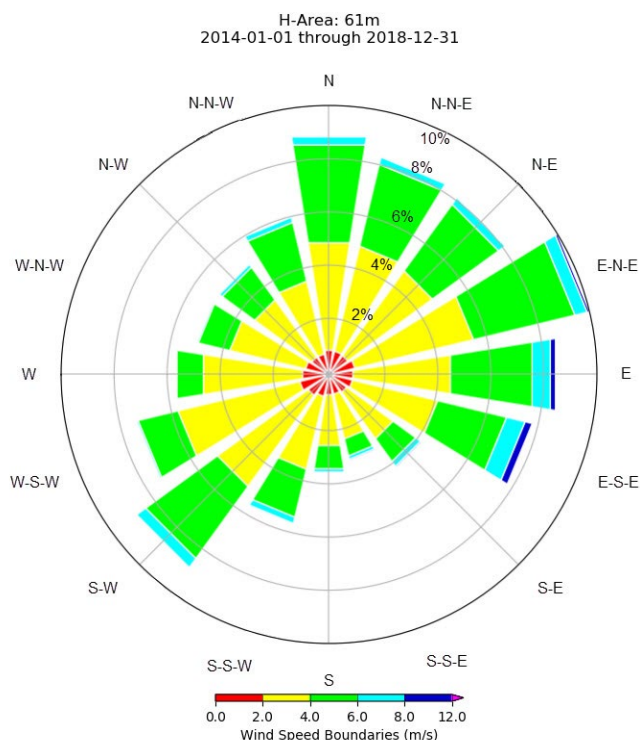


Figure 6-2 2014-2018 Wind Rose Plot for H Area (Showing Direction and Frequency Toward Which the Wind Blows)

population within a 50-mile radius of H Area is 803,370 people. This translates to about 107 people per square mile outside the SRS boundary, with the largest concentration in the Augusta metropolitan area.

Table 6-1 presents the number of people currently served by the three drinking water supply plants that are downriver of SRS.

The total population dose from routine SRS liquid releases is the sum of the following five contributing categories:

- 1) Consumers of water from Beaufort-Jasper Water and Sewer Authority (BJWSA)
- 2) Consumers of water from City of Savannah Industrial and Domestic (I&D) Domestic Water Supply Plant
- 3) Consumers of fish and invertebrates of Savannah River origin
- 4) Participants of recreational activities on the Savannah River
- 5) Gardeners and farmers irrigating foodstuffs with river water near River Mile (RM) 141.5

Table 6-1 Regional Water Supply Service

Water Supply Plant	Nearest City	Population Served
City of Savannah I&D	Port Wentworth, Georgia	36,667 people
BJWSA Chelsea Water Treatment Plant	Beaufort, South Carolina	102,000 people
BJWSA Purrysburg Water Treatment Plant	Beaufort, South Carolina	81,000 people

6.3.3 River Flow Rate Data

The annual rate of flow in the Savannah River, which varies greatly from year to year, is an important criterion for determining down-river concentrations of the contaminants SRS releases. The U.S. Geological Survey (USGS) measures Savannah River flow rates downriver of SRS at its RM 118.8 gauging station near the U.S. Hwy 301 Bridge.

Figure 6-3 provides the river flow rates the USGS measured at this location from 1981 to 2021. It also shows that the average river flow rate for these years is about 10,032 cubic feet per second (cfs). However, except for in 2020, there has been a downward trend in these data, with an average measured flow rate of 9,045 cfs.

For 2021, SRS used a calculated “effective” Savannah River flow rate of 8,456 cfs in the dose calculations. The 2021 effective flow rate is about 19% less than the 2020 effective flow rate of 10,501 cfs. This effective flow rate (based on actual measured tritium concentrations in the river) is more conservative than the 2021 USGS measured flow rate of 10,534 cfs (based on daily flow rates). By using a more conservative method, the calculated effective flow rate assumes radioactive material is less diluted and, therefore, increases the estimated potential dose.

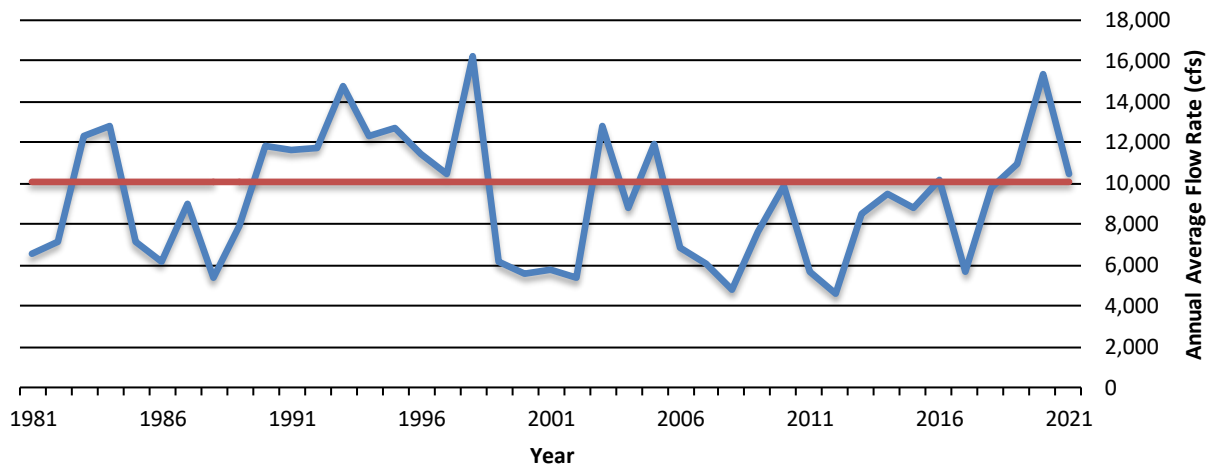


Figure 6-3 Savannah River Annual Average Flow Rates Measured by USGS at River Mile 118.8

6.4 OFFSITE REPRESENTATIVE PERSON DOSE CALCULATION RESULTS

To determine whether the Site is complying with DOE public dose requirements, SRS calculates the potential offsite doses from Site effluent releases of radioactive materials in air and liquid pathways for a representative person living near the SRS boundary. SRS calculates the pathways individually and then adds the two results to obtain the total representative person dose.

6.4.1 Liquid Pathway

6.4.1.1 Liquid Release Source Terms

Table 6-2 shows, by radionuclide, the amount of radioactivity in liquid form that SRS released in 2021. SRS uses these release amounts in the dose calculations. Chapter 5, *Radiological Environmental Monitoring Program*, discusses these sources of data.

Tritium accounts for more than 99% of the total amount of radioactivity released from the Site to the Savannah River. In 2021, SRS released 483 curies (Ci) of tritium to the river, a 7% decrease from the 2020 amount of 519 Ci. For compliance dose calculations, SRS used the measured direct release total (483 Ci), which was higher than the stream transport measurement (428 Ci).

During 2021, in addition to the 483 Ci SRS released, the Georgia Power Company's Vogtle Electric Generating Plant (VEGP) released 986 Ci of tritium to the Savannah River, and about 29 Ci migrated from the Barnwell Low-Level Disposal Facility (BLLDF). In Table 6-2, SRS used the "river transport" total of 1,918 Ci of tritium, which includes SRS, VEGP, and BLLDF contributions. Refer to Chapter 5, *Radiological Environmental Monitoring Program*, Section 5.4.5 for details concerning these measurements.

Radionuclide Concentrations in Savannah River Water, Drinking Water, and Fish—SRS measures concentrations of tritium in the river water and cesium-137 in fish at several locations along the Savannah River. SRS uses these direct measurements to make dose determinations. The amounts of all other radionuclides SRS released are so small that conventional analytical techniques usually cannot detect their concentration in the Savannah River. The Site calculates the concentrations in the river based on the annual release amounts and river flow rates and then compares them to the Safe Drinking Water Act, 40 CFR 141 (EPA 2000) maximum contaminant level (MCL) for each radionuclide.

Table 6-2 2021 Liquid Release Source Term and 12-Month Average Downriver Radionuclide Concentrations Compared to the EPA's Drinking Water Maximum Contaminant Levels (MCLs)

Nuclide	Curies Released	12-Month Average Concentration (pCi/L)		
		Below SRS ^a	BJWSA Purrysburg Plant ^b	EPA MCL ^c
H-3^d	1.92E+03	2.54E+02	2.35E+02	2.00E+04
C-14	5.80E-04	7.67E-05	7.10E-05	2.00E+03
Mn-54	9.70E-06	1.28E-06	1.19E-06	3.00E+02
Co-58	1.61E-04	2.13E-05	1.97E-05	3.00E+02
Sr-90	2.15E-02	2.85E-03	2.63E-03	8.00E+00
Tc-99	3.42E-02	4.52E-03	4.18E-03	9.00E+02
I-129	2.19E-02	2.90E-03	2.68E-03	1.00E+00
Cs-137^e	3.90E-01	5.15E-02	4.77E-02	2.00E+02
U-234	3.28E-02	4.34E-03	4.02E-03	1.03E+01
U-235	3.85E-04	5.09E-05	4.71E-05	4.67E-01
U-238	3.34E-02	4.41E-03	4.08E-03	1.00E+01
Np-237	1.17E-04	1.55E-05	1.43E-05	1.50E+01
Pu-238	3.98E-04	5.26E-05	4.87E-05	1.50E+01
Pu-239	2.01E-05	2.66E-06	2.46E-06	1.50E+01
Am-241	3.18E-05	4.21E-06	3.89E-06	1.50E+01
Cm-244	1.46E-04	1.93E-05	1.79E-05	1.50E+01
Alpha	6.22E-03	8.23E-04	7.61E-04	1.50E+01
Beta	5.27E-02	6.97E-03	6.45E-03	8.00E+00

^a Near Savannah River Mile 141.5, downriver of SRS near the Steel Creek mouth

^b Beaufort-Jasper Water and Sewer Authority, drinking water at the Purrysburg Water Treatment Plant

^c MCLs for uranium based on radioisotope-specific activity X 30 µg/L X isotopic abundance

^d Actual measurements of the Savannah River water at the various locations are the basis for the tritium concentrations and source term. They include contributions from VEGP and the BLLDF. In 2021, SRS used the effective river flow rate of 8,456 cfs (see Section 6.3.3) to calculate all other radionuclide concentrations.

^e Depending on which value is higher, the Cs-137 release total is based on concentrations measured in Steel Creek fish or on the actual measured effluent + migration release total from the Site. (See section "Radionuclide Concentrations in Fish" below.)

Radionuclide Concentrations in River Water and Treated Drinking Water—Table 6-2 shows the measured concentrations of tritium in the Savannah River near RM 141.5 and at the BJWSA Purrysburg Water Treatment Facility, which is representative of the BJWSA Chelsea and the City of Savannah I&D water treatment plants. These downriver tritium concentrations include tritium releases from SRS, VEGP, and BLLDF. In 2021, the 12-month average tritium concentration measured in Savannah River water near RM 141.5 was 254 picocuries per liter (pCi/L). This concentration is well below EPA's MCL for tritium of 20,000 pCi/L. Table 6-2 also provides the calculated concentrations for the other released radionuclides and a comparison of these concentrations to the EPA's MCLs. As shown, all radionuclide concentrations are well below the MCLs.

Radionuclide Concentrations in Fish—

Consuming fish is an important dose pathway for the representative person. Fish exhibit a high degree of bioaccumulation for certain elements. For cesium (including radioactive isotopes of cesium, such as cesium-137), the bioaccumulation factor for Savannah River fish is estimated to be 3,000, meaning the cesium concentration in fish flesh is about 3,000 times the concentration of cesium found in the water in which the fish live (Carlton et al. 1994).

Because of this high bioaccumulation factor, SRS can detect cesium-137 more easily in fish flesh than in river water. Therefore, when conservative to do so, SRS bases the fish pathway dose from cesium-137 directly on

analyzing the fish collected from the location of the hypothetical representative person, which is near the mouth of Steel Creek, at RM 141.5. In 2021, SRS used the Steel Creek fish concentrations to determine the Site's overall cesium-137 release value of 0.390 Ci, which is conservatively higher than the measured cesium-137 effluent release value of 0.0237 Ci.

6.4.1.2 Dose to the Representative Person

SRS estimates the 2021 potential dose to the representative person from all liquid pathways (including irrigation) to be 0.28 mrem (0.0028 mSv), which is 20% less than the comparable dose of 0.35 mrem in 2020.

Table 6-3 shows that the total liquid pathway dose is 0.28% of the DOE public dose limit of 100 mrem/yr (1 mSv/yr).

About 30% of the 2021 total dose to the representative person is from consuming vegetables grown and meat and milk from animals raised using Savannah River water from near RM 141.5. The fish consumption pathway accounted for 66%, and the drinking water pathway accounted for 4%. As Figure 6-4 shows, cesium-137 (71%), technetium-99 (13%), nonvolatile beta (4%) and iodine-129 (4%) contributed the most to the liquid pathway dose.



SRS Samples Fish from the Savannah River Using Electrofishing Methods. Radionuclide Concentrations in Fish Harvested from the Steel Creek Mouth are Used in the Representative Person Dose Calculations.

Table 6-3 Potential Dose to the Representative Person from SRS Liquid Releases in 2021

	Dose (mrem)	Applicable Limit (mrem)	Percent of Limit (%)
Near Site Boundary (All Liquid Pathways)			
All Liquid Pathways Except Irrigation	0.20		
Irrigation Pathways	0.086		
Total Liquid Pathways	0.28	100 ^a	0.28%

^a DOE dose limit: 100 mrem/yr (DOE Order 458.1)

6.4.1.3 Drinking Water Pathway Dose

People living downriver of SRS may receive some dose by drinking water that contains radioactive releases from the Site as well as from VEGP and BLLDF. In 2021, SRS estimated the maximum potential drinking water dose from all sources to be 0.022 mrem (0.00022 mSv). Tritium in downriver drinking water represented the highest percentage of the dose (about 71%) customers of the three downriver water treatment plants received.

SRS-only releases were responsible for a maximum potential drinking water dose of 0.010 mrem (0.00010 mSv). DOE and EPA do not have a specific regulatory drinking water dose limit, but EPA bases its MCLs, as defined in 40 CFR 141 (EPA 2000), on a potential dose of about 4 mrem/yr for beta and gamma emitters. The 2021 maximum drinking water dose of 0.010 mrem is well below this value.

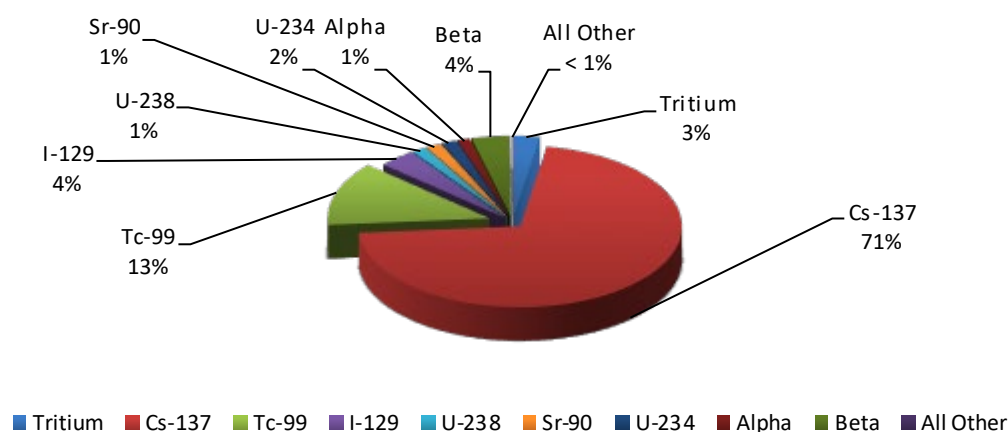


Figure 6-4 Radionuclide Contributions to the 2021 SRS Total Liquid Pathway Dose of 0.28 mrem (0.0028 mSv)

6.4.1.4 Collective (Population) Dose

SRS calculates the collective drinking water consumption dose for the separate population groups that are customers of the BJWSA and City of Savannah I&D water treatment plants. Calculations of collective doses from agricultural irrigation assume that major food types (vegetables, milk, and meat) grow or originate from animals kept on 1,000-acre parcels of land in the SRS area, with the population within 50 miles of SRS consuming all the food produced on these 1,000-acre parcels.

SRS calculates the collective dose in person-rem as the average dose per typical person, multiplied by the number of people exposed. DOE Order 458.1 requires that SRS calculate and report a collective dose, but there is not a separate collective dose limit for comparison. In 2021, the collective dose from all liquid pathways was 3.3 person-rem (0.033 person-Sv).

6.4.2 Air Pathway

6.4.2.1 Air Release Source Terms

Chapter 5, *Radiological Environmental Monitoring Program*, documents the 2021 radioactive air release quantities used as the source term in SRS dose calculations. Tritium accounts for most of the dose from SRS air releases.

6.4.2.2 Air Concentrations

SRS uses calculated radionuclide concentrations instead of measured concentrations for dose determinations because conventional analytical methods do not detect most of the radionuclides that SRS released in the air samples collected at the Site perimeter and offsite locations. However, SRS can routinely measure tritium concentrations at locations along the Site perimeter and compare these results with the calculated concentrations to confirm the dose models. In 2021, this comparison showed that the dose models used at SRS were about two times more conservative than the actual measured tritium concentrations.

6.4.2.3 Dose to the Representative Person

The 2021 estimated dose from air releases to the representative person is 0.017 mrem (0.00017 mSv), 0.17% of the EPA air pathway limit of 10 mrem per year. DOE Order 458.1 requires that all DOE sites comply with the EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations. Table 6-4 compares the representative person dose with the EPA dose limit of 10 mrem/yr. The 2021 dose is 33% higher than the 2020 dose of 0.012 mrem (0.00012 mSv). SRS attributes most of this increase to the 29% increase in tritium oxide releases during 2021. Refer to Chapter 5, *Radiological Environmental Monitoring Program*, Section 5.3.2 for details concerning these measurements. The air pathway representative person is located at the SRS boundary in the north compass point direction, near New Ellenton, South Carolina.

As Figure 6-5 shows, tritium releases were 72% of the air pathway dose to the representative person. Iodine-129 accounted for 13% of the dose. Krypton-85 (6%), cesium-137 (4%), strontium-90 (2%), and plutonium-239 (1%) were the only other individual radionuclides that contributed 1% or more to the representative person dose.

The predominant ways a representative person received radiation dose from air releases were consuming vegetables (36%), inhalation (34%), and consuming cow milk (21%).

In 2017, the Site began to calculate the potential dose for an adult worker at the Three Rivers Landfill near SRS's B Area. The public has direct access to the landfill from South Carolina Highway 125, which is outside of the Site's security perimeter. The workers at Three Rivers Landfill are not Site employees and are now considered members of the public to comply with DOE Order 458.1.

Table 6-4 Potential Doses to the Representative Person and to the MEI from SRS Air Releases in 2021 and Comparison to the Applicable Dose Limit

	DOE Representative Person (MAXDOSE-SR)	EPA NESHAP MEI (CAP88-PC)
Calculated dose (mrem)	0.017	0.020
Applicable Limit (mrem)	10 ^a	10 ^b
Percent of Limit (%)	0.17	0.20

^a DOE: DOE Order 458.1

^b EPA: (NESHAP) 40 CFR 61, Subpart H

For this assessment, SRS assumed that an adult person worked at Three Rivers Landfill for 2,000 hours during the year (8 hours a day, 5 days a week, 50 weeks a year). SRS also assumed that this worker was exposed only from the inhalation and external-exposure pathways. The Site did not consider any locally grown food consumption at this industrial location.

For 2021, SRS calculated a potential dose of 0.012 mrem (0.00012 mSv) to a Three Rivers Landfill worker. This dose is less than the representative person dose of 0.017 mrem that SRS reported to comply with DOE Order 458.1.

6.4.2.4 Collective (Population) Dose

SRS calculates the air-pathway collective dose for all 803,370 members of the population living within 50 miles of the Site's H Area. In 2021, SRS estimated the airborne-pathway collective dose to be 0.73 person-rem (0.0073 person-Sv).

DOE Order 458.1 requires that SRS calculate and report a collective dose, but there is not a separate collective dose limit for comparison.

6.4.2.5 National Emission Standards for Hazardous Air Pollutants (NESHAP) Compliance

DOE Order 458.1 requires the Site to comply with the EPA's NESHAP regulations (EPA 2002). To demonstrate this compliance, SRS calculated the MEI and collective doses using the following:

- 1) The CAP88 PC version 4.1.0.2 computer code (released January 2020), which the EPA requires
- 2) The 2021 airborne-release source term
- 3) Site-specific input parameters

The EPA requires using the MEI concept and not the representative person concept, and it specifies most of the input parameters in the CAP88 PC program. The EPA requires specific approval for any changes to these parameters.

For 2021, SRS calculated doses to two potential MEIs to demonstrate the Site complied with the EPA's 10 mrem/yr (0.1 mSv/yr) public dose limit for air emissions from DOE sites. One potential MEI was at the usual offsite location, near the Site boundary in the north compass point direction. The second potential MEI was a worker at the Three Rivers Landfill. The EPA requires that the Site consider all exposure pathways (including food consumption) for the potential MEI, even for an industrial worker.

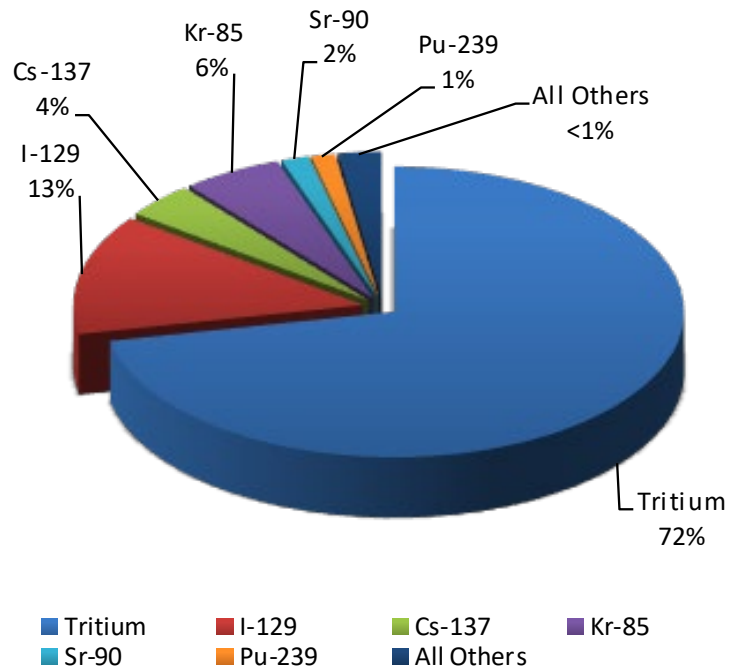


Figure 6-5 Radionuclide Contributions to the 2021 SRS Air Pathway Dose of 0.017 mrem (0.00017 mSv)

NESHAP dose calculations use H Area as the location for all Site releases because a large majority of SRS's radiological air releases are from the area's Tritium and Separations facilities (Minter et al. 2018).

SRS estimated the MEI dose at the Site boundary to be 0.0192 mrem (0.000192 mSv). SRS estimated the MEI dose for the Three Rivers Landfill worker to be 0.0199 mrem (0.000199 mSv). For 2021, SRS reported the slightly higher Three Rivers Landfill worker dose of 0.0199 mrem for NESHAP compliance. This dose is 0.20% of the 10 mrem/yr EPA limit, as Table 6-4 shows.

The radionuclides that accounted for most of the MEI dose, were tritium oxide (72%), elemental tritium (15%), cesium-137 (6.4%), krypton-85 (2.0%), and strontium-90 (1.6%). No other radionuclide contributed 1% or more to the total MEI dose. The 2021 NESHAP compliance dose (Three Rivers Landfill dose) is 29% more than the 2020 dose of 0.0154 mrem (0.000154 mSv). SRS attributes most of this increase to the 29% increase in tritium oxide releases during 2021. Refer to Chapter 5, *Radiological Environmental Monitoring Program*, Section 5.3.2 for details concerning these measurements.

6.4.3 All-Pathway Doses

6.4.3.1 All-Pathway Representative Person Dose

As stated in DOE Order 458.1, the all-pathway dose limit to a member of the public is 100 mrem/yr. SRS ensures a conservative estimate by combining the representative person airborne all-pathway and liquid all-pathway dose estimates, even though the two estimated doses are for hypothetical individuals living in different geographic locations.

For 2021, the potential representative person all-pathway dose is 0.30 mrem (0.0030 mSv), calculated as 0.28 mrem from liquid pathways plus 0.017 mrem from air pathways. As Table 6-5 shows, the all-pathway representative person dose is 0.30% of the 100 mrem/yr (1 mSv/yr) DOE dose limit. The all-pathway total dose is less than the 2020 total dose of 0.36 mrem (0.0036 mSv). As discussed previously, SRS attributes this decrease in 2021 to the decrease in radioactive liquid releases.

Figure 6-6 shows a 10-year history of SRS's all-pathway (airborne pathways plus liquid pathways) doses to the representative person.

Table 6-5 Potential Dose to the Representative Person from all Standard Pathways in 2021

Pathways	Committed Dose (mrem)	Applicable Limit (mrem)	Percent of Limit
<i>Near Site Boundary (All Pathways)</i>			
Total Liquid Pathways	0.28	100 ^a	0.28%
Total Air Pathways	0.017	10 ^{a,b}	0.17%
Total All Pathways	0.30	100 ^a	0.30%

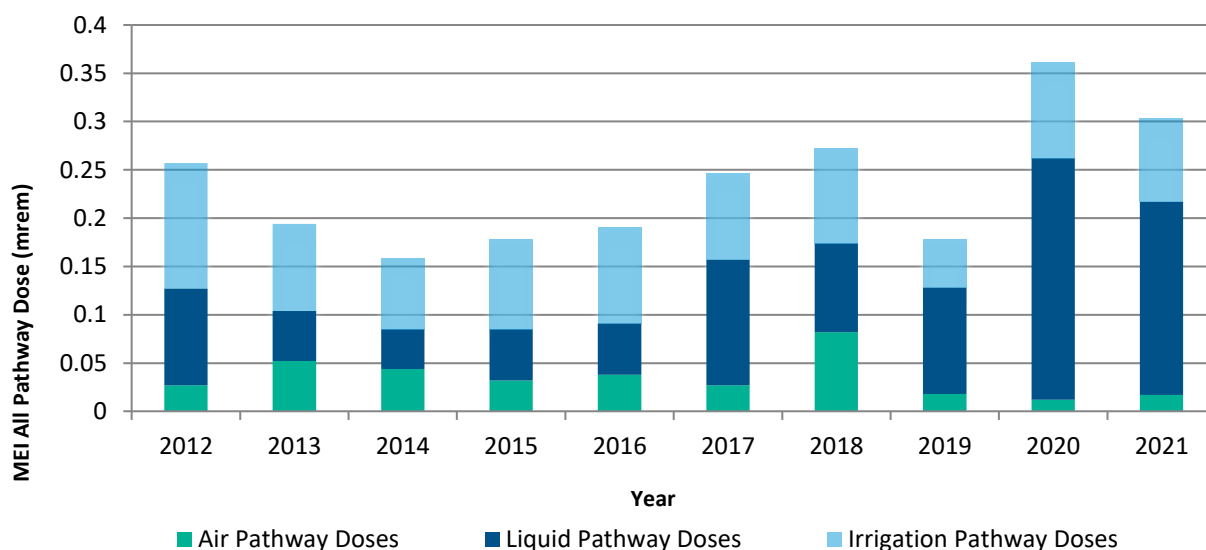
^a DOE: DOE Order 458.1

^b EPA: (NESHAP) 40 CFR 61, Subpart H

Table 6-6 Potential Collective Dose to the 50-Mile Population Surrounding SRS, Including the People Served by the Downriver Drinking Water Plants (Based on Dose to a Typical Person from all Standard Pathways in 2021)

Pathways	Collective Dose (person-rem)	Natural Background Dose (person-rem)	Percent of Natural Background
50-mile Population Dose (All Pathways)			
Total Liquid Pathways	3.3	Not Applicable	Not Applicable
Total Air Pathways	0.73	Not Applicable	Not Applicable
Total All Pathways	4.0	250,000 ^a	< 0.01%

^a Calculated as 803,370 people (surrounding SRS population) times 311 mrem (0.311 rem) per person per year, which is the average annual natural background dose for people living in the United States (NCRP 2009).

**Figure 6-6 10-Year History of SRS Maximum Potential All-Pathway Doses**

6.4.3.2 All-Pathway Collective (Population) Dose

DOE Order 458.1 requires that SRS calculate and report a collective dose, but there is not a separate collective dose limit for comparison. For 2021, the total potential collective all-pathway dose is 4.0 person-rem (0.040 person-Sv), calculated as 3.3 person-rem from liquid pathways plus 0.73 person-rem from air pathways. To compare, the annual collective dose from natural sources of radiation that the population within the 50-mile radius surrounding SRS's H Area is about 250,000 person-rem. As Table 6-6 shows, the SRS all-pathway collective dose of 4.0 person-rem is less than 0.01% of the annual collective background dose from natural resources.

6.5 SPORTSMAN DOSE CALCULATION RESULTS

DOE Order 458.1 specifies radiation dose limits for individual members of the public. The dose limit of 100 mrem/yr includes the dose a person receives from routine DOE operations through all exposure pathways. Additionally, SRS considers and quantifies nontypical exposure pathways the standard calculations of the doses to the representative person do not include. This is because they apply to unlikely scenarios such as eating fish caught only from the mouths of SRS streams (“creek-mouth fish”) or to special scenarios such as hunters who volunteer to participate in an onsite hunt.

SRS also considered the following exposure pathways for a hypothetical offsite hunter and offsite fisherman on Creek Plantation, a neighboring, privately owned portion of the Savannah River Swamp:

- Ingesting deer meat or fish harvested on Creek Plantation
- Receiving external exposure to contaminated soil
- Incidentally ingesting contaminated soil
- Incidentally inhaling resuspended contaminated soil

6.5.1 Onsite Hunter Dose

Deer and Hog Consumption Pathway—SRS holds annual hunts for the public to control the Site’s deer and wild hog populations and to reduce animal-vehicle accidents. The estimated dose from consuming harvested deer or hog meat is determined for every onsite hunter. Due to pandemic restrictions, there were no annual hunts held in 2021. However, SRS collected flesh samples from feral hogs that had been trapped in various hunt compartments onsite and analyzed them for radionuclides. The results were used to calculate dose to sportsman in the vicinity of the Site.

Turkey Consumption Pathway—SRS typically hosts a special turkey hunt in April for hunters with mobility impairments. However, due to pandemic restrictions, there were no turkey hunts in 2021.

6.5.2 Hypothetical Offsite Hunter Dose

Deer and Hog Consumption Pathway—The deer and hog consumption pathways considered were for hypothetical offsite individuals whose entire intake of meat (81 kg [179 lbs]) during the year was either deer or hog meat. SRS assumes that these individuals harvest deer or hogs that had lived on SRS during the year but then moved offsite before hunting season.

Based on these unlikely assumptions and on the measured average concentration of cesium-137 in all deer (1.23 pCi/g) and hogs (1.77 pCi/g) harvested from SRS during 2020 and 2021, respectively, the potential maximum doses from this pathway were estimated to be 2.97 mrem (0.0297 mSv) for the offsite deer hunter and 5.17 mrem (0.0517 mSv) for the offsite hog hunter.

Savannah River Swamp Hunter Soil Exposure Pathway—SRS estimated the potential dose to a recreational hunter exposed to SRS legacy contamination on the privately owned Creek Plantation. SRS used the soil concentration data obtained during the 2017 comprehensive survey of Creek Plantation for this assessment (SRNS 2018). The potential dose assumed that this person hunted for 120 hours during the year (8 hours a day for 15 days) at the location of maximum radionuclide contamination. SRS estimated this offsite-hunter soil exposure dose to be 1.86 mrem.

As Table 6-7 shows, the offsite hog consumption pathway dose (5.17 mrem) and the Savannah River Swamp hunter soil exposure pathway dose (1.86 mrem) were conservatively added together to obtain a total maximum offsite hunter dose of about 7.03 mrem (0.0703 mSv). This potential dose is 7.03% of the DOE 100 mrem/yr dose limit.

Table 6-7 2021 Sportsman Doses Compared to the DOE Dose Limit

	Committed Dose (mrem)	Applicable Standard (mrem)^a	Percent of Standard (%)
Sportsman Dose			
Onsite Hunter	0.00	100	0.00
Creek-Mouth Fisherman^b	0.43	100	0.43
Savannah River Swamp Hunter			
Offsite Hog Consumption	5.17		
Offsite Deer Consumption	2.97		
Soil Exposure^c	1.86		
Maximum Offsite Hunter Dose (Hog + Soil Exposure)	7.03	100	7.03
Savannah River Swamp Fisherman			
Steel Creek Fish Consumption	0.43		
Soil Exposure^d	2.08		
Total Offsite Fisherman Dose (Fish + Soil Exposure)	2.51	100	2.51

^a DOE dose limit; 100 mrem/yr (DOE Order 458.1)

^b The 2021 maximum dose to a hypothetical fisherman resulted from consuming bass from the mouth of Steel Creek

^c Includes the dose from combining external exposure and incidentally ingesting and inhaling the worst-case Savannah River swamp soil

^d Includes the dose from combining external exposure and incidentally ingesting and inhaling Savannah River swamp soil near the mouth of Steel Creek

6.5.3 Hypothetical Offsite Fisherman Dose

Creek-Mouth Fish Consumption Pathway—For 2021, SRS analyzed four species of fish (panfish, catfish, flathead catfish, and bass), taken from the mouths of four SRS streams, for radionuclides. Using these concentrations, SRS estimated the maximum potential dose from fish consumption to be 0.43 mrem (0.0043 mSv) from bass collected at the mouth of Steel Creek. SRS bases this hypothetical dose on the low probability scenario that during 2021, a fisherman consumed 24 kilograms (53 pounds) of bass caught exclusively from the mouth of Steel Creek. All this potential dose was from cesium-137. As Table 6-6 shows, this dose is 0.43% of the DOE 100 mrem/yr dose limit.

Savannah River Swamp Fisherman Soil Exposure Pathway—SRS calculated the potential dose to a recreational fisherman exposed to SRS legacy contamination in Savannah River Swamp soil on the privately owned Creek Plantation using the RESRAD code (Yu et al., 2001). SRS assumes that this recreational

sportsman fished on the South Carolina bank of the Savannah River near the mouth of Steel Creek for 250 hours during the year.

Using the radionuclide concentrations measured at this location, SRS estimated the potential dose to a fisherman from a combination of 1) external exposure to the contaminated soil, 2) incidental ingestion of the soil, and 3) incidental inhalation of renewed suspension soil to be 2.08 mrem (0.0208 mSv).

As Table 6-6 shows, SRS added the maximum Steel Creek fish consumption dose (0.43 mrem) and the Savannah River Swamp fisherman soil exposure dose (2.08 mrem) to conservatively obtain a total offsite fisherman dose of 2.51 mrem (0.0251 mSv). This potential dose is 2.51% of the DOE 100 mrem/yr dose limit.

6.5.4 Potential Risk from Consumption of SRS Creek-Mouth Fish

During 1991 and 1992, in response to a U.S. House of Representatives Appropriations Committee request for a plan to evaluate risk to the public from fish collected from the Savannah River, SRS developed a fish monitoring plan in conjunction with the EPA, Georgia Department of Natural Resources, and South Carolina Department of Health and Environmental Control. This plan includes assessing radiological risk from consuming Savannah River fish and requires that SRS summarize the results in the annual *SRS Environmental Report*. SRS estimated the potential risks using the cancer morbidity risk coefficients from Federal Guidance Report No. 13 (EPA 1999). For 2021, SRS estimated the maximum potential lifetime risk of developing fatal and nonfatal cancer from consuming SRS creek-mouth fish to be $3.2\text{E-}07$. That is, if 10 million people each received a dose of 0.43 mrem, there is a potential for 3.2 extra cancer incidents.

6.6 RELEASE OF MATERIAL CONTAINING RESIDUAL RADIOACTIVITY

DOE Order 458.1 establishes authorized surface contamination limits for unconditional release of personal and real property. This Order defines personal property as “property of any kind, except for real property” and defines real property as “land and anything permanently affixed to the land such as buildings, fences and those things attached to the buildings, such as light fixtures, plumbing and heating fixtures, or other such items, that would be personal property if not attached.” SRS handles the unconditional release of real property on an individual basis that requires DOE approval. SRS did not release any real property in 2021; therefore, the following discussion is associated with release of personal property from SRS. DOE Order 458.1 specifies that the Site must prepare and submit an annual summary of cleared property to the DOE-SR Manager.

6.6.1 Property Release Methodology

SRS uses procedures to govern unconditionally releasing equipment. SRS can release the item after it has a radiological survey if it meets specific documented limits. For items meeting unconditional release criteria, SRS generates a form and attaches it electronically to the applicable radiological survey via the Site’s Visual Survey Data System (VSIDS). In some areas, SRS documents equipment and material release directly on the radiological survey form. SRS subsequently compiled these VSIDS and survey forms and coordinated a site-wide review to determine the amount of material and equipment SRS released from its facilities in 2021. These measures ensure that radiological material releases from SRS are consistent with DOE Order 458.1 requirements.

SRS unconditionally released 12,158 items of personal property from radiological areas in 2021. Most of these items did not leave the SRS and were reused elsewhere on the Site. Therefore, all items required no additional radiological controls post-survey as they met DOE Order 458.1 release criteria. (DOE Order 458.1 allows using DOE Order 5400.5-derived supplemental limits for unconditionally releasing equipment and materials.)

In 2003, DOE approved an SRS request to use supplemental limits to release material from the Site with no further DOE controls. These supplemental release limits, provided in Table 31 of *Radiological Impact of 2021 Operations at the Savannah River Site* (Stagich, Dixon, and LaBone 2022), are dose-based and are such that if any member of the public received any exposure, it would be less than 1 mrem/yr. The supplemental limits include both surface and volume concentration criteria. The volume criteria allow SRS the option to dispose of potentially volume-contaminated material in Three Rivers Landfill, an onsite sanitary waste facility. In 2021, an unrestricted release to the onsite Three Rivers Landfill of volumetrically contaminated grit that occurred on October 28, 2020, was identified and found to be below the approved supplemental release limits.

6.7 RADIATION DOSE TO AQUATIC AND TERRESTRIAL BIOTA

DOE Order 458.1 requires that SRS operate in a manner that protects the local biota from adverse effects of radiation and radioactive material releases. To demonstrate it is complying with this requirement, SRS follows the approved DOE Standard, DOE-STD-1153-2019, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2019).

The biota dose rate limits specified in this standard are the following:

- Aquatic animals: 1.0 rad/day
- Riparian animals: 0.1 rad/day
- Terrestrial plants: 1.0 rad/day
- Terrestrial animals: 0.1 rad/day

6.7.1 DOE Biota Concentration Guides

SRS evaluates plant and animal doses for water and land systems using the RESRAD Biota model (version 1.8) (SRS EDAM 2017), which directly implements the DOE (2019) guidance. The RESRAD Biota model uses a graded approach consisting of three increasingly more detailed steps of analysis:

- Level 1 Screening—uses maximum measured concentrations and conservative default model input parameters
- Level 2 Screening—uses average concentrations or site-specific input parameters, as appropriate
- Level 3 Analysis—uses site-specific biota parameters or measured concentrations in the actual biota living at the assessed location

For water systems (animals and plants that live in the water or along riverbanks), the RESRAD Biota model performs a combined water-plus-sediment evaluation. SRS performed initial (Level 1) screenings in 2021 using radionuclide concentration data from SRS's 14 onsite, colocated stream and sediment sampling locations. A sum of the fractions less than 1.0 indicates the sampling site has passed its initial pathway screening, which means that the sampling site did not exceed its biota dose rate limits, and SRS does not

have to assess the location further. All SRS aquatic system locations passed the Level 1 screenings and did not require further assessment.

To evaluate land-based systems, SRS performed Level 1 screenings using concentration data from the five onsite radiological soil sampling locations. Typically, SRS collects and analyzes only one soil sample per year from each location. For 2021, all land-based locations passed their initial Level 1 pathway screenings.