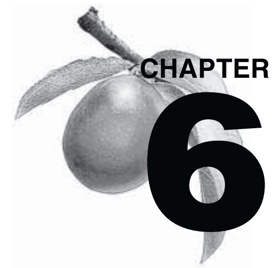
Radiological Dose Assessments



G. Timothy Jannik, Eduardo B. Farfan, Wendy W. Kuhne, and Kenneth L. Dixon
Savannah River National Laboratory

This chapter presents the potential doses to offsite individuals and the surrounding population from the 2010 Savannah River Site (SRS) atmospheric and liquid radioactive releases. Also documented are potential doses from special-case exposure scenarios—such as the consumption of deer meat, fish, and goat milk. Unless otherwise noted, the generic term "dose" used in this report includes both the committed effective dose (50-year committed dose) from internal deposition of radionuclides and the effective dose attributable to sources external to the body. Use of the effective dose allows doses from different types of radiation and to different parts of the body to be expressed on the same basis.

Descriptions of the SRS effluent monitoring and environmental surveillance programs discussed in this chapter can be found in chapter 4, "Effluent Monitoring," and chapter 5, "Environmental Surveillance." A complete description of how potential doses are calculated at SRS can be found in the SRS Environmental Dose Assessment Manual [SRS EDAM, 2010].

All dose calculation results are presented in data tables on the CD housed inside the back cover of this report and are referred to in this chapter as "data table 6–X." Tables provided in the chapter are simply referred to as "table 6–X."

Calculating Dose

Potential offsite doses from SRS effluent releases of radioactive materials (atmospheric and liquid) are calculated for the following scenarios:

- hypothetical maximally exposed individual living at the SRS boundary
- population living within a 50-mile (80-km) radius of SRS (see figure 1 in the "SRS Environmental Data/Maps" section of the CD accompanying this report)

For compliance purposes, SRS calculates maximally-exposed-individual and collective doses as if the entire 50-mile population consists of adults. For the radioisotopes that contribute the most to SRS's estimated maximum individual doses (i.e., tritium and cesium-137), the dose to infants can be approximated as two to three times more than the adult dose. The dose to older children becomes progressively closer to the adult dose [ICRP, 1996].

SRS also uses adult consumption rates for food and drinking water and adult usage parameters to estimate intakes of radionuclides. A detailed review of all applicable land- and water-use parameters was

Dose to the Hypothetical Maximally Exposed Individual

When calculating radiation doses to the public, SRS uses the concept of the hypothetical maximally exposed individual; however, because of the conservative lifestyle assumptions used in the dose models, no such person is known to exist. The parameters used for the dose calculations are as follows:

For airborne releases - Someone who lives at the SRS boundary (in the sector that has the highest calculated radionuclide concentrations) 365 days per year and consumes milk, meat, and vegetables produced at that location

For liquid releases - Someone who lives downriver of SRS (near River Mile 118.8) 365 days per year, drinks 2 liters of untreated water per day from the Savannah River, consumes 19 kg (42 pounds) per year of Savannah River fish, and spends time on or near the river

To demonstrate compliance with the DOE Order 5400.5 all-pathway dose standard of 100 mrem per year, SRS conservatively combines the airborne pathway and liquid pathway dose estimates, even though the two doses are calculated for hypothetical individuals residing at different geographic locations.

conducted in 2010, and the updated values based on this review were used in the 2010 dose calculations. These parameters include local characteristics of food production; river recreational activities; and meat, milk, and vegetable consumption rates, as well as other human usage parameters required in the SRS dosimetry models. In addition, the preferred elemental bioaccumulation and transfer factors to be used in human health exposure calculations at SRS were documented as part of this review [Jannik et al., 2010]. The site-specific input parameters used in the dose calculations are shown in data tables 6–1 and 6–2.

For dose calculations, unspecified alpha releases were treated as plutonium-239, and unspecified beta releases were treated as strontium-90. These radionuclides have the highest dose factors of the alpha- and beta-emitters, respectively, that are commonly measured in SRS waste streams.

Dose Calculation Methods

To calculate annual offsite doses, SRS uses transport and dose models developed for the commercial nuclear industry [NRC, 1977]. The models are described in SRS EDAM [2010].

From 1988 through 2009, SRS used the internal and external dose conversion factors provided in DOE [1988]. For 2010, the internal dose conversion factors were updated to use the latest dose factors provided in International Commission on Radiological Protection (ICRP) Publication 72, *Age-dependent Doses to the Members of the Public from Intake of Radionuclides Part 5, Compilation of Ingestion and Inhalation Coefficients* [ICRP, 1996]. External dose conversion factors were updated to the latest dose factors from Federal Guidance Report 12, *External Exposures to Radionuclides in Air, Water, and Soil* [EPA, 1993].

For comparison, the doses estimated for 2009 were recalculated using the updated input parameters and dose conversion factors. The liquid-pathway maximally exposed individual dose would have been about 11 percent less (0.068 mrem vs. 0.077 mrem) using the updated factors. Most of this decrease is attributed to the decrease in the plutonium dose factors. The liquid-pathway population dose would have been about 35 percent less with the updated factors (1.4 person-rem vs. 2.2 person-rem). This larger percent decrease is mainly attributed to the decrease in the average drinking water consumption rate (updated value is 337 as compared to the previous value of 370 liters per year). For the airborne pathway, the maximally exposed individual dose would have been about 2 percent less using the updated factors (0.0411 mrem vs. 0.0419 mrem). There was only a minor difference because factors applicable to tritium, which accounts for most of the air-pathway dose, changed very little. The air-pathway population dose would have been about 25-percent less with the updated factors (1.5 person-rem vs. 2.0 person-rem). This difference is mainly attributed to the decrease in the average individual breathing rate from 8,000 to 5,548 cubic meters per year.

Meteorological Database

To show compliance with DOE environmental orders, potential offsite doses from releases of radioactivity to the atmosphere were calculated with quality-assured meteorological data for A Area, K Area (for combined releases from C Area, K Area, and L Area), and H Area (for combined releases from all other areas). The meteorological databases—for the years 2002–2006, reflecting the most recent 5-year compilation period—are shown in data table 6–3.

