SRNL-STI-2011-00503
Revision 0

Keywords: *Environmental Dosimetry*

Retention: *Permanent*

Critical Radionuclide and Pathway Analysis for the Savannah River Site

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August 2011

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

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EXECUTIVE SUMMARY

During the operational history of SRS, many different radionuclides have been released from site facilities. However, as shown in this analysis, only a relatively small number of the released radionuclides have been significant contributors to doses/risks to offsite people. This report is an update to the analysis - Assessment of SRS Radiological Liquid and Airborne Contaminants and Pathways that was performed in 1997.

Performance Assessments for E-Area, Saltstone, F-Tank Farm, and H-Tank Farm and a Comprehensive SRS Composite Analysis have recently been completed at SRS. The critical radionuclides and pathways identified in these extensive reports are discussed and included in this analysis.

The following recommendations/considerations were identified during this assessment:

- The irrigation pathway (using Savannah River water) was not included in the 1997 analyses. However, the potential for agricultural irrigation does exist. Therefore, this pathway is included in this report and it is recommended that it be included in the official MEI and population doses that are reported in the annual SRS environmental report.
- The SRS-specific and regional cesium-137 background concentrations used for onsite deer, hogs, and turkeys have not been updated or validated since the early 1990's. It is recommended that these values be reestablished.
- Since 2006, a special turkey hunt has been held onsite. The maximum hunter doses from these hunts have not been reported in the annual SRS environmental report. It is recommended that these doses be documented in future reports.
- According to the SRS Fish Monitoring Plan, all non-negative radioanalytical results (even those below the minimum detectable activity) are included in the average radionuclide concentrations used for the dose/risk calculations. It is recommended that in the future the non-negative concentrations be included in the averages only if at least one of the three composites is significant.
- There are no species of fish in the Savannah River that are commonly eaten whole and there are no known critical sub-populations in the SRS area that routinely eat whole fish. Therefore, the dose/risk from the fish will continue to be based only on the edible portion of the fish. Consideration should be given to eliminating the analysis of the non-edible portions of fish, or, at least reducing it to measuring only for strontium-90 in fish bones.
- In the recent SRS PA's and CA, the following long-lived radionuclides were identified as being important in long-term dose projections (>100 y): chlorine-36, niobium-94, niobium-93m, radium-226, and nickel-59, cesium-135, carbon-14, and protactinium-231. These radionuclides have not been routinely analyzed for in SRS effluent or environmental samples. Consideration should be given to at least periodically analyzing for these radionuclides.

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1.0 INTRODUCTION

This report is an update to the analysis, *Assessment of SRS Radiological Liquid and Airborne Contaminants and Pathways,* that was performed in 1997 (Jannik 1997). An electronic version of this large original report is included in the attached CD to this report.

During the operational history (1954 to the present) of the Savannah River Site (SRS), many different radionuclides have been released to the environment from the various production facilities. However, as will be shown by this updated radiological critical contaminant/critical pathway analysis, only a small number of the released radionuclides have been significant contributors to potential doses and risks to offsite people.

The analysis covers radiological releases to the atmosphere and to surface waters, the principal media that carry contaminants offsite. These releases potentially result in exposure to offsite people. The groundwater monitoring performed at the site shows that an estimated 5 to 10 percent of SRS has been contaminated by radionuclides, no evidence exists from the extensive monitoring performed that groundwater contaminated with these constituents has migrated off the site (SRS 2011). Therefore, with the notable exception of radiological source terms originating from shallow surface water migration into site streams, onsite groundwater was not considered as a potential exposure pathway to offsite people.

In addition, in response to the Department of Energy's (DOE) Order 435.1, several Performance Assessments (WSRC 2008; LWO 2009; SRR 2010; SRR 2011) and a Comprehensive SRS Composite Analysis (SRNL 2010) have recently been completed at SRS. The critical radionuclides and pathways identified in these extensive reports are discussed and, where applicable, included in this analysis.

2.0 DESCRIPTION

The major steps in performing public radiation dose and risk assessments are:

1. Characterization and quantification of source terms
2. Calculation of atmospheric and surface water transport (dispersion/dilution)
3. Characterization and quantification of environmental pathway transport to humans (exposure pathways)
4. Calculation of radiation dose and subsequent potential risk

2.1 Source Terms

For the years 1954 through 2010, environmental release data, obtained from continuously monitored airborne and liquid effluent release points, were used in conjunction with calculated release estimates of unmonitored radionuclides (such as noble gases, carbon-14, and fission product tritium) to quantify the annual and total amounts of radioactive materials released to the environment from SRS. In addition, since 1991, an estimate of airborne radionuclide releases from unmonitored diffuse and fugitive sources is included in the atmospheric release totals. The radiological source terms used in this analysis were compiled from Hetrick et al. (1991) and from the subsequent annual SRS environmental reports (SRS 1990-2010); they are documented by radionuclide as an electronic attachment to this report.

2.2 Exposure Pathways

At SRS, the principal pathways by which offsite people may be exposed to released radionuclides are:

- Inhalation of radionuclides in air at the site boundary
- Ingestion of foodstuffs (i.e., leafy vegetables, grains, beef, and cow milk) raised at the site boundary and contaminated by airborne deposition or absorption of radionuclides

- Immersion in radioactive noble gas plumes at the site boundary
- External exposure from airborne radionuclides deposited on the ground at the site boundary

- Ingestion of Savannah River water contaminated by site liquid releases
- Ingestion of foodstuffs (i.e., leafy vegetables, grains, beef, and cow milk) raised downriver of the site and contaminated by aqueous (irrigation with river water) deposition or absorption of radionuclides

- Ingestion of Savannah River fish contaminated by site liquid releases
- Submersion in Savannah River water contaminated by site liquid releases
- External exposure from radionuclides deposited on the shoreline/sediments of the Savannah River

2.3 Transport and Exposure Models

To demonstrate compliance with DOE public dose limits (DOE 2011), SRS uses the concept of the maximally exposed individual (MEI) when calculating radiation doses to the public. However, because of the very conservative lifestyle assumptions used as input parameters in the dose models, no such person is known to exist.

