Radiological Dose Assessments

CHAPTER 6

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This chapter presents the potential doses to offsite individuals and the surrounding population from the 2011 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.

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

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), a copy of which is included on the accompanying CD.

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 (MEI) living at the SRS boundary
- Population living within a 50-mile (80-kilometer [km]) radius of SRS (Figure 1 in the "SRS Environmental Data/Maps" section of the CD accompanying this report)

For compliance purposes, SRS calculates MEI 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 (International Commission on Radiological Protection [ICRP] 1996).

Dose to the Hypothetical Maximally Exposed Individual

When calculating radiation doses to the public, SRS uses the concept of the hypothetical MEI; 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 two liters of untreated water per day from the Savannah River, consumes 19 kilogram (42 pounds) per year of Savannah River fish, and spends time on or near the river. Beginning in 2011, the irrigation pathway (consumption of food products irrigated with Savannah River water) was added to the MEI dose for liquid releases.

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.

SRS also uses adult consumption rates for food and drinking water and adult usage parameters to estimate intakes of radionuclides. All applicable land- and water-use parameters in the dose calculations are documented in the Land and Water Use Characteristics and Human Health Input Parameters for use in Environmental Dosimetry and Risk Assessments at the Savannah River Site (Jannik et al. 2010). 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 are documented in this report. The site-specific input parameters that are the most important to the dose calculations are summarized in data tables 6-1 and 6-2.

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

Dose Calculation Methods

During routine operations at SRS, radioactive materials are incidentally released to the environment through atmospheric and/or liquid pathways. These releases potentially result in a radiation dose commitment to offsite people. The principal pathways by which people are exposed to releases of radioactivity are:

- Inhalation
- Ingestion
- Skin absorption
- External exposure

Figure 6-1 is a simplified representation of the principal exposure pathways.

At SRS, the potential effects of routine radioactive releases have been assessed annually since operations began. Since 1972, annual offsite dose estimates have been published in site environmental reports made available to the public. For all routine environmental dose calculations performed since 1978, SRS has used environmental transport models based on codes