To show compliance with U.S. Environmental Protection Agency (EPA) regulations, only the H Area meteorological database was used in the calculations because the EPA-required dosimetry code (CAP88, Mainframe version 1.0, henceforth referred to simply as CAP88) is limited to a single release location.

Population Database and Distribution

Collective (population) doses from atmospheric releases are calculated for the population within a 50-mile radius of SRS. Based on the U.S. Census Bureau's 2010 decennial data, the population within a 50-mile radius of the center of SRS is 781,058—an increase of 9.6 percent over the 2000 population in this area. This translates to an average population density of about 104 people per square mile outside the SRS boundary, with the largest concentration in the Augusta metropolitan area. The population distribution around SRS is provided in data table 6–4.

Some of the collective doses resulting from SRS liquid releases are calculated for the populations served by the City of Savannah Industrial and Domestic Water Supply Plant (Savannah I&D), near Port Wentworth, Georgia, and by the Beaufort-Jasper Water and Sewer Authority's (BJWSA) Chelsea and Purrysburg Water Treatment Plants, both near Beaufort, South Carolina. According to the treatment plant operators, the population served by the Savannah I&D facility during 2010 was 26,300 persons, while the population served by the BJWSA Chelsea facility was 77,000 persons and by the BJWSA Purrysburg facility, 58,000 persons. The total population dose resulting from routine SRS liquid releases is the sum of four contributing categories: (1) BJSWA water consumers, (2) Savannah I&D water consumers, (3) consumption of fish and invertebrates of Savannah River origin, and (4) recreational activities on the Savannah River.

River Flow Rate Data

Savannah River flow rates—recorded at a gauging station near River Mile 118.8 (U.S. Highway 301 bridge)—are based on the measured water elevation. The river flow rates measured at this location from 1954 to 2010 are provided in data table 6–5. However, these data are not used directly in the SRS dose calculations. Used instead are "effective" flow rates, which are based on (1) the measured annual release of tritium and (2) the annual average tritium concentrations measured at River Mile 118.8 and at the three downriver water treatment plants. The effective river flow rate calculations are shown in data table 6–6. The use of effective flow rates in the dose calculations generally is more conservative than the use of measured flow rates because it accounts for less dilution.

For 2010, the River Mile 118.8 calculated (effective) flow rate of 6,603 cubic feet per second (cfs) was used in the dose calculations. This flow rate was about 4 percent more than the 2009 effective flow rate of 6,324 cfs. For comparison, the 2010 annual average flow rate, as measured by the U.S. Geological Survey (USGS), was 9,893 cfs. This flow rate is slightly less than the 1954–2010 mean annual flow rate of 10,222 cfs. The 2010 calculated effective flow rates were 8,030 cfs for the Savannah I&D facility, 8,898 cfs for the BJWSA Chelsea facility, and 7,113 cfs for the BJWSA Purrysburg facility.

Dose Calculation Results

Liquid Pathway

Liquid Release Source Terms

The 2010 radioactive liquid release quantities used as the source term in SRS dose calculations are discussed in chapter 4 and shown by radionuclide in table 6–1 and by operational area in data table 6–7. Data table 6–8 provides a 5-year history of SRS liquid radioactive releases. Tritium accounts for more than 99 percent of the total amount of radioactivity released from the site to the Savannah River. In 2010, a total of 1,285 curies of tritium were released from SRS to the river. In the recent past, the total amount of tritium used in SRS dose calculations was based on the measured tritium concentration at River Mile 118.8. However, the total from this location includes the tritium releases from Georgia Power Company's Vogtle Electric Generating Plant (VEGP). Since 2006, maximally-exposed-individual doses have been calculated and documented in this report using SRS-only releases.

Data from continuously monitored liquid effluent discharge points are used in conjunction with site seepage basin and Solid Waste Disposal Facility migration release measurements to quantify the total tritium released from SRS. A separate dose calculation is performed (for information only) that includes the total amount of tritium (SRS plus VEGP) measured at River Mile 118.8, which in 2010 was 2,058 curies.

Radionuclide Concentrations in Savannah River Water, Drinking Water, and Fish

The concentrations of tritium in Savannah River water and cesium-137 in Savannah River fish are measured at several locations along the river for use in dose determinations and model comparisons. The amounts of all other radionuclides released from SRS are so small that they usually cannot be detected in the Savannah River using conventional analytical techniques. Therefore, their concentrations in the river are calculated using the LADTAP XL© code, based on the annual release amounts and on the applicable effective flow rate.

Radionuclide Concentrations in River Water and Treated Drinking Water The measured concentrations of tritium in the Savannah River near River Mile 118.8 and at the Savannah I&D and BJWSA water treatment facilities are shown in table 6–1, as are the calculated concentrations for the other released radionuclides. These downriver tritium concentrations include tritium releases from SRS and the neighboring VEGP.

In 2010, the 12-month average tritium concentration measured in Savannah River water near River Mile 118.8 (349 pCi/L) was 29 percent less the 2009 concentration of 493 pCi/L. This decrease is attributed to fewer curies of tritium released from SRS and VEGP and to the increase in river flow from 2009 to 2010. The 2010 concentrations at the BJSWA Chelsea (259 pCi/L) and Purrysburg (324 pCi/L) facilities, and at the Savannah I&D (287 pCi/L) water treatment plant, were proportionately lower than in 2009, and remained below the EPA drinking water maximum contaminant level (MCL) of 20,000 pCi/L. The drinking water MCL for each radionuclide released from SRS during 2010 is provided in table 6–1. The table indicates that all individual radionuclide concentrations at the three downriver community drinking water systems, as well as at River Mile 118.8, were below the MCLs.

Table 6–1 2010 Radioactive Liquid Release Source Term and 12-Month Average Downriver Radionuclide Concentrations Compared to EPA's Drinking Water Maximum Contaminant Levels (MCLs)

		12-Month Average Concentration (pCi/L)				
Nuclide	Curies Released	Below SRS[a]	BJWSA Chelsea[b]	BJWSA Purrysburg[b]	Savannah I&D[c]	EPA MCL
H-3[(d)]	2.06E+03	3.49E+02	2.59E+02	3.24E+02	2.87E+02	2.00E+04
Sr-90	3.84E-02	6.51E-03	4.83E-03	6.04E-03	5.35E-03	8.00E+00
Tc-99	2.39E-02	4.05E-03	3.01E-03	3.76E-03	3.33E-03	9.00E+02
I-129	2.65E-02	4.49E-03	3.33E-03	4.17E-03	3.70E-03	1.00E+00
Cs-137	4.53E-02	1.02E-02	7.55E-03	9.44E-03	8.37E-03	2.00E+02
U-234	4.09E-04	6.94E-05	5.15E-05	6.44E-05	5.70E-05	1.03E+01
U-235	1.95E-05	3.31E-06	2.45E-06	3.07E-06	2.72E-06	4.67E-01
U-238	3.61E-04	6.12E-05	4.54E-05	5.68E-05	5.03E-05	1.00E+01
Pu-238	2.05E-03	3.48E-04	2.58E-04	3.23E-04	2.86E-04	1.50E+01
Pu-239	1.64E-04	2.78E-05	2.06E-05	2.58E-05	2.29E-05	1.50E+01
Am-241	7.34E-05	1.24E-05	9.24E-06	1.16E-05	1.02E-05	1.50E+01
Cm-244	1.76E-05	2.98E-06	2.21E-06	2.77E-06	2.45E-06	1.50E+01
Alpha	7.15E-02	1.21E-02	9.00E-03	1.13E-02	9.97E-03	1.50E+01
Beta	1.26E-01	2.14E-02	1.59E-02	1.98E-02	1.76E-02	8.00E+00

[a] Near Savannah River Mile 118.8, downriver of SRS at the U.S. Highway 301 bridge
[b] Beaufort-Jasper, South Carolina, drinking water
[c] Port Wentworth, Georgia, drinking water
[d] The tritium concentrations and source term are based on actual measurements of the Savannah River water at the various locations. They include contributions from the VEGP.
All other radionuclide concentrations are calculated based on the measured releases and the effective river flow rate.
[e] MCLs for uranium based on radioisotope-specific activity X 30 µg/L X isotopic abundance

Because more than one radionuclide is released from SRS, the sum of the fractions of the reported concentration of each radionuclide divided by its corresponding MCL must not exceed 1.0. As shown in data table 6–9, the sums of the fractions were 0.0195 at the BJSWA Chelsea facility, 0.0244 at the BJSWA Purrysburg facility, and 0.0217 at the Savannah I&D facility. These are below the 1.0 sum-of-the-fractions requirement.

For 2010, the sum of the fractions at the River Mile 118.8 location was 0.0263. This is provided only for comparison because River Mile 118.8 is not a community drinking water system location.

Radionuclide Concentrations in River Fish At SRS, an important dose pathway for the maximally exposed individual is from the consumption of fish. Fish exhibit a high degree of bioaccumulation for certain elements. For the element cesium (including radioactive isotopes of cesium), the bioaccumulation factor for Savannah River fish is 3,000. That is, the concentration of cesium found 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, cesium-137 is detected more easily in fish flesh than in river water. Therefore, the fish pathway dose from cesium-137 normally is based directly on the radioanalysis of the fish collected near Savannah River Mile 118.8, which is the assumed location of the hypothetical maximally exposed individual. The amount of cesium-137 estimated to have been released from SRS during the year is adjusted to equate to the concentration measured in fish, as shown in data table 6–10. For 2010, the adjusted cesium-137 source term (based on fish concentrations) was 0.060 Ci, as compared to the amount measured in effluent releases of 0.045 Ci.

Dose to the Maximally Exposed Individual

As shown in table 6–2, the highest potential dose to the maximally exposed individual from SRS liquid releases in 2010 was estimated at 0.06 mrem (0.0006 mSv). This dose is 0.06 percent of the DOE Order 5400.5 ("Radiation Protection of the Public and the

Environment") 100-mrem all-pathway dose standard for annual exposure. The 2010 dose is 25-percent less than the 2009 dose of 0.08 mrem (0.0008 mSv). This reduction is attributed primarily to decreases in tritium and cesium-137 releases from SRS (data table 6–8). A 5-year history of SRS doses is provided in data table 6–11.

Approximately 48 percent of the 2010 dose to the maximally exposed individual resulted from the ingestion of cesium-137, mainly from the consumption of fish. About 18 percent of the dose resulted from the ingestion of tritium (mainly via drinking water) and about 25 percent was attributed to the ingestion of unspecified alpha emitters. Every other radionuclide contributed less than 5 percent to the dose. The doses by radionuclide and pathway are provided in data table 6–12.

Using the 2010 total Savannah River tritium source term (which includes SRS and VEGP releases) of 2,058 curies, the maximally-exposed-individual dose was calculated to be 0.07 mrem (0.0007 mSv). This dose, which is provided here for information only, is about 22 percent less than the 2009 dose of 0.09 mrem (0.0009 mSv).

Drinking Water Pathway Dose

Persons downriver of SRS may receive a radiation dose by consuming drinking water that contains radioactivity as a result of liquid releases from the site. As shown in data tables 6–13 and 6–14, tritium in downriver drinking water represented the majority of the dose (about 46 percent) received by customers of the three downriver water treatment plants. Unspecified alpha-emitters accounted for about 36 percent, unspecified beta-emitters contributed 7 percent, and iodine-129 releases, about 6 percent. All other individual radionuclides contributed 2 percent or less to the dose.

Based on SRS-only releases, the maximum potential drinking water dose during 2010 was determined to be 0.02 mrem (0.0002 mSv), which was about the same as the 2009 dose (data table 6–11). As shown in table 6–2, the maximum dose of 0.02 mrem (0.0002 mSv) is 0.5 percent of the DOE standard of 4 mrem per year for public drinking water supplies.

Using the SRS-plus-VEGP total tritium source term of 2,058 curies, the maximum drinking water dose was calculated to be 0.03 mrem (0.0003 mSv) in 2010.

Collective (Population) Dose

The collective drinking water consumption dose is calculated for the discrete population groups served by the BJWSA and Savannah I&D water treatment plants. The collective dose from other pathways is calculated for a diffuse population that makes use of the Savannah River; however, this population cannot be described as being in a specific geographical location.

As shown in data table 6–15, the collective dose from SRS liquid releases was estimated at 1.9 person-rem (0.019 person-Sv) in 2010. This is about 14 percent less than the 2009 collective dose of 2.2 person-rem (0.022 person-Sv). Again, this decrease is attributed mainly to decreases in tritium and cesium-137 releases from SRS (data table 6–8).

Using the SRS-plus-VEGP total tritium source term of

Table 6–2 Potential Dose to the Maximally Exposed Individual from SRS Liquid Releases in 2010

	Committed Dose (mrem)	Applicable Standard (mrem)	Percent of Standard (%)
Maximally Exposed Individual			
Near Site Boundary (all liquid pathways)	0.06	100[a]	0.06
At BJSWA Chelsea (public water supply only)	0.02	4[b]	0.5
At BJSWA Purrysburg (public water supply only)	0.02	4[b]	0.5
At Savannah I&D (public water supply only)	0.02	4[b]	0.5

[a] All-pathway dose standard: 100 mrem per year (DOE Order 5400.5)

[b] Drinking water pathway standard: 4 mrem per year (DOE Order 5400.5)

Table 6–3 Potential Dose to the Maximally Exposed Individual from SRS Atmospheric Releases in 2010

	MAXDOSE–SR	CAP88 (NESHAP)
Calculated dose (mrem)	0.05	0.06
Applicable Standard (mrem)	10[a]	10[b]
Percent of Standard (%)	0.5	0.6

[a] DOE: DOE Order 5400.5, February 8, 1990
[b] EPA: (NESHAP) 40 CFR 61, Subpart H, December 15, 1989

2,058 curies, the collective dose was calculated to be 2.3 person-rem (0.023 person-Sv) in 2010.

Potential Dose from Agricultural Irrigation

Based on discussions with personnel in the Georgia Department of Natural Resources (GDNR), the South Carolina Department of Health and Environmental Control (SCDHEC), and the U.S. Geological Survey (USGS), there are no known large-scale uses of Savannah River water downstream of SRS for agricultural irrigation purposes. However, the potential for agricultural irrigation does exist, so doses from this pathway are calculated for informational purposes only, but are not included in calculations of the official maximally-exposed-individual or collective doses.

Collective doses from agricultural irrigation were calculated assuming that 1,000 acres of land were devoted to each of the major food types grown in the SRS area (vegetables, milk, and meat). It is assumed that all the food produced on these 1,000-acre parcels is consumed by the population (781,058) within 50 miles of SRS.

As shown in data table 6–16, a potential dose of 0.1 mrem (0.001 mSv) to the maximally exposed individual and a potential collective dose of 1.5 person-rem (0.015 person-Sv) were estimated for this exposure pathway in 2010.

Air Pathway

Atmospheric Source Terms

The 2010 radioactive atmospheric release quantities used as the source term in SRS dose calculations are discussed in chapter 4 and are provided in data table 6–17. Estimates of unmonitored diffuse and fugitive sources were included in the atmospheric source term, as required, for demonstrating compliance with National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations. A 5-year history of SRS atmospheric releases is provided in data table 6–18.

Atmospheric Concentrations

Calculated radionuclide concentrations instead of measured concentrations are used for dose determinations. This is because most radionuclides released from SRS cannot be measured (using conventional analytical methods) in the air samples collected at the site perimeter and offsite locations. However, the concentrations of tritium oxide at the site perimeter locations usually can be measured—and are compared with calculated concentrations as a verification of the dose models in data table 6–19.

Dose to the Maximally Exposed Individual

The 2010 estimated dose from atmospheric releases to the maximally exposed individual (calculated with MAXDOSE–SR) was 0.05 mrem (0.0005 mSv), which is 0.5 percent of the DOE Order 5400.5 air pathway standard of 10 mrem per year. Table 6–3 compares the maximally-exposed-individual dose with the DOE standard. The 2010 dose was 25 percent more than the 2009 dose of 0.04 mrem (0.0004 mSv). This increase is attributed primarily to increases in the estimated diffuse and fugitive releases of (1) plutonium isotopes from the Burial Ground Transuranic (TRU) Facility and (2) tritium and low levels of various other isotopes from the P Reactor Disassembly Basin Decommissioning Project (evaporation of P Reactor Disassembly Basin water during 2010). A 5-year history of SRS doses is provided in data table 6–11.

The 2010 atmospheric doses by radionuclide and pathway are provided in data table 6–20. Tritium oxide releases accounted for about 82 percent of the dose to the maximally exposed individual, and plutonium-238 releases accounted for about 8 percent of the dose. No other individual radionuclide accounted for more than 5 percent of the maximally-exposed-individual dose. The major pathways contributing to the maximally-exposed-individual dose from atmospheric releases were inhalation (47 percent), vegetation consumption (32 percent), and cow milk consumption (17 percent). As shown in data table 6–21 and in data map figure 16, the due north sector of the site was the location of the highest dose to the maximally exposed individual.

Because of the potential in the SRS area for exposure to goat milk, additional calculations of the dose to the maximally exposed individual were performed substituting goat milk for the customary cow milk pathway. As shown in data table 6–22, the potential dose to the maximally exposed individual using the goat milk pathway instead of the cow milk pathway also was estimated at about 0.06 mrem (0.0006 mSv).

Collective (Population) Dose

The air-pathway collective dose is calculated for the entire 781,058 population living within 50 miles of SRS. The population distribution around SRS is provided in data table 6–4. In 2010, the airborne-pathway collective dose (calculated with POPDOSE–SR) was estimated at 1.9 person-rem (0.019 person-Sv)—less than 0.01 percent of the annual collective dose received from natural sources of radiation (about 214,000 person-rem). The 2010 air-pathway collective doses by radionuclide and pathway are provided in data table 6–23. Tritium oxide releases accounted for about 79 percent of the collective dose. The 2010 collective dose was about 5 percent less than the 2009 collective dose of 2.0 person-rem (0.020 person-Sv). This decrease is attributed mainly to the reduction in the assumed breathing rate for the average person from 8,000 to 5,548 cubic meters per year, which offset the 9.6-percent increase in the total population [Jannik et al., 2010].

NESHAP Compliance

To demonstrate compliance with NESHAP regulations [EPA, 2002a], maximally-exposed-individual and collective doses were calculated using (1) the CAP88 computer code, (2) the 2010 airborne-release source term (data table 6–24), and (3) site-specific input parameters (data table 6–25). Changes to the CAP88 code cannot be made without specific EPA approval. Therefore, changes to the input parameters and dose factors (refer to the Dose Calculation Methods section of this chapter) that were made in 2010 for the MAXDOSE–SR and POPDOSE–SR codes were not incorporated into the CAP88 code.

The CAP88 code estimates a higher dose for tritium oxide than do the MAXDOSE–SR and POPDOSE–SR codes, which are used for demonstrating compliance with DOE environmental orders. Most of the differences occur in the tritium dose estimated from food consumption. The major cause of this difference is the CAP88 code's use of 100-percent equilibrium between tritium in air moisture and tritium in food moisture, whereas the MAXDOSE–SR and POPDOSE–SR codes use 50-percent equilibrium values, as recommended by the Nuclear Regulatory Commission [NRC, 1977]. A site-specific study indicated that the 50-percent value is correct for the atmospheric conditions at SRS [Hamby and Bauer, 1994].

For 2010, the maximally-exposed-individual dose was estimated at 0.06 mrem (0.0006 mSv), which is 0.6 percent of the 10-mrem-per-year EPA standard, as shown in table 6–3. The 2010 doses by radionuclide are provided in data table 6–26. Tritium oxide releases accounted for about 88 percent of this dose and plutonium-238 accounted for 9 percent. The 2010 NESHAP compliance dose was about 50 percent more than the 2009 dose of 0.04 mrem (0.0004 mSv). This increase is attributed to the increased tritium and plutonium diffuse and fugitive releases discussed previously.

Because tritium oxide dominates the doses determined using the CAP88 code, other radionuclides (such as iodine-129) are less important—on a percentage-of-dose basis—for the CAP88 doses than for the MAXDOSE–SR and POPDOSE–SR doses.

For NESHAP, the dose from diffuse and fugitive releases is required to be reported separately. As shown in data table 6–27, the maximally-exposed-individual dose from diffuse and fugitive releases was estimated to be about 0.03 mrem (0.0003 mSv), which accounts for half of the total 2010 maximally-exposed-individual dose calculated using CAP88.

The CAP88-determined collective dose was estimated at 6.5 person-rem (0.065 person-Sv). Tritium oxide releases accounted for about 88 percent of this dose.

Comparisons (by pathway and major radionuclides) of the CAP88-determined maximally exposed individual and collective doses with the MAXDOSE–SR and POPDOSE–SR doses are provided in data tables 6–28 and 6–29, respectively.

All-Pathway Dose

To demonstrate compliance with the DOE Order 5400.5 all-pathway dose standard of 100 mrem (1.0 mSv) per year, SRS conservatively combines the maximally-exposed-individual airborne pathway and liquid pathway dose estimates, even though the two doses are calculated for hypothetical individuals residing at different geographic locations.