The radiological transport and dosimetry models used in this analysis were

- MAXDOSE-SR - used for determining dose to the MEI from routine atmospheric releases (Jannik and Dixon 2011)
- POPDOSE-SR - used for determining dose to the surrounding 80-km population from routine atmospheric releases (Jannik and Dixon 2011)
- LADTAP XL - used for determining dose to the MEI and population from routine liquid releases to surface waters (Jannik et al. 2011)

MAXDOSE-SR and POPDOSE-SR are Savannah River National Laboratory (SRNL)-modified version of the U.S. Nuclear Regulatory Commission (NRC) computer programs called XOQDOQ (Sagendorf et al. 1982) and GASPAR (Eckerman et al. 1980). XOQDOQ calculates downwind radionuclide concentrations and GASPAR, using those concentrations, calculates doses to individuals at specified locations. Modifications to the NRC codes have been made to accommodate input of specific SRS physical and biological data and to expand the amount of printed output data. The basic calculation methods used in the XOQDOQ and GASPAR programs have not been modified.

LADTAP XL is a Microsoft Excel^{TM} spreadsheet version of LADTAP II, an unmodified version of the NRC program of the same name (Simpson and McGill 1980). LADTAP XL incorporates dilution models, described in NRC Regulatory Guide 1.113 (NRC 1977a).

Concerning calculations, many parameters—such as source terms, meteorological conditions, radionuclide dose factors, dose-to-risk factors, human consumption rates, and environmental dispersion—are considered in the models used to calculate offsite doses and risks at SRS. Most of the usage and transport parameters used at SRS have changed in varying degrees over the years. Therefore, in this analysis—to maintain consistency in year-to-year comparisons—the potential offsite MEI and population doses and risks from each year (1954-2010) have been calculated using the most recent meteorological, demographic, consumption, transport, and dispersion parameters as documented in Jannik and Dixon (2011) and Jannik et al. (2011). Some biological and physical parameters contained in Regulatory Guide 1.109 (NRC 1977b) are included as default assumptions in the codes, but many have been replaced with SRS-specific parameters (Jannik et al. 2010).

The external dose conversion factors used in the codes are taken from the U.S. Environmental Protection Agency's (EPA) Federal Guidance Report #12 (EPA 1993). The internal dose conversion factors are taken from International Commission on Radiological Protection (ICRP) Publication 72 (ICRP 1996).

2.3.1 *Atmospheric Dose Calculations*

MEI and population airborne pathway doses were calculated, using the MAXDOSE-SR and POPDOSE-SR codes, for the following pathways:

- Plume shine
- Inhalation
- Cow milk consumption
- Ground shine
- Vegetation consumption
- Meat (beef) consumption

2.3.1.1 Maximally Exposed Individual Air Pathway Doses

For each year, the MEI was assumed to reside continuously at the offsite location where the largest dose would be expected to occur. The MEI was assumed to be indoors 30% of the time; therefore, an external exposure transmission factor of 0.7 was used to account for shielding from buildings. The major parameters used in calculating doses to the MEI are summarized in Table 2-1 (Jannik et al. 2010).

Table 2-1. Major Parameters in MAXDOSE-SR for MEI Dose Calculations.

Parameter	Value
Inhalation (m^3/y)	8,000
Ingestion	
Cow's milk (L/y)	230
Meat (kg/y)	81
Leafy vegetables (kg/y)	43
Other vegetables (kg/y)	276
Release Location and Height	58000E, 62000N; height = 61m
Meteorological Data	H-Area Met Tower (2002-2006)

2.3.1.2 Population Air Pathway Doses

The POPDOSE-SR code calculates the annual air and ground deposition concentrations per unit release for each of 160 segments (16 wind direction sectors at 10 distances) within an 80-km radius of the center of SRS. The 2010 U.S. Census Data were used in the analysis (Jannik and Dixon 2011). The major parameters used in calculating doses to the surrounding population are summarized in Table 2-2 (Jannik et al. 2010).

Table 2-2. Major Parameters Used in POPDOSE-SR for Population Dose Calculations.

Parameter	Value
Inhalation (m^3/y)	5,548
Ingestion	
Cow's milk (L/y)	120
Meat (kg/y)	43
Leafy vegetables (kg/y)	21
Other vegetables (kg/y)	163
Release Location and Height	58000E, 62000N; Height = 61m
Meteorological Data	H-Area Met Tower (2002-2006)
Population	781,058 (2010 U.S. Census)

2.3.2 *Liquid Dose Calculations*

MEI and population liquid pathway doses were calculated, using the LADTAP XL code, for the following pathways:

- Water consumption
- Fish consumption
- Recreational external exposure (swimming, boating, and shoreline use)
- Vegetable, meat, and milk consumption (crops irrigated with river water)

2.3.2.1 Agricultural Irrigation Pathway

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 uses of Savannah River water exist downstream of SRS for agricultural irrigation purposes. In Jannik (1997), the irrigation pathway was not included in the analyses. However, the potential for agricultural irrigation does exist, especially on a small scale for the MEI exposure scenario. Therefore, this pathway is included in this report, and it is recommended that it be included in the official MEI and population doses that are reported in the annual SRS environmental report for documenting compliance with DOE Order 458.1 (DOE 2011). Including agricultural irrigation as a pathway is consistent with the SRS Composite Analysis (SRNL 2010).

Population 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 the 1,000-acre parcels is consumed by the population residing within 50 miles of SRS (Jannik et al. 2011).

2.3.2.2 Maximally Exposed Individual Liquid Pathway Dose

The offsite individual (MEI) who receives the maximum dose from SRS routine liquid releases is a hypothetical person who lives on the shore of the Savannah River just beyond the SRS boundary, at U.S. Hwy 301 near River Mile 118. Complete mixing of all SRS liquid effluents into the river water is assumed to have occurred and the dose from the consumption of aquatic food is calculated assuming the concentrations of radionuclides in edible tissues are under equilibrium or steady-state conditions with those in the surrounding water.