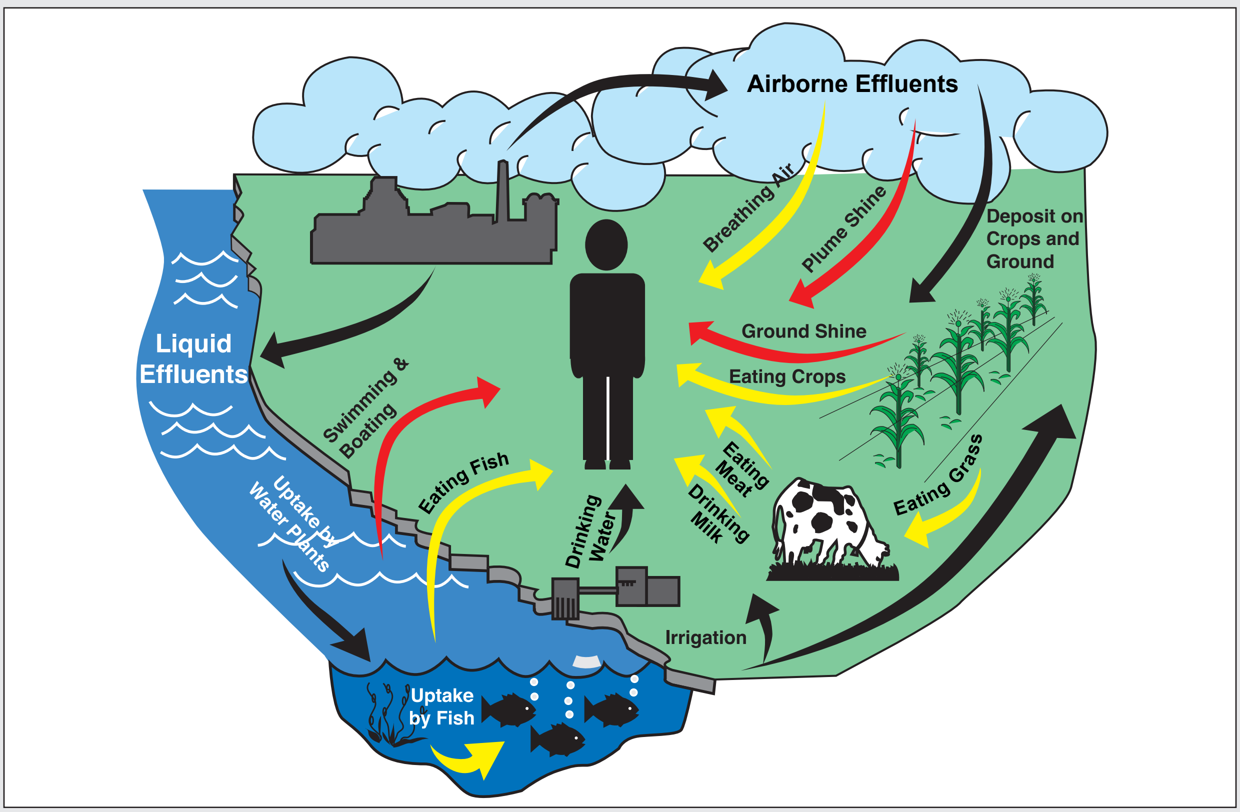

Figure 6-1 Exposure Pathways to Humans from Atmospheric and Aqueous Releases

developed by the Nuclear Regulatory Commission (NRC) (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. At SRS, the MAXDOSE-SR and POPDOSE-SR codes are used for atmospheric releases and LADTAP XL© is used for liquid releases. These models are described in SRS EDAM (2010).

From 1988 through 2009, SRS used the internal and external dose conversion factors provided in DOE [1988]. Beginning in 2010, the internal dose conversion factors were updated to use the dose factors from ICRP Publication 72, (ICRP 1996). External dose conversion factors were updated to the dose factors provided in Federal Guidance Report 12, (Environmental Protection Agency [EPA] 1993).

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 five-year compilation period, are provided in data table 6-3.

To show compliance with regulations, only the H-Area meteorological database was used in the calculations because the USEPA-required dosimetry code (CAP88 PC [Personal Computer] version 3.0, henceforth referred to simply as CAP88 PC) is limited to a single release location. Refer to the Compliance section for more details on CAP88 PC.

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 data, the population within a 50-mile radius of the center of SRS is 781,060, 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 2011 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 five contributing categories: (1) BJSWA water consumers, (2) Savannah I&D water consumers, (3) consumption of fish and invertebrates of Savannah River origin, (4) recreational activities on the Savannah River, and (5) irrigation of food stuffs using river water near River Mile 118.8.

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 2011 are provided in data table 6-5. However, these data are not used directly in the SRS dose calculations. "Effective" flow rates are used instead and they 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 2011, the River Mile 118.8 calculated (effective) flow rate of 4,329 cubic feet per second (cfs) was used in the dose calculations. This flow rate was about 33 percent less than the 2010 effective flow rate of 6,603 cfs. For comparison, the 2011 annual average flow rate, as measured by the U.S. Geological Survey (USGS), was 5,714 cfs. This flow rate is much less than the 2010 mean annual flow rate of 10,144 cfs, indicating 2011 was a severe drought year in the Savannah River basin. The 2011 calculated effective flow rates were 5,188 cfs for the Savannah I&D facility, 5,327 cfs for the BJWSA Chelsea facility, and 5,008 cfs for the BJWSA Purrysburg facility.

Dose Calculation Results

Liquid Pathway

Liquid Release Source Terms

The 2011 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 site streams in data table 6-7. Data table 6-8 provides a five-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 2011, a total of 942 curies of tritium were released from SRS to the river, a 27 percent decrease from the 2010 amount of 1,285 curies. In the past, the total amount of tritium 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, 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), which in 2011 was 2,312 curies (942 curies from SRS and 1,370 curies from VEGP). This was a 12 percent increase from the 2010 total of 2,058 curies.

Table 6-1 2011 Radioactive Liquid Release Source Term and 12-Month Average Downriver Radionuclide Concentrations Compared to the USEPA's Drinking Water Maximum Contaminant Levels (MCL)

Nuclide	ActivityReleased (Ci)	12-Month Average Concentration (pCi/L)				
		Below SRS[a]	BJWSA Chelsea[b]	BJWSA Purrysburg[b]	Savannah I&D[c]	USEPA MCL[e]
H-3[d]	2.31E+03	5.98E+02	4.86E+02	5.17E+02	4.99E+02	2.00E+04
C-14	1.11E-02	2.87E-03	2.33E-03	2.48E-03	2.40E-03	2.00E+03
Sr-90	2.94E-02	7.60E-03	6.18E-03	6.57E-03	6.35E-03	8.00E+00
Tc-99	1.07E-02	2.77E-03	2.25E-03	2.39E-03	2.31E-03	9.00E+02
I-129	1.48E-02	3.83E-03	3.11E-03	3.31E-03	3.19E-03	1.00E+00
Cs-137	8.05E-02	2.08E-02	1.69E-02	1.80E-02	1.74E-02	2.00E+02
U-234	7.44E-02	1.92E-02	1.56E-02	1.66E-02	1.61E-02	1.03E+01
U-235	3.50E-03	9.05E-04	7.36E-04	7.83E-04	7.55E-04	4.67E-01
U-238	8.80E-02	2.28E-02	1.85E-02	1.97E-02	1.90E-02	1.00E+01
Np-237	3.56E-06	9.21E-07	7.48E-07	7.96E-07	7.68E-07	1.50E+01
Pu-238	1.03E-03	2.66E-04	2.16E-04	2.30E-04	2.22E-04	1.50E+01
Pu-239	4.39E-05	1.14E-05	9.23E-06	9.82E-06	9.47E-06	1.50E+01
Am-241	4.06E-04	1.05E-04	8.53E-05	9.08E-05	8.76E-05	1.50E+01
Cm-244	3.99E-04	1.03E-04	8.39E-05	8.92E-05	8.61E-05	1.50E+01
Alpha[f]	1.35E-02	3.49E-03	2.84E-03	3.02E-03	2.91E-03	1.50E+01
Beta[g]	3.30E-02	8.54E-03	6.94E-03	7.38E-03	7.12E-03	8.00E+00

[a] Near 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 VEGP. All other radionuclide concentrations are calculated based on the effective river flow rate.

[e] MCLs for uranium based on radioisotope specific activity X 30 µg/L X isotopic abundance

[f, g] For dose calculations and MCL comparisons, unspecified alpha and beta releases are assumed to be Pu-239 and Sr-90, respectively

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 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 2011, the 12-month average tritium concentration measured in Savannah River water near River Mile 118.8 (598 picocuries per liter (pCi/L)) was 71 percent more than the 2010 concentration of 349 pCi/L. This increase is mainly attributed to the decrease in river flow from 2010 to 2011 and to increased releases of tritium from VEGP. The 2011 concentrations at the BJSWA Chelsea (486 pCi/L) and Purrysburg (517 pCi/L) facilities and at the Savannah I&D (499 pCi/L) water treatment plant were proportionately higher than in 2010 but remained well 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 2011 is 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.

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 0.0343 at the BJSWA Chelsea facility, 0.0365 at the BJSWA Purrysburg facility, and 0.0352 at the Savannah I&D facility. These are below the 1.0 sum-of-the-fractions requirement.

For 2011, the sum of the fractions at the River Mile 118.8 location was 0.0422. 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 MEI 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 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 River Mile 118.8, the assumed location of the hypothetical MEI. However, as shown in data table 6-10, the LADTAP XL dose model calculated concentration of cesium-137 in fish, based on measured 2011 effluent releases, was determined to be more than the actual measured concentration in fish. To be conservative, this higher calculated cesium-137 concentration in fish was used in the 2011 dose determinations.

Dose to the Maximally Exposed Individual

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), no known large-scale uses of Savannah River water downstream of SRS exist for agricultural irrigation purposes. However, the potential for agricultural irrigation does exist, especially for individual garden use. Therefore, beginning in 2011, the doses from the irrigation pathway are included in the totals for the official MEI and collective doses.

As shown in data table 6-12, the 2011 dose to the MEI from all liquid pathways except irrigation was estimated at 0.084 mrem (0.00084 millisievert (mSv)). This dose was 42 percent more than the comparable dose in 2010 of 0.059 mrem (0.00059 mSv). This increase is mainly attributed to the 33 percent decrease in river flow rate from 2010 to 2011. As shown in data table 6-16, the irrigation pathway MEI dose was estimated to be 0.092 mrem (0.00092 mSv). Adding these two doses together leads to a total liquid, all-pathway dose of 0.18 mrem (0.00018 mSv). Table 6-2 shows this total dose is 0.18 percent of the DOE Order 5400.5 all-pathway dose standard for annual exposure of 100 mrem. A five-year

history of SRS doses is provided in data table 6-11.

Nearly 52 percent of the 2011 total dose to the MEI resulted from the irrigation pathway (ingestion of meat, milk, and vegetables). The fish consumption pathway accounted for 34 percent and the drinking water pathway, 13 percent. Cesium-137 (36 percent), tritium oxide (13 percent), and uranium-238 (10 percent) were the major radionuclides contributing to the total liquid pathway dose.

Using the 2011 total Savannah River tritium source term (which includes SRS and VEGP releases) of 2,312 curies, the MEI dose (including the irrigation pathway) was calculated to be 0.21 mrem (0.0021 mSv). This dose, provided for information only, is about 17 percent more than the 2010 comparable dose of 0.18 mrem (0.0018 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 51 percent) received by customers of the three downriver water treatment plants.

Based on SRS-only releases, the maximum potential drinking water dose during 2011 was determined to be 0.02 mrem (0.0002 mSv), about the same as the 2010 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 2,312 curies, the maximum drinking water dose in 2011 was calculated to be 0.035 mrem (0.00035 mSv), which is 0.9 percent of the DOE standard.

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. 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 (781,060) within 50 miles of SRS. 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 all pathways except irrigation was estimated at 1.8 person-rem (0.018 person-Sv) in 2011. As shown in data table 6-16, the collective dose from the irrigation pathway was 1.3 person-rem (0.013 person-Sv). Adding these two doses together leads to a total all pathway collective dose of 3.1 person-rem (0.031 person-Sv). This is about 8 percent less than the comparable 2010 collective dose of 3.4 person-rem (0.034 person-Sv). This decrease is

Table 6-2 Potential Dose to the Maximally Exposed Individual from SRS Liquid Releases in 2011

	Committed Dose (mrem)	Applicable Standard (mrem)	Percent of Standard (percent)
Near Site Boundary (all liquid pathways)			
• All Pathways except irrigation	0.084		
• Irrigation Pathways	0.092		
Total Pathways	0.18	100[a]	0.18
At BJSWA Chelsea (public water supply only)	0.019	4[b]	0.48
At BJSWA Purrysburg (public water supply only)	0.020	4[b]	0.50
At Savannah I&D (public water supply only)	0.019	4[b]	0.48

[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)

attributed mainly to decreases in tritium releases from SRS (data table 6-8). Using the SRS-plus-VEGP total tritium source term of 2,312 curies, the collective dose was calculated to be 4.4 person-rem (0.044 person-Sv) in 2011.

Air Pathway

Atmospheric Source Terms

The 2011 radioactive atmospheric release quantities used as the source term in SRS dose calculations are discussed in Chapter 4 and are 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 NESHAP regulations. A five-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 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 2011 estimated dose from atmospheric releases to the MEI (calculated with MAXDOSE-SR) was 0.032 mrem (0.00032 mSv), 0.32 percent of the DOE Order 5400.5 air pathway standard of ten mrem per year. Table 6-3 compares the MEI dose with the DOE standard. The 2011 dose was about 41 percent less than the 2010 dose of 0.05 mrem (0.00054 mSv). This decrease is attributed primarily to the large decrease in the estimated diffuse and fugitive releases of tritium from 2010 to 2011 (see Chapter 4). A five-year history of SRS air pathway doses is in data table 6-11.

The 2011 atmospheric doses by radionuclide and pathway are provided in data table 6-20. Tritium oxide releases accounted for about 74 percent of the dose to the MEI, strontium-90 releases accounted for about 12 percent, and unidentified beta accounted for 6 percent of the dose. No other individual radionuclide accounted for more than 5 percent of the MEI dose. The major pathways contributing to the MEI dose from atmospheric releases were vegetation consumption (42 percent), inhalation (36 percent), and cow milk consumption (16 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 MEI.

Table 6–3 Potential Dose to the Maximally Exposed Individual from SRS Atmospheric Releases in 2011

	MAXDOSE–SR	CAP88 PC (NESHAP)
Calculated dose (mrem)	0.032	0.015
Applicable Standard (mrem)	10[a]	10[b]
Percent of Standard (%)	0.32	0.15

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

Because of the potential in the SRS area for exposure to goat milk, additional calculations of the dose to the MEI were performed substituting goat milk for the customary cow milk pathway. As shown in data table 6-22, the potential dose to the MEI using the goat milk pathway was estimated to be 0.036 mrem (0.00036 mSv), which is about 13 percent more than “official” MEI dose of 0.032 mrem (0.00032 mSv) using the customary cow milk pathway.

Collective (Population) Dose

The air-pathway collective dose is calculated for the entire 781,060 population living within 50 miles of SRS. The population distribution around SRS is provided in data table 6-4. In 2011, the airborne-pathway collective dose (calculated with POPDOSE-SR) was estimated at 1.2 person-rem (0.012 personSv), less than 0.01 percent of the annual collective dose received from natural sources of radiation (about 234,000 person-rem). The 2011 air-pathway collective doses by radionuclide and pathway are provided in data table 6-23. Tritium oxide releases accounted for about 82 percent of the collective dose. The 2011 collective dose was about 37 percent less than the 2009 collective dose of 1.9 person-rem (0.019 person-Sv). This decrease is again mainly attributed to the decrease in estimated diffuse and fugitive tritium releases from 2010 to 2011.

NESHAP Compliance

To demonstrate compliance with NESHAP regulations (USEPA, 2002a), MEI and collective doses were calculated using (1) the CAP88 PC version 3.0 computer

code, (2) the 2011 airborne-release source term (data table 6-24), and (3) site-specific input parameters (data table 6-25).

In 2011, SRS began using the PC version of the CAP88 code. Previously, the mainframe version of the code was used, but a mainframe computer is no longer available for these calculations at SRS. Several major differences occur between the two versions of the CAP88 code, as documented in Farfan and Powell (2012). The main differences are that the PC version uses updated dose conversion factors based on ICRP 72 (ICRP 1996) and updated usage and transfer parameters. Also, differences exist in the food ingestion and external (ground shine) exposure calculations. For SRS, where the major source term is tritium oxide, these differences lead to a reduction in the estimated MEI dose of about 50 percent (Farfan and Powell 2012). Most parameters in CAP88 PC are hard coded in the program and cannot be changed without specific USEPA approval.

For 2011, using the CAP88 PC code, the maximally-exposed-individual dose was estimated at 0.015 mrem (0.00015 mSv), 0.15 percent of the 10-mrem-per-year USEPA standard, as shown in table 6-3. The 2011 doses by radionuclide are provided in data table 6-26. Tritium oxide releases accounted for about 50 percent of this dose and strontium-90 accounted for 43 percent. Strontium-90 became more important on a percentage of dose basis in 2011, as compared to 2010; because (1) the CAP88 PC code uses larger soil-to-plant and plant-to-animal uptake ratios for the element strontium than did the mainframe version and (2) a relatively large increase in the estimated diffuse and fugitive releases of strontium-90 occurred (Chapter 4).

The 2011 NESHAP compliance dose was about 74 percent less than the 2010 dose of 0.057 mrem (0.00057 mSv) in spite of the significant increase in the diffuse and fugitive emissions of strontium-90. This large decrease is attributed mainly to the differences in the CAP88 PC code as compared to mainframe version and to the decrease in diffuse and fugitive releases of tritium oxide discussed previously.

For NESHAP, the dose from diffuse and fugitive releases is required to be reported separately. As shown in data table 6-27, the MEI dose from diffuse and fugitive releases was estimated to be about 0.089 mrem (0.00089 mSv), which accounts for more than half of the total 2011 maximally-exposed-individual dose calculated using CAP88 PC.

The CAP88 PC-determined collective dose for 2011 was estimated at 1.9 person-rem (0.019 person-Sv). Tritium oxide releases accounted for about 58 percent and strontium-90 accounted for about 35 percent of this dose. Comparisons (by pathway and major radionuclides) of the CAP88 PC-determined MEI 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 MEI airborne all-pathway and liquid all-pathway dose estimates, even though the two doses are calculated for hypothetical individuals residing at different geographic locations. As previously discussed, beginning in 2011, the SRS all-pathway dose includes the irrigation pathway dose estimate.

For 2011, the potential MEI all-pathway dose was 0.21 mrem (0.0021 mSv), 0.032 mrem from air pathways plus 0.084 mrem and 0.092 mrem from the standard liquid pathways and the irrigation pathways, respectively. The all-pathway dose is 0.21 percent of the 100-mrem-per-year DOE dose standard. The 2011 all-pathway dose is about 91 percent more than the reported 2010 dose of 0.11 mrem (0.0011 mSv). Most of the increase is caused by the addition of the irrigation pathway dose. Without the irrigation pathway, the 2011 all-pathway dose would have been 0.12 mrem (0.0012 mSv), which is 9 percent more than the 2010 comparable all-pathway dose.

Figure 6-2 shows a ten-year history of SRS's all-pathway (airborne pathway plus liquid pathway) doses to the MEI.

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 MEI, 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 ("creekmouth 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

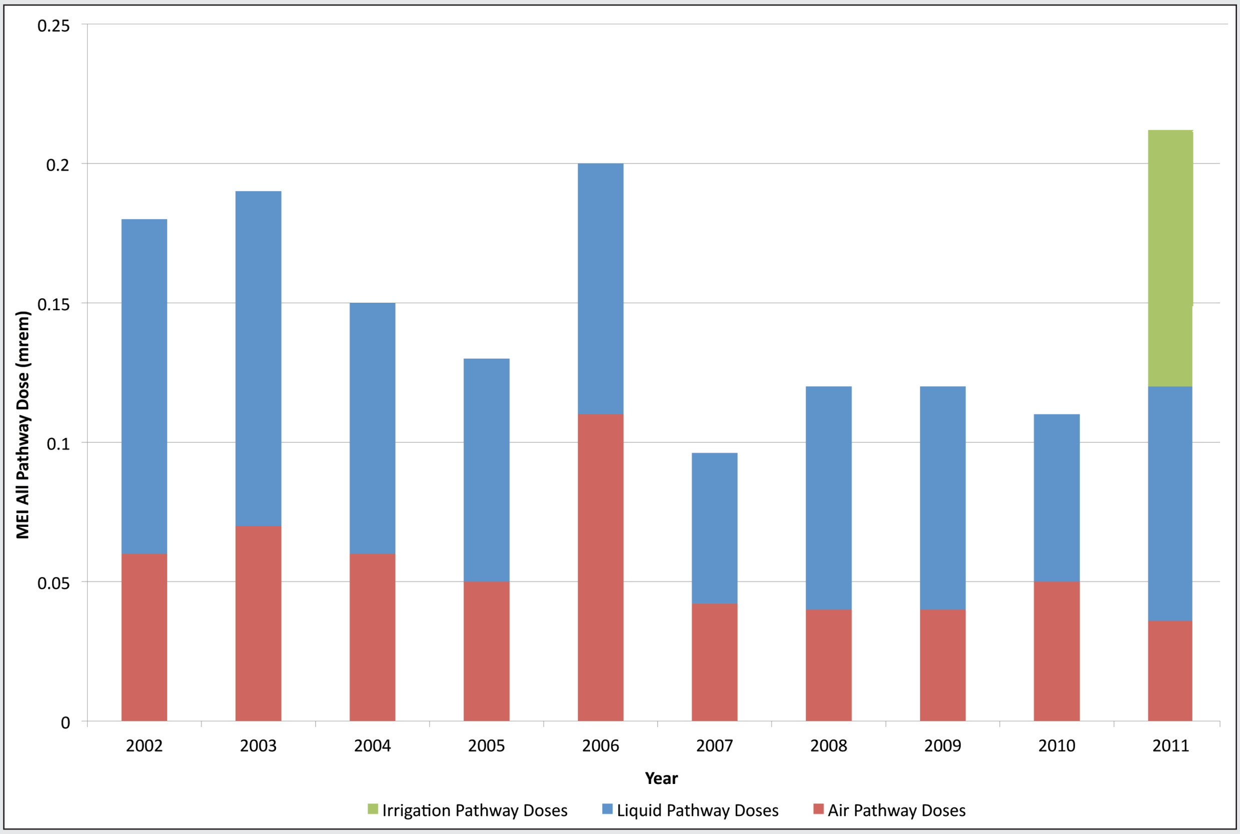

Figure 6–2 Ten-Year History of SRS Maximum Potential All-Pathway Doses

Note: Beginning in 2011, the irrigation pathway dose is included in the liquid pathway dose. Previous years do not include the irrigation pathway dose.

River Swamp, contaminated by SRS operations in the 1960s (Chapter 9):

- 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 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 2011, the maximum dose that could have been received by an actual onsite hunter was estimated at 14.7 mrem (0.147 mSv), or 14.7 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 14 animals (five deer and nine hogs) during the 2011 hunts. The hunter-dose calculation is based on the conservative assumption that this prolific hunter individually consumed the entire edible portion, almost 213 kilogram (kg) (469 pound (lb)) of the animals that this individual harvested from SRS in 2011.

Turkey Consumption Pathway—SRS hosts a special turkey hunt during April for hunters with mobility impairments. Twenty-eight turkeys were harvested in 2011. The dose assigned from each turkey was 1.0 mrem (0.01 mSv), which is the minimum assigned dose to each successful hunter. One of the hunters harvested four turkeys in 2011, so the maximum potential dose from this pathway was 4.0 mrem (0.04 mSv).

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

Table 6-4 2011 Maximally-Exposed-Individual All-Pathways and Sportsman Doses Compared to the DOE All-Pathways Dose Standard

	Committed Dose (mrem)	Applicable Standard (mrem)[a]	Percent of Standard (%)
Maximally-Exposed-Individual Dose			
All-Pathway (Liquid Plus Airborne Pathway)	0.21	100	0.21
Sportsman Dose			
Onsite Hunter	14.7	100	14.7
Creek-Mouth Fisherman[b]	0.068	100	0.068
Savannah River Swamp Hunter			
Offsite Hog Consumption	1.29		
Offsite Deer Consumption	0.74		
Soil Exposure[c]	2.90		
Total Offsite Deer Hunter Dose	3.64	100	3.64
Savannah River Swamp Fisherman			
Steel Creek Fish Consumption	0.068		
Soil Exposure[d]	0.28		
Total Offsite Fisherman Dose	0.35	100	0.35

[a] All-pathway dose standard: 100 mrem per year (DOE Order 5400.5)
[b] In 2011, 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

individuals harvested deer or hogs that had resided at SRS but then moved offsite. Based on these low probability assumptions and on the measured average concentration of cesium-137 in all deer (1.19 pCi/g) and hogs (1.33 pCi/g) harvested from SRS during 2011, the potential maximum doses from this pathway were estimated at 0.74 mrem (0.0074 mSv) for the offsite deer hunter and 1.3 mrem (0.013 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 2011 (Chapter 5) was estimated using the RESRAD code (Yu et al., 2001 and SRS EDAM 2010). 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 radionuclide contamination.

Using the worst-case radionuclide concentrations from the most recent comprehensive survey, which was 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 3.6 mrem (0.036 mSv). This potential dose is 3.6 percent of the DOE 100-mrem all-pathway dose standard.

Offsite Fisherman Dose

Creek-Mouth Fish Consumption Pathway — For 2011, radioanalyses were conducted of three species of fish (panfish, catfish, and bass) taken from the mouths of the five SRS streams. Three composites of up to five fish of each species are analyzed from each

sampling location. The resulting estimated doses are provided in data table 6-31. Beginning in 2011, at least one of the three composites had to have a significant result for an average concentration to be reported. In previous years, 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 0.068 mrem (0.00068 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 2011, a fisherman consumed 19 kg (42 lb) of bass caught exclusively from the mouth of Steel Creek. About 88 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 fish consumption dose (0.068 mrem) and the Savannah River Swamp fisherman soil exposure pathway were conservatively added together to obtain a total offsite fisherman dose of 0.35 mrem (0.0035 mSv). This potential dose is 0.35 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 a Fish Monitoring Plan in conjunction with EPA, GDNR and SCDHEC. This plan assesses radiological risk from the consumption of Savannah River fish, and presents a summary of the results in the annual SRS environmental report.

Risk Comparisons — For 2011, 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 (USEPA, 1999a)

For 2011, the maximum recreational fisherman dose was caused by the consumption of bass collected at the mouth of Steel Creek. Figure 6-3 shows a ten-year history of the annual potential radiation doses from consumption of Savannah River fish. Over the past seven years, no apparent trends can be discerned from these data 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 SRS, and
- the water quality at each SRS stream mouth, caused by annual changes in stream flow rates (turbulence) and water chemistry.

As indicated in table 6-5, the 50-year maximum potential lifetime risk from consumption of SRS creek-mouth fish was 2.8E-06, 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, 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

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	0.068	5.6E-08
30-Year Exposure	2.04	1.7E-06
50-Year Exposure	3.4	2.8E-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.

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 2011. 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 2011.

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, 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 SRS the option to dispose of potentially volume-contaminated material in Three Rivers Landfill, an onsite sanitary facility. In 2011, 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 absorbed dose limit to these organisms is 1.0 rad per day (0.01 gray (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 1.5) (SRS EDAM 2010), based on the DOE standard, 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 (BCG)s are based on the 1.0-rad-per-day dose limit for aquatic animals and a 0.1 rad-per-day limit for riparian animals. Aquatic plants are not considered. The terrestrial-systems evaluation includes exposures to terrestrial plants and animals and is based on a 1.0-rad-per-day dose limit for plants and a 0.1-rad-per-day dose limit for animals. These two terrestrial dose

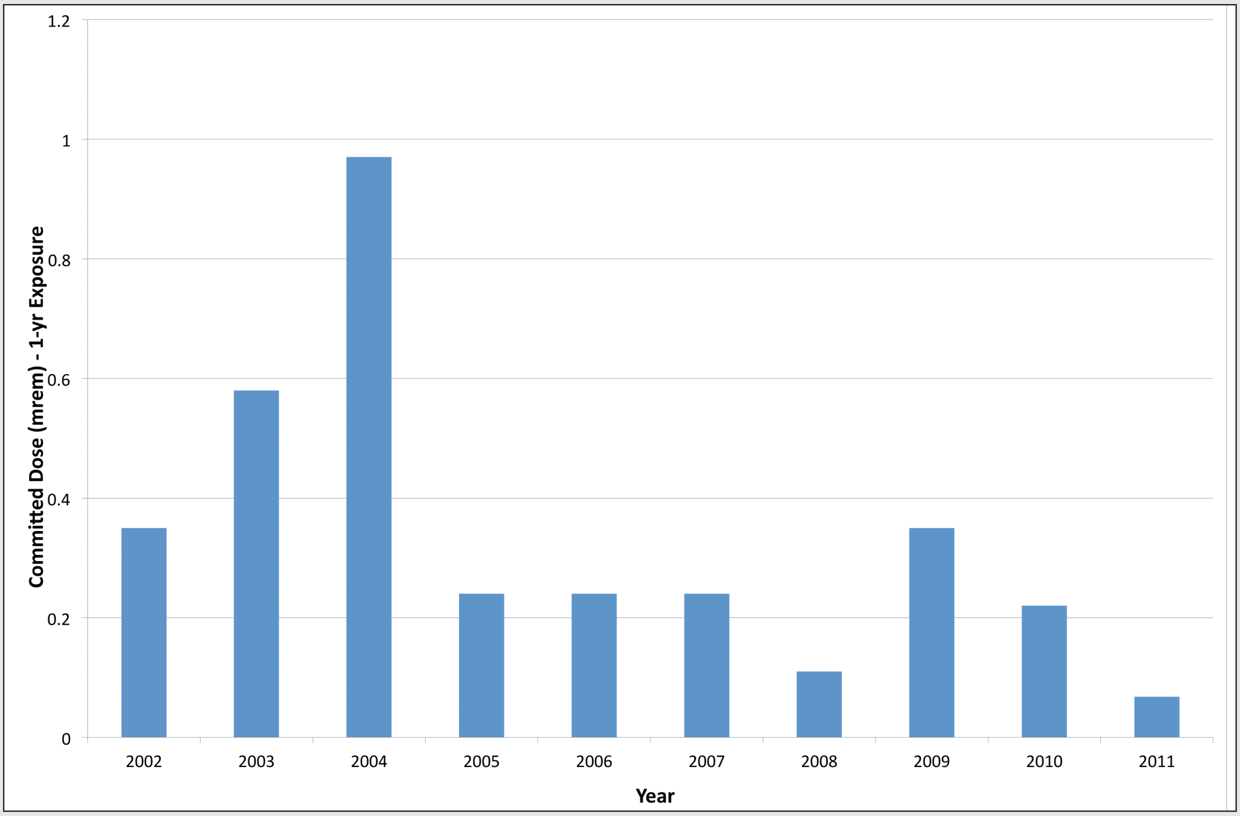

Figure 6–3 Ten-Year History of SRS Creek-Mouth Fisherman's Doses

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 applicable species.

For the aquatic-systems evaluation, initial screenings were performed in 2011 using maximum radionuclide concentration data from the ten 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 (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. 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 2011, all terrestrial locations and all aquatic locations passed their initial pathway screenings. All of the RESRAD-Biota screening results are provided in data table 6-33.