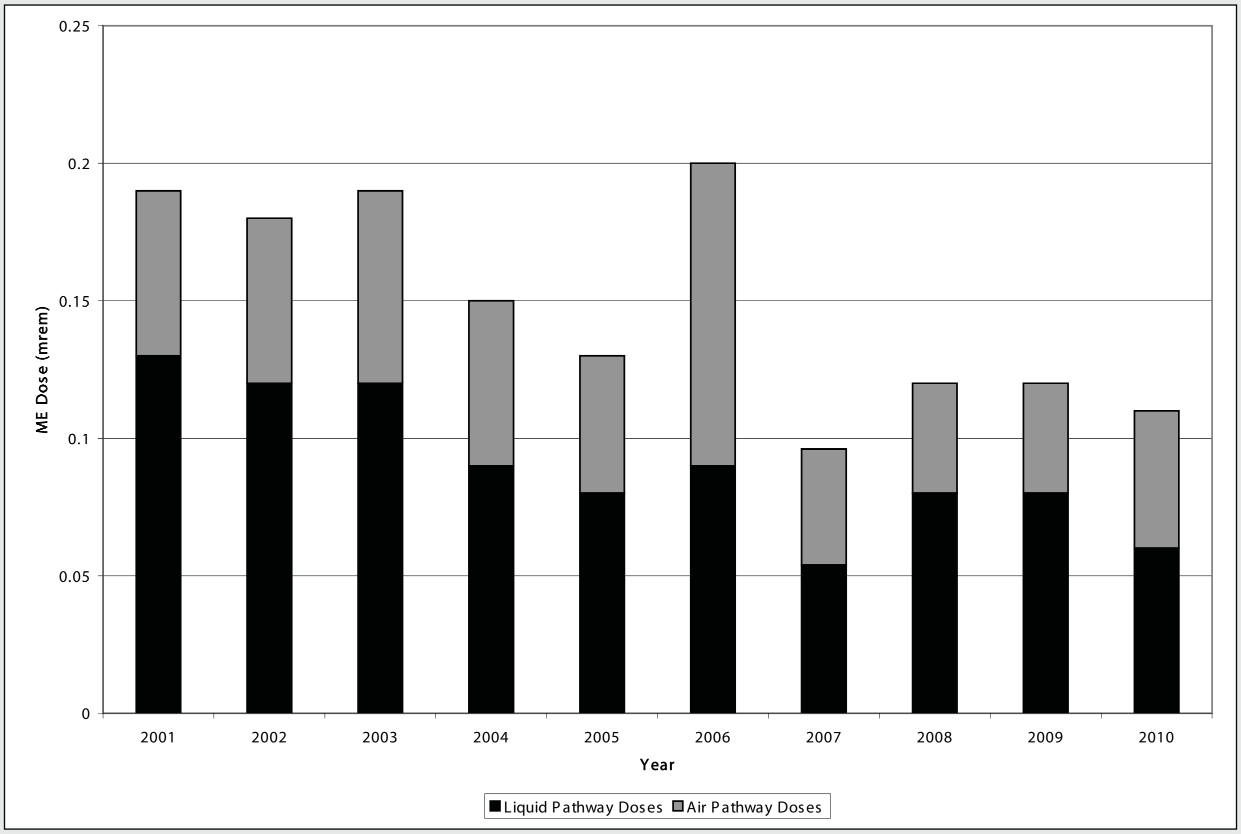


Figure 6–1 Ten-Year History of SRS Maximum Potential All-Pathway Doses

For 2010, the potential maximally-exposed-individual all-pathway dose was 0.11 mrem (0.0011 mSv)—0.05 mrem from air pathways plus 0.06 mrem from liquid pathways. The all-pathway dose is 0.11 percent of the 100-mrem-per-year DOE dose standard. The 2010 all-pathway dose is about 8 percent less than the 2009 dose of 0.12 mrem (0.0012 mSv).

Figure 6–1 shows a 10-year history of SRS's all-pathway (airborne pathway plus liquid pathway) doses to the maximally exposed individual. The increase in dose in 2006 was due primarily to an increase in the estimated diffuse and fugitive releases from a specific remediation project—the General Separations Area Consolidated Unit (GSACU)—which was completed that year [Mamatey et al., 2007].

Sportsman Dose

DOE Order 5400.5 specifies radiation dose standards for individual members of the public. The dose standard of 100 mrem per year includes doses a person receives from routine DOE operations through all exposure pathways. Nontypical exposure pathways—not included in the standard calculations of the doses to the maximally exposed individual—are considered and quantified separately. This is because they apply to low-probability scenarios, such as consumption of fish caught exclusively from the mouths of SRS streams ("creek-mouth fish"), or to unique scenarios, such as volunteer deer hunters.

In addition to deer, hog, and fish consumption, the following exposure pathways were considered for an offsite hunter and an offsite fisherman—both on Creek Plantation, a privately owned portion of the Savannah River Swamp, which was contaminated by SRS operations in the 1960s (chapter 5):

- External exposure to contaminated soil
- Incidental ingestion of contaminated soil
- Incidental inhalation of resuspended contaminated soil

Onsite Hunter Dose

Deer and Hog Consumption Pathway Annual hunts, open to members of the general public, are conducted at SRS to control the site's deer and feral hog populations and to reduce animal-vehicle accidents. The estimated dose from the consumption of harvested deer or hog meat is determined for every onsite hunter. During 2010, the maximum dose that could have been received by an actual onsite hunter was estimated at 12.4 mrem (0.0124 mSv), or 12.4 percent of DOE's 100-mrem all-pathway dose standard (table 6–4). This dose was determined for an actual hunter who in fact harvested eight animals (seven deer and one hog) during the 2010 hunts. The hunter-dose calculation is based on the conservative assumption that this prolific hunter individually consumed the entire edible portion—approximately 245 kg (540 pounds)—of the animals he harvested from SRS.

Offsite Hunter Dose

Deer and Hog Consumption Pathway The deer and hog consumption pathway considered was for hypothetical offsite individuals whose entire intake of meat (assumed to be 81 kg) during the year was either deer or hog meat. It was assumed that these individuals harvested deer or hogs that had resided at SRS but then moved off site.

Based on these low-probability assumptions and on the measured average concentration of cesium-137 in all deer (1.09 pCi/g) and hogs (1.05 pCi/g) harvested from SRS during 2010, the potential maximum doses from this pathway were estimated at 0.37 mrem (0.0037 mSv) for the offsite deer hunter and 0.18 mrem (0.0018 mSv) for the offsite hog hunter. These dose calculations are provided in data table 6–30.

A background cesium-137 concentration of 1 pCi/g is subtracted from the onsite average concentrations before calculating the doses. The background concentration is based on previous analyses of deer harvested at least 50 miles from SRS (table 33, *SRS Environmental Data for 1994*) [SRS Data, 1995].

Savannah River Swamp Hunter Soil Exposure Pathway The potential dose to a recreational hunter exposed to SRS legacy contamination in Savannah River Swamp soil on the privately owned Creek Plantation in 2010 (chapter 5) was estimated using the RESRAD code [Yu et al., 2001]. It was assumed that this recreational sportsman hunted for 120 hours during the year (8 hours per day for 15 days) at the location of maximum

Table 6–4 2010 Maximum Potential All-Pathway and Sportsman Doses Compared to the DOE All-Pathway Dose Standard

	Committed Dose (mrem)	Applicable Standard (mrem)[a]	Percent of Standard (%)
Maximally-Exposed-Individual Dose			
All-Pathway (Liquid Plus Airborne Pathway)	0.11	100	0.11
Sportsman Dose			
Onsite Hunter	12.4	100	12.4
Creek-Mouth Fisherman[b]	0.22	100	0.22
Savannah River Swamp Hunter			
Offsite Hog Consumption	0.18		
Offsite Deer Consumption	0.37		
Soil Exposure[c]	2.90		
Total Offsite Deer Hunter Dose	3.27	100	3.27
Savannah River Swamp Fisherman			
Steel Creek Fish Consumption	0.22		
Soil Exposure[d]	0.28		
Total Offsite Fisherman Dose	0.40	100	0.40

[a] All-pathway dose standard: 100 mrem per year (DOE Order 5400.5)
[b] In 2010, the maximum dose to a hypothetical fisherman resulted from the consumption of bass from the mouth of Steel Creek.
[c] Includes the dose from a combination of external exposure to and incidental ingestion and inhalation of the worst-case Savannah River Swamp soil
[d] Includes the dose from a combination of external exposure to and incidental ingestion and inhalation of Savannah River Swamp soil near the mouth of Steel Creek

radionuclide contamination.

Using the worst-case radionuclide concentrations from the most recent comprehensive survey—conducted in 2007—the potential dose to a hunter from a combination of (1) external exposure to the contaminated soil, (2) incidental ingestion of the soil, and (3) incidental inhalation of resuspended soil was estimated to be 2.9 mrem (0.029 mSv).

As shown in table 6–4, the offsite deer consumption pathway and the Savannah River Swamp hunter soil exposure pathway were conservatively added together to obtain a total offsite hunter dose of 3.27 mrem (0.0327 mSv). This potential dose is 3.27 percent of the DOE 100-mrem all-pathway dose standard.

Offsite Fisherman Dose

Creek-Mouth Fish Consumption Pathway For 2010, radioanalyses were conducted of three species of fish (panfish, catfish, and bass) taken from the mouths of the five SRS streams. The resulting estimated doses are provided in data table 6–31. To be conservative, all radioanalytical results (even those below the minimum detectable activity) were included in the average radionuclide concentrations. SRS reports the maximum dose from this combination of creek-mouth fish. As shown in table 6–4, the maximum potential dose from this pathway was estimated at 0.22 mrem (0.0022 mSv)—from the consumption of bass collected at the mouth of Steel Creek This hypothetical dose is based on the low-probability scenario that, during 2010, a fisherman consumed 42 pounds (19 kg) of bass caught exclusively from the mouth of Steel Creek. About 64 percent of this potential dose was from cesium-137.

Savannah River Swamp Fisherman Soil Exposure Pathway The potential dose to a recreational fisherman exposed to SRS legacy contamination in Savannah River Swamp soil on the privately owned Creek Plantation was estimated using the RESRAD code [Yu et al., 2001]. It was assumed 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, 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 resuspended soil was estimated to be 0.28 mrem (0.0028 mSv).

As shown in table 6–4, the maximum Steel Creek-mouth fish consumption dose (0.22 mrem) and the Savannah River Swamp fisherman soil exposure pathway were conservatively added together to obtain a total offsite creek-mouth fisherman dose of 0.40 mrem (0.0040 mSv). This potential dose is 0.40 percent of the DOE 100-mrem all-pathway dose standard.

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—in conjunction with EPA, GDNR, and SCDHEC—the *Westinghouse Savannah River Company/ Environmental Monitoring Section Fish Monitoring Plan.* Among the reporting requirements of this plan are (1) assessing radiological risk from the consumption of Savannah River fish and (2) presenting a summary of the results in the annual *SRS Environmental Report.*

Risk Comparisons For 2010, the maximum potential radiation doses and lifetime risks from the consumption of SRS creek-mouth fish for 1-year, 30-year, and 50-year exposure durations are provided in data table 6–31, and the maximum values are compared to the radiation risks associated with the DOE Order 5400.5 all-pathway dose standard of 100 mrem (1.0 mSv) per year in table 6–5. The potential risks were estimated using the cancer morbidity risk coefficients from Federal Guidance Report No. 13 [EPA, 1999a].

For 2010, the maximum recreational fisherman dose was caused by the consumption of bass collected at the mouth of Steel Creek. Figure 6–2 shows a 10-year history of the annual potential radiation doses from consumption of Savannah River fish. No apparent trends can be discerned from these data. This is because of large variability in the cesium-137 concentrations measured in fish from the same location due to differences in

- the size of the fish collected each year
- their mobility and location within the stream mouth from which they are collected
- the time of year they are collected
- the amount of cesium-137 (and other radionuclides) available in the water and sediments at the SRS stream mouths—caused by annual changes in stream flow rates (turbulence) and water chemistry

Table 6–5 Potential Lifetime Risks from the Consumption of Savannah River Fish Compared to Dose Standards

	Committed Dose (mrem)	Potential Risk[a] (unitless)
2010 Savannah River Fish		
1-Year Exposure	0.22	1.5E-07
30-Year Exposure	6.60	4.6E-06
50-Year Exposure	11.00	7.6E-06
Dose Standard		
100-Mrem/Year All Pathway		
1-Year Exposure	100	7.3E-05
30-Year Exposure	3,000	2.2E-03
50-Year Exposure	5,000	3.7E-03

[a] All radiological risk factors are based on observed and documented health effects to actual people who have received high doses (more than 10,000 mrem) of radiation, such as the Japanese atomic bomb survivors. Radiological risks at low doses (less than 10,000 mrem) are theoretical and are estimated by extrapolating the observed health effects at high doses to the low-dose region by using a linear, no-threshold model. However, cancer and other health effects have not been observed consistently at low radiation doses because the health risks either do not exist or are so low that they are undetectable by current scientific methods.

As indicated in table 6–5, the 50-year maximum potential lifetime risk from consumption of SRS creek-mouth fish was 7.6E–06, which is below the 50-year risk (3.7E–03) associated with the 100-mrem-per-year dose standard.

If a potential lifetime risk is calculated to be less than 1.0E–06 (i.e., one additional case of cancer over what would be expected in a group of 1,000,000 people), then the risk is considered minimal and the corresponding contaminant concentrations are considered negligible. If a calculated risk is more than 1.0E–04 (one additional case of cancer in a population of 10,000), then some form of corrective action or remediation usually is required. However, if a calculated risk falls between 1.0E–04 and 1.0E–06, which is the case with the maximum potential lifetime risks from the consumption of Savannah River fish, then the risk may be deemed acceptable if it is kept as low as reasonably achievable (ALARA), although actions to further reduce this risk can be considered. At SRS, an environmental ALARA program is in place to ensure that the potential risk from site radioactive liquid effluents (and, therefore, from consumption of Savannah River fish) is kept ALARA [SRS EM Plan, 2010].

Release of Material Containing Residual Radioactivity

No materials containing residual radioactivity were released from SRS during 2010. DOE issued a moratorium in January 2000 prohibiting the release of volume-contaminated metals, and subsequently suspended the release of metals for recycling purposes from DOE radiological areas in July 2000. No volume-contaminated metals or metals for recycling purposes were released from SRS in 2010.

DOE approved an SRS request in 2003 to use supplemental limits for releasing material from the site with no further DOE controls. These supplemental release limits, which are provided in data table 6–32, are dose-based, and are such that if any member of the public received any exposure, it would be less than 1 mrem/year. The supplemental limits include both surface and volume concentration criteria. The surface criteria are very similar to those used in previous years. The volume criteria allow the disposal of potentially volume-contaminated material in SRS's Three Rivers Landfill, an onsite sanitary facility. In 2010, no material was released from the site using the SRS supplemental release limits volume concentration criteria.

These measures ensure that radiological releases of material from SRS are consistent with the requirements of DOE Order 5400.5.

Radiation Dose to Aquatic and Terrestrial Biota

DOE Order 5400.5 establishes an interim dose standard for protection of native aquatic animals. The

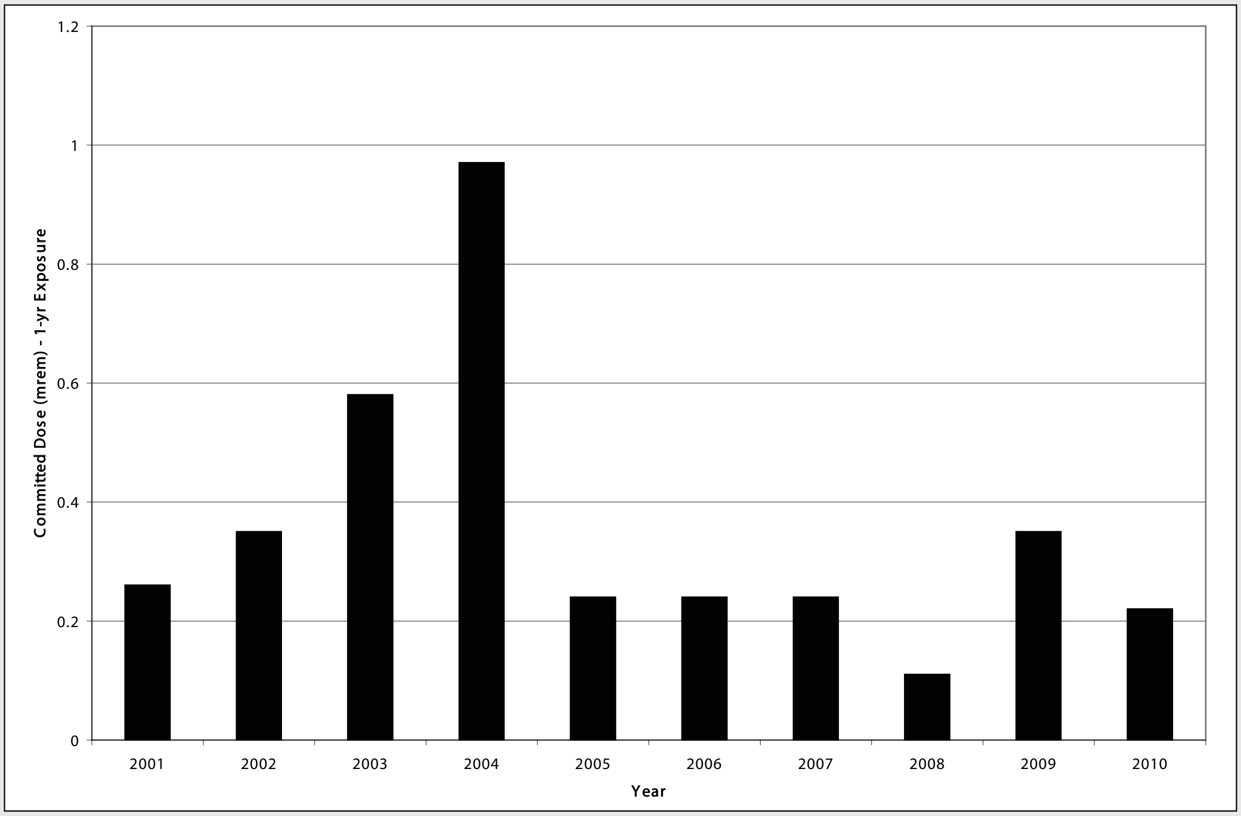


Figure 6–2 Ten-Year History of SRS Creek-Mouth Fisherman's Doses

absorbed dose limit to these organisms is 1.0 rad per day (0.01 Gy per day) from exposure to radioactive material in liquid effluents released to natural waterways.

DOE Biota Concentration Guides

At SRS, the evaluations of biota doses for aquatic and terrestrial systems are performed using the RESRAD-Biota model (version 1.21), which is based on the DOE standard entitled *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* [DOE, 2002].

The aquatic-systems evaluation includes exposures to primary (herbivores) and secondary (predators) aquatic animals, and the biota concentration guides (BCGs) are based on the 1.0-rad-per-day dose limit. Aquatic plants are not considered. The terrestrial-systems evaluation includes exposures to terrestrial plants and animals, and is based on a 10-rad-per-day dose limit for plants and a 0.1-rad-per-day dose limit for animals. These two terrestrial dose limits—included as part of the RESRAD-Biota model—are not specified in DOE Order 5400.5. All three biota dose limits are for chronic, long-term exposures to the maximally exposed individual of the applicable species.

For the aquatic-systems evaluation, initial screenings were performed in 2010 using maximum radionuclide concentration data from the 10 SRS Environmental Monitoring stream sampling locations from which collocated water and sediment samples are collected. An exception to this was made for sample location FM–2B (located on Fourmile Branch between F Area and H Area) because of its historically high cesium and tritium concentration levels. This location was included in the initial screening even though no collocated sediment sample is collected there. The combined water-plus-sediment BCG sum of the fractions was used for the aquatic systems evaluation. A sum of the fractions less than 1.0 indicates the sampling site has passed its initial pathway screening.

For the terrestrial-systems evaluation, initial screenings were performed using concentration data from the five Environmental Monitoring onsite radiological soil sampling locations. Only one soil sample per year is collected and analyzed for radioactivity from each location.

For 2010, all terrestrial locations and all but two aquatic locations passed their initial pathway screenings. Failure of the initial screening is not an indication that the biota are at risk at that location; it simply means that additional analysis is needed. The aquatic locations FM–A7 and R–1 failed their initial conservative screening but passed the secondary screening by using average concentrations in lieu of the maximum concentrations. All the RESRAD-Biota screening results are provided in data table 6–33.