It is conservatively assumed that the MEI (1) uses untreated river water for drinking and foodstuff irrigation, (2) consumes river (RM 118) fish, and (3) receives external exposure from the shoreline, swimming, and boating. The major consumption and usage parameters used as inputs to LADTAP XL for calculating the MEI dose are summarized in Table 2-3 (Jannik et al. 2010).

Table 2-3. Major Parameters Used for LADTAP XL MEI Dose Calculations.

Parameter	Value
MEI Usage Rates	
Fish	19 kg/y
Drinking water	730 L/y
Shoreline	20 hr/y
Swimming	14 hr/y
Boating	44 hr/y
Cow's milk	230 L/y
Meat	81 kg/y
Leafy vegetables	43 kg/y
Other vegetables	276 kg/y
River Flow Rate at River Mile 118.8 (Annual Average)	9,700 cfs

2.3.2.3 Population Liquid Pathway Dose

A majority of the population doses resulting from SRS liquid releases are calculated for the people 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, 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 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) consumption of irrigated foodstuffs.

The major consumption and usage parameters used as inputs to LADTAP XL for calculating the population liquid pathway doses are summarized in Table 2-4 (Jannik et al. 2010).

Table 2-4. Major Parameters Used for LADTAP XL Population Dose Calculations.

Parameter	Value
Population Usage Rates	
Fish	9 kg/y
Invertebrate	2 kg/y
Drinking Water	337 L/y
Shoreline Time	82,200 person-hr/y
Swimming	29,500 person-hr/y
Boating	3,110,000 person-hr/y
Cow's milk	12 L/y
Meat	43 kg/y
Leafy vegetables	21 kg/y
Other vegetables	163 kg/y
River Flow Rate at Drinking Water Plants (Annual Average)	10,000 cfs

2.3.3 *Atmospheric and Liquid Pathway MEI Risk Calculations*

For the MEI, the total, lifetime stochastic risks from SRS radiological atmospheric and liquid releases were estimated using the total morbidity (fatal and non-fatal cancer-incidence) risk coefficient for 30-year-old adults (at time of exposure) documented by the National Research Council in BEIR VII (2006). The BEIR VII (sex-averaged) total morbidity risk coefficient, 8.7E-07 per mrem, includes factors for solid cancers and leukemia.

According to risk assessment guidance provided by EPA, the upper-bound value of 30 years was used to determine and compare projected lifetime risks (EPA 1993). For the projected 30-y lifetime risk comparisons, the total dose for the last 10-years (2001-2010) was multiplied by three and then multiplied by the BEIR VII risk factor. It is assumed that future SRS radiological operations and conditions will not vary significantly from this 10-y baseline.

The projected 30-y risks were determined using equation 1:

$$Risk_{projected} = 30 years \bullet \frac{8.3E-07}{mrem} \bullet \sum \overline{Dose}_i \qquad (1)$$

where

$Risk_{projected}$ = projected 30-y risks

$8.7E-07 \big/ mrem$ = BEIR VII total morbidity risk coefficient

$\sum_{i=2001}^{2010} Dose_i$ = total dose from radionuclide *i* for the last 10-years (2001-2010) (mrem)

The cumulative risks used in the comparisons were determined using equation 2:

$$Risk_{cumulative} = 8.7E-07\big/_{mrem} \bullet \sum_{i} \sum_{y=1954}^{2010} Dose_i(\mathrm{y}) \qquad (2)$$

where

$Risk_{cumulative}$ = cumulative risk for the years 1954-2010

$8.7E-07\big/_{mrem}$ = BEIR VII total morbidity risk coefficient

$Dose_i(\mathrm{y})$ = dose from radionuclide *i* during year *y* (mrem)

When comparing radiological risks, it should be noted that if a potential risk is determined to be less than 1.0E-06 (i.e., one additional case of severe detriment in a group of 1,000,000 people), then the risk is considered minimal. If a calculated risk is greater than 1.0E-04, then some form of corrective action or remediation usually is required. However, if a calculated risk falls between 1.0E-06 and 1.0E-04, the risk is considered acceptable if it is kept as low as reasonably achievable.

3.0 RESULTS

In Appendix A (included on the enclosed CD), the annual and cumulative airborne and liquid source terms are documented by radionuclide for the years 1954-2010. In addition, the source terms are graphically presented for all years and separately for the most recent 10-y period (2001-2010). In Appendices B-1 and B-2 (also included on the enclosed CD), the associated MEI and population doses are documented for the atmospheric and liquid pathways, respectively. The relative importance of each individual radionuclide was then determined, on a cumulative and a 30-y projected basis, by percentage of total risk for the MEI and percentage of total dose for the population. Also established was the relative percentage importance of individual exposure pathways for the most recent 10-y time period (2001-2010).

3.1 Critical Airborne Radionuclides and Pathways

The cumulative (1954-2010) and projected (30-y) MEI and population risk comparisons are provided in Tables 3.1 and 3.2, respectively, for each radionuclide that had a cumulative MEI risk over 1.0E-10 or a cumulative population dose over 1.0E-03 person-rem.

3.1.1 *MEI Airborne Pathway Risk Comparison*

During the early years of operations at SRS, short-cooled (about 100 days) fuel and target rods were processed in the separations areas because of the urgency to obtain special nuclear materials (Kantelo et al. 1993). Because of this, iodine-131 was the most critical airborne pathway radionuclide on an overall cumulative risk basis (1954-2010). During the 1960's, physical and administrative controls (e.g., increasing cooling time to a minimum of 200 days) were implemented to reduce iodine-131 releases. During subsequent years, tritium, iodine-129, plutonium-239, argon-41, and carbon-14 increased in relative importance. Their percentage of importance varied depending on operational missions and accidental releases.

From 1954-2010, over 50 radionuclides were measured or estimated to have been released from SRS, but only the cumulative airborne pathway MEI risks attributable to iodine-131, tritium, argon-41, iodine-129, plutonium-239, and carbon-14 releases were determined to be greater than 1.0E-06. However, on a projected 30-y risk basis, only tritium is estimated to potentially cause an airborne pathway MEI risk of greater than 1.0E-06 and only iodine-129 is greater than 1.0E-07 (Table 3-1).

In Figure 3-1, critical airborne radionuclides are presented by percent contribution to the total projected 30-y risk. As shown, tritium (85% of risk) is projected to be the most critical radionuclide followed by iodine-129 (9%), unidentified alpha-emitters (2%), plutonium-238+239 (2%), and all others combined (2%). As shown in Figure 3-2, atmospheric tritium oxide releases from SRS have remained relatively constant from 2001 to 2010 and have remained over 30,000 Ci/y during this period. Therefore, on a projected basis, tritium will continue to be the critical airborne radionuclide at SRS as long as the site's Tritium Facility missions continue to remain constant.

Table 3-1. Atmospheric Pathway MEI Risk Comparisons (Unitless).

Radionuclide (Historical)	Cumulative Risk (1954-2010)	Rank	Radionuclide (Past 10-y)	Projected 30-y Risk (Based on 10-y Dose)
I-131	**3.8E-05**	1	**H-3**	**1.6E-06**
H-3	**3.6E-05**	2	**I-129**	**1.7E-07**
Ar-41	**1.0E-05**	3	Alpha	2.9E-08
I-129	**2.9E-06**	4	Pu-238	2.4E-08
Pu-239	**2.9E-06**	5	Pu-239	2.0E-08
C-14	**1.8E-06**	6	Beta	1.4E-08
Beta	**8.7E-07**	7	Cs-137	9.2E-09
Kr-88	**6.7E-07**	8	Kr-85	5.1E-09
Pu-238	**6.3E-07**	9	Am-241	3.6E-09
Ru-106	**2.3E-07**	10	Sr-90	3.3E-09
Xe-135	**1.0E-07**	11	C-14	1.3E-09
Alpha	8.8E-08	12	U-238	7.8E-10
Kr-85	8.7E-08	13	Tc-99	7.1E-10
Cs-137	6.6E-08	14	U-234	7.1E-10
Xe-133	4.8E-08	15	Th-232	4.4E-10
Cm-244	4.6E-08	16	Cm-244	2.8E-10
Kr-85m	3.8E-08	17	Co-60	1.8E-10
Sr-90	3.2E-08	18	Np-237	1.4E-10
Ru-103	1.7E-08	19	U-235	8.0E-11
Kr-87	1.3E-08	20	Ce-144	5.8E-11
Am-241	6.1E-09	21	Cs-134	4.4E-11
Ce-144	2.4E-09	22	U-232	2.7E-11
Co-60	1.3E-09	23	Ru-106	1.6E-11
Cs-134	1.3E-09	24	Sb-124	1.5E-11
Nb-95	1.2E-09	25	Eu-154	1.0E-11
Zr-95	1.1E-09	26	Cm-242	1.0E-11
Ce-141	8.7E-10	27	Ru-103	4.8E-12
U-238	4.3E-10	28	Zn-65	3.8E-12
U-234	2.8E-10	29	Co-58	3.8E-12
Xe-131m	2.6E-10	30	Ce-141	1.8E-12
Tc-99	2.4E-10	31	Nb-95	1.5E-12
U-235	2.3E-10	32	Mn-54	1.5E-12
Cm-242	2.1E-10	33	I-131	1.3E-12
Th-232	1.5E-10	34	Np-239	5.6E-13

Note: Radionuclides in bold exceed a total risk of 1.0E-07.

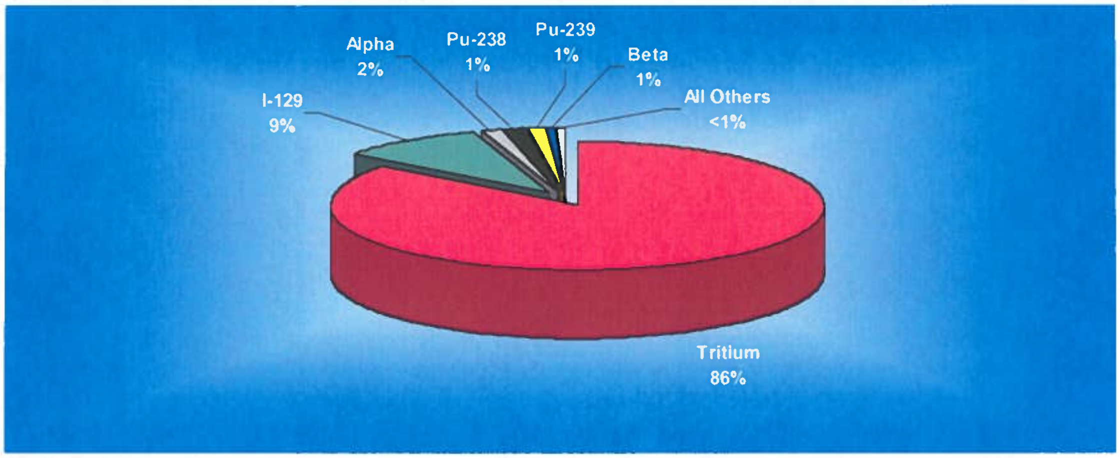


Figure 3-1. Critical Airborne Radionuclides at SRS by Percent of MEI Projected 30-y Risk.

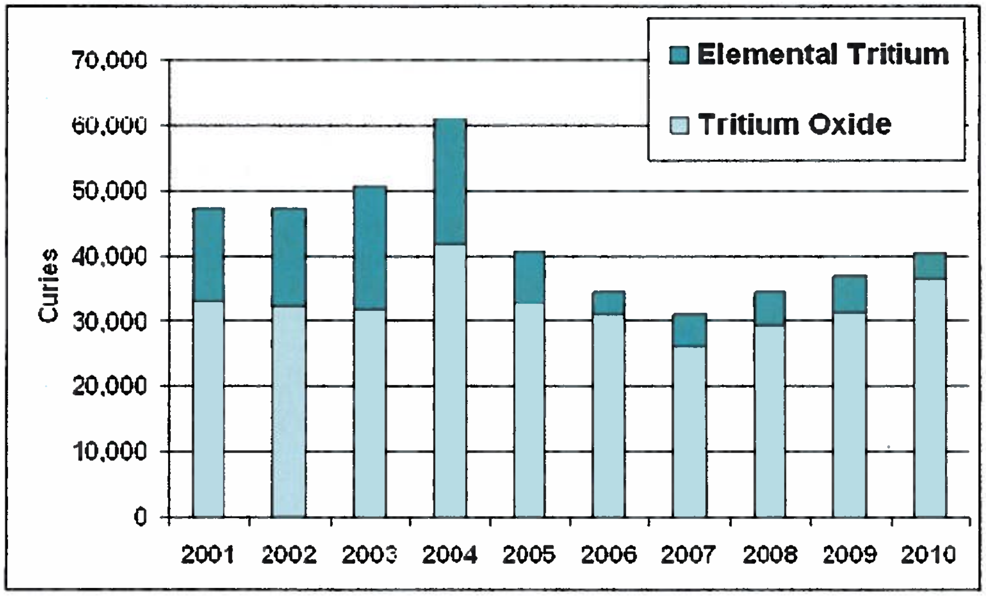


Figure 3-2. Ten-Year History of SRS Annual Atmospheric Tritium Releases.

3.1.2 *Critical Airborne Exposure Pathways*

As discussed, iodine-131 was the most critical contaminant during the early years of operations (1954-1960) and because of this, on a cumulative basis, cow milk and vegetation consumption were the most critical pathways, accounting for about 75% of the dose from iodine-131 releases. In subsequent years, tritium dominated the airborne pathway MEI risk. Inhalation and vegetable consumption became the critical pathways, and the plume pathway was negligible.

In Figure 3-3, critical airborne pathways are presented by percent contribution to the total projected 30-y risk (based on the past 10-y). Because tritium is projected to remain the critical airborne pathway radionuclide at SRS, the inhalation (44%) and vegetable consumption (36%) pathways will remain critical. Due to continuing iodine-129 releases from the site's Separations Areas the milk consumption pathway (19%) will remain important. The ground shine, plume shine, and meat consumption pathways are projected to be negligible, with each contributing less than 1% to the total 30-y risk.

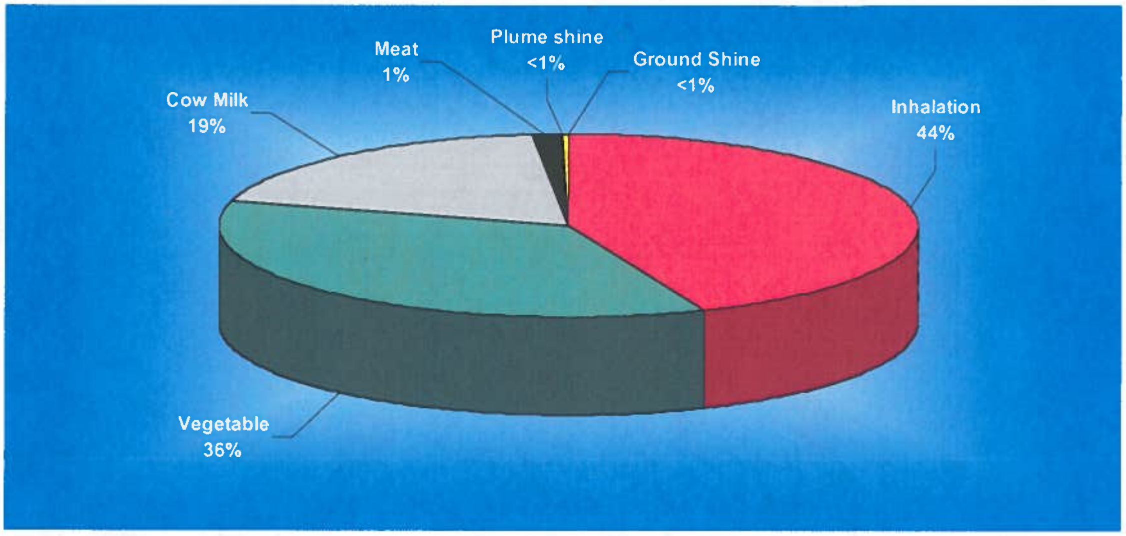


Figure 3-3. Critical Airborne Pathways at SRS by Percent of MEI Projected 30-y Risk.

3.1.3 *Population Airborne Pathway Dose Comparisons*

As shown in Table 3-2, the cumulative airborne pathway population doses follow a similar trend to the MEI risks. However, because of radioactive decay during transport, the shorter-lived radionuclides, such as iodine-131(half-life = 8 d), have less of an impact on the population dose than they do on the site-boundary MEI dose and risk. This is why tritium is the most critical radionuclide, on a cumulative population dose basis, and not iodine-131.

The projected 30-y population doses provided in Table 3-2 also follow a similar trend to the MEI doses and risks, with tritium (92%), iodine-129 (2%), unidentified alpha (2%), plutonium-238 (2%), and plutonium-239 (1%) being the critical radionuclides. However, because the amount of vegetables produced in the 80-km (50 mile) radius surrounding SRS is not sufficient to feed all of the people living in that area (Jannik et al. 2010), the importance of the vegetable consumption pathway is greatly reduced. On a projected 30-y population dose basis, the inhalation pathway (78%) becomes more important than in the MEI risk projections, the cow milk consumption pathway (19%) remains about the same, the vegetable consumption pathway is reduced to 2%, and the meat consumption, ground shine, and plume shine pathways all remain below 1% of the total projected dose.

Table 3-2. Atmospheric Pathway Population Dose Comparisons (person-rem).

Radionuclide (Historical)	Cumulative Risk (1954-2010)	Rank	Radionuclide (Past 10-y)	Projected 30-y Risk (Based on 10-y Dose)
H-3	**2.2E+03**	1	**H-3**	**9.9E+01**
I-131	**9.5E+02**	2	**I-129**	**2.2E+00**
Pu-239	**2.1E+02**	3	**Alpha**	**2.0E+00**
Ar-41	**1.9E+02**	4	**Pu-238**	**1.7E+00**
Pu-238	**4.5E+01**	5	**Pu-239**	**1.5E+00**
I-129	**3.7E+01**	6	Kr-85	5.3E-01
C-14	**3.6E+01**	7	Am-241	2.6E-01
Kr-88	**2.1E+01**	8	Cs-137	1.8E-01
Xe-133	**1.9E+01**	9	Beta	1.2E-01
Kr-85	**9.1E+00**	10	U-238	4.3E-02
Beta	**7.1E+00**	11	U-234	4.0E-02
Xe-135	**6.9E+00**	12	Th-232	2.8E-02
Alpha	**6.3E+00**	13	C-14	2.7E-02
Ru-106	**4.4E+00**	14	Sr-90	2.7E-02
Cm-244	**3.3E+00**	15	Cm-244	2.0E-02
Kr-85m	**1.7E+00**	16	Np-237	1.0E-02
Cs-137	**1.2E+00**	17	Co-60	8.7E-03
Ru-103	8.4E-01	18	Tc-99	5.0E-03
Am-241	4.4E-01	19	U-235	4.5E-03
Sr-90	2.5E-01	20	Ce-144	1.1E-03
Kr-87	1.6E-01	21	Cs-134	1.0E-03
Co-60	6.5E-02	22	U-232	9.5E-04
Nb-95	6.5E-02	23	Cm-242	7.9E-04
Zr-95	5.5E-02	24	Sb-124	7.3E-04
Ce-144	4.7E-02	25	Eu-154	4.5E-04
Ce-141	3.5E-02	26	Ru-106	3.0E-04
Cs-134	3.0E-02	27	Ru-103	2.3E-04
Xe-131m	2.7E-02	28	Co-58	2.0E-04
U-238	2.4E-02	29	Nb-95	8.1E-05
Cm-242	1.7E-02	30	Mn-54	7.9E-05
U-234	1.6E-02	31	Ce-141	7.2E-05
U-235	1.3E-02	32	Zn-65	6.5E-05
Th-232	9.5E-03	33	I-131	3.2E-05
Np-237	3.4E-03	34	Np-239	2.9E-05
Tc-99	1.7E-03	35	Zr-95	2.0E-05

Note: Radionuclides in bold exceed a total dose of 1.0 person-rem.

3.2 Critical Aqueous Radionuclides

In Table 3-3 and Table 3-4, cumulative (1954-2010) and projected (30-y) MEI risk and population dose comparisons, respectively, are provided to show the relative importance of each radionuclide measured or calculated to have been released to the Savannah River from SRS. The risks are based on the annual doses calculated using an average annual Savannah River flow rate of 9,700 cfs.

3.2.1 *MEI Liquid Pathway Risk Comparison*

Because they were released in relatively large quantities and/or have large bioaccumulation factors in freshwater fish, cesium-137, phosphorus-32, strontium-90, zinc-65, tritium, iodine-131, unidentified beta, and sulfur-35 were the most critical radionuclides at SRS on a cumulative MEI risk basis. The cumulative risks for each of these radionuclides were determined to be greater than 1.0E-06. Most of the releases of these radionuclides to SRS streams and seepage basins occurred during the early years of operations (prior to 1970) and usually were the result of abnormal operating events, such as fuel failures, cooling coil leaks, or faulty storage containers (Carlton 1998). Cesium-137 was the most critical radionuclide from 1954-2010. During the 1970s, physical and administrative controls (e.g., filters, redesigned fuel rods, and disassembly basin heat exchangers) were implemented to lessen the offsite impact of most fission and activation products (Carlton et al. 1992). During subsequent years, tritium, which cannot be practically filtered from effluent streams, increased in relative importance. During the most recent 10-y period (2001-2010) and, therefore, on a 30-y projected basis, tritium is the most critical liquid pathway MEI radionuclide, accounting for about 28% of the risk. Cesium-137 accounts for about 27% of the risk. However, on a projected 30-y risk basis, no radionuclides exceed a risk of 1.0E-06, but tritium, cesium-137, iodine-129, alpha, beta, technetium-99, and strontium-90 all exceed a potential risk of 1.0E-07.

As shown in Figure 3-4, over the past 10-y, direct process liquid discharges of tritium account for about 20% or less of the total amount of tritium released to the Savannah River from SRS. The remainder is legacy tritium that is migrating out of site seepage basins and the Solid Waste Disposal Facility (SRS 2010). As seen in Figure 3-4, total aqueous tritium releases from SRS continue a general downward trend, which will decrease its importance in the future. In Figure 3-5, critical aqueous radionuclides are presented by percent contribution to the total projected 30-y risk. As shown, tritium (28%) and cesium-137 (27%) are projected to be the most critical radionuclides. However, as anticipated in Jannik (1997), iodine-129 (14%) and technetium-99 (7%), which are long-lived and highly mobile in the environment, have become more important on a percentage risk basis as site aqueous tritium releases have declined. Strontium-90, which has a 29-y half-life, continues to be important (5% of projected risk) at SRS because of its mobility in the environment. Unidentified alpha and beta releases are conservatively included in the assessment and they account for 10% and 8% of the projected risk, respectively. Most of these unidentified releases are probably naturally occurring radionuclides such as uranium, thorium, and potassium-40, but they are not subtracted out of the effluent release totals. The dose and risk from the unidentified alpha and beta releases are based on the dose factors for plutonium-239 and strontium-90, respectively.

Table 3-3. MEI Liquid Pathway Risk Comparison

Radionuclide (Historical)	Cumulative Risk (1954-2010)	Rank	Radionuclide (Past 10-y)	Projected 30-y Risk (Based on 10-y Dose)
Cs-137	**1.8E-04**	1	**H-3**	**8.5E-07**
P-32	**7.8E-05**	2	**Cs-137**	**8.4E-07**
Sr-90	**3.6E-05**	3	**I-129**	**4.4E-07**
Zn-65	**1.6E-05**	4	**Alpha**	**3.1E-07**
H-3	**1.6E-05**	5	**Beta**	**2.4E-07**
I-131	**5.7E-06**	6	**Tc-99**	**2.2E-07**
Beta	**5.3E-06**	7	**Sr-90**	**1.7E-07**
S-35	**2.2E-06**	8	Pu-238	1.7E-08
Sr-89	**6.5E-07**	9	Am-241	1.9E-09
Co-60	**6.0E-07**	10	Pu-239	1.5E-09
Alpha	**4.4E-07**	11	U-234	1.1E-09
Ba-La-140	**3.9E-07**	12	Co-60	1.9E-10
I-129	**3.7E-07**	13	Zn-65	1.9E-10
Y-91	**3.7E-07**	14	Cm-244	1.7E-10
Np-239	**3.6E-07**	15	U-235	4.1E-11
Ce-141,144	**2.7E-07**	16	Np-237	3.2E-13
Cs-134	**2.4E-07**	17	**Total**	**3.2E-06**
Cr-51	**2.2E-07**	18		
Zr-Nb-95	**1.5E-07**	19		
Tc-99	7.2E-08	20		
Cm-244	6.6E-08	21		
Pm-147	4.2E-08	22		
Pu-238	4.1E-08	23		
Pu-239	6.7E-09	24		
Mo-99	3.8E-09	25		
U-234	2.8E-09	26		
Mn-54	1.4E-09	27		
Am-241	6.9E-10	28		
U-235	2.4E-10	29		
Sb-124,125	7.6E-11	30		
Ru-106	5.3E-11	31		
Np-237	1.1E-13	32		

Note: Radionuclides in bold exceed a total risk of 1.0E-07.

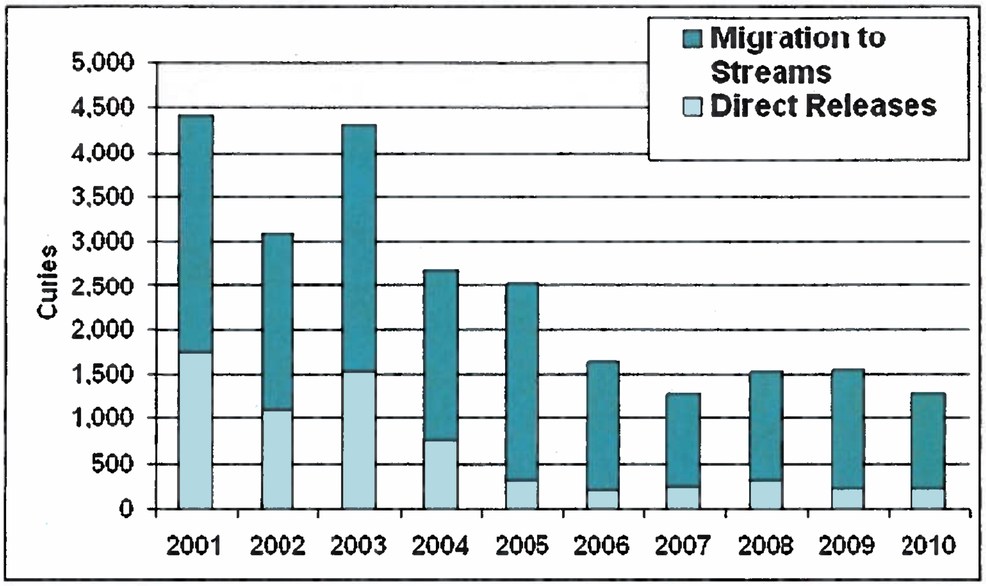


Figure 3-4. Ten-Year History of Tritium Releases to SRS Streams.

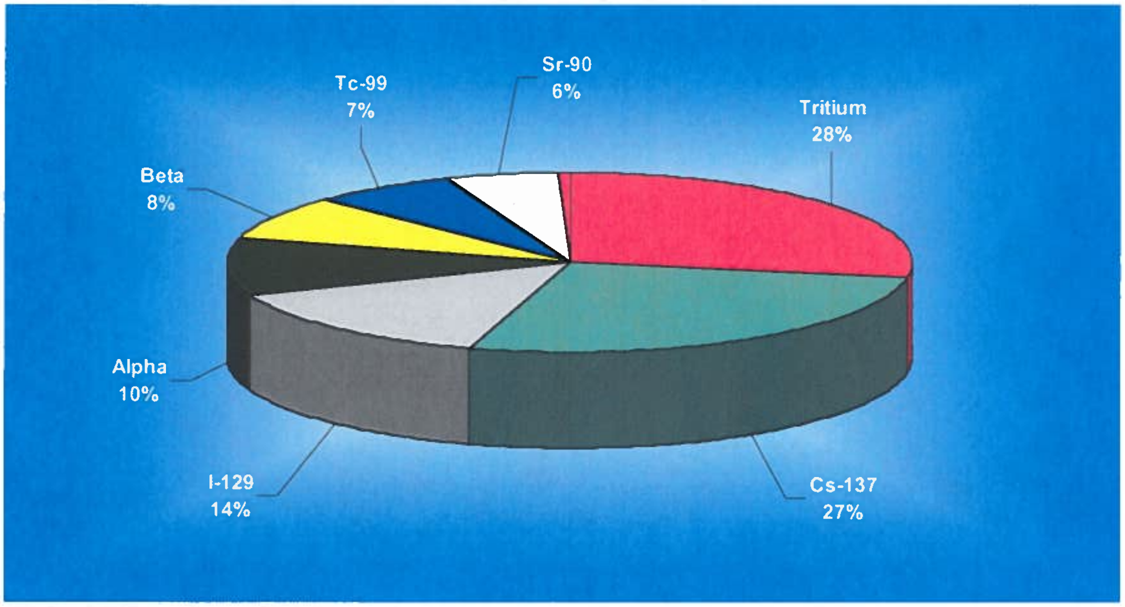


Figure 3-5. Critical Aqueous Radionuclides at SRS by Percent of Projected 30-y Risk.

3.2.2 *Critical MEI Liquid Exposure Pathways*

As discussed, cesium-137 was the most critical radionuclide on a cumulative basis (especially during the years 1954-1975) and because the fish consumption pathway accounts for about 90% of the dose from cesium-137, it is by far the most critical pathway during this time period. For the projected 30-y MEI risk, the critical liquid pathways are presented by percent contribution to the risk in Figure 3-6.

In Jannik (1997), the food ingestion pathway (following agricultural irrigation with Savannah River water) was not included in the analyses, but was included in this updated assessment. For the past 10-y and, therefore, on a 30-y projected basis, the irrigated food ingestion pathway is now the critical pathway at SRS accounting for about 53% of the projected risk (Figure 3-6). The fish consumption pathway accounts for 27% and the water ingestion pathway accounts for 19% of the 30-y projected risk. The combined recreation pathways (swimming, boating, and shoreline) account for less than 1% of the liquid pathway MEI risk.

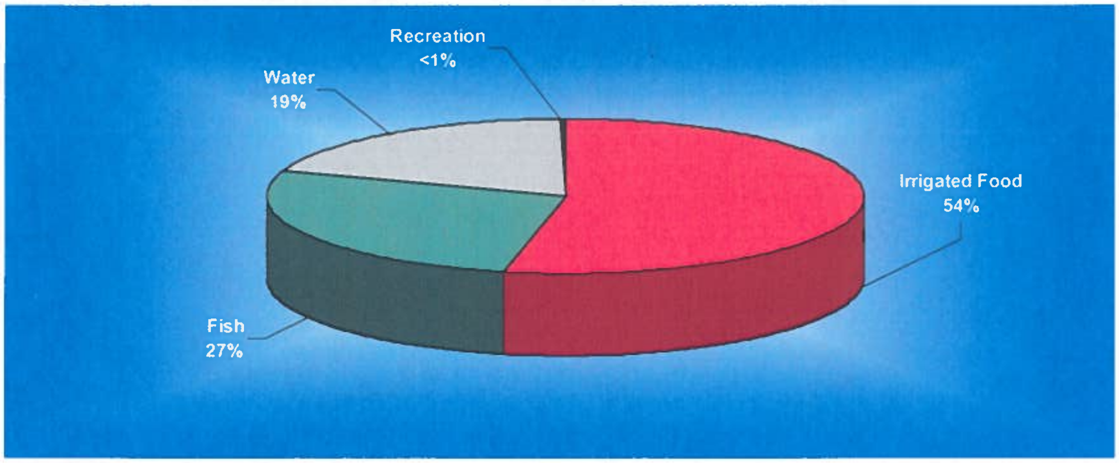


Figure 3-6. Critical Liquid Pathways at SRS by percent of Projected 30-y Risk.

3.2.3 *Population Liquid Pathway Dose Comparisons*

As shown in Table 3-4, the liquid pathway population doses follow a similar trend to the MEI risks. However, zinc-65, which has an extremely large bioaccumulation factor (50,000 L/kg) in saltwater invertebrates, was the most critical radionuclide for the cumulative (1954-2010) population dose. In addition, the short-lived radionuclides such as phosphorus-32 and sulfur-35 have less of an impact on the population dose than they do on the site-boundary MEI dose and risk.

The projected 30-y population doses provided in Table 3-4 also follow a similar trend to the MEI doses and risks. However, because of the three downriver drinking water plants, the drinking water pathway (60% of projected 30-y dose) is more important than the irrigated food ingestion (31%), fish consumption (9%), or recreation (<1%) pathways. As shown in Table 3-4, tritium and unidentified alpha are the most critical radionuclides based on the projected 30-y population doses, followed by iodine-129, unidentified beta, cesium-137, strontium-90, and technetium-99.

Table 3-4. Liquid Pathway Population Dose Comparisons (person-rem).

Radionuclide (Historical)	Cumulative Dose (1954-2010)	Rank	Radionuclide (Past 10-y)	Projected 30-y Dose (Based on 10-y Dose)
Zn-65	**1.4E+03**	1	**H-3**	**4.2E+01**
Cs-137	**1.0E+03**	2	**Alpha**	**1.3E+01**
Sr-90	**8.1E+02**	3	**I-129**	**9.4E+00**
H-3	**7.9E+02**	4	**Beta**	**5.4E+00**
P-32	**2.7E+02**	5	**Cs-137**	**4.9E+00**
I-131	**1.4E+02**	6	**Sr-90**	**3.8E+00**
Beta	**1.2E+02**	7	**Tc-99**	**3.8E+00**
Co-60	**4.1E+01**	8	Pu-238	6.6E-01
Y-91	**2.2E+01**	9	Pu-239	6.0E-02
Sr-89	**2.0E+01**	10	Am-241	4.2E-02
Alpha	**1.7E+01**	11	U-234	3.0E-02
Ba-La-140	**1.4E+01**	12	Zn-65	1.6E-02
Ce-141,144	**1.3E+01**	13	Co-60	1.3E-02
S-35	**1.2E+01**	14	Cm-244	7.6E-03
Cr-51	**8.6E+00**	15	U-235	1.2E-03
Np-239	**8.4E+00**	16	Np-237	9.4E-06
I-129	**8.0E+00**	17		
Cm-244	**3.0E+00**	18		
Pm-147	**2.6E+00**	19		
Pu-238	**1.6E+00**	20		
Cs-134	**1.3E+00**	21		
Tc-99	**1.3E+00**	22		
Pu-239	2.6E-01	23		
Mo-99	1.2E-01	24		
U-234	8.0E-02	25		
Mn-54	4.3E-02	26		
Am-241	1.5E-02	27		
U-235	6.8E-03	28		
Sb-124,125	2.4E-03	29		
Ru-106	1.5E-03	30		
Np-237	3.1E-06	31		
Zr-95	5.5E-07	32		

Note: Radionuclides in bold exceed a total dose of 1.0 person-rem.

3.3 Nontypical Exposure Pathways

Nontypical exposure pathways, not included in the standard calculations of the dose to the maximally exposed individual, are considered and quantified separately. These pathways apply to relatively low probability or unique exposure scenarios.

3.3.1 *Critical Subpopulations*

Within 80 km of SRS are no known sensitive subpopulations (e.g., Native Americans) with unique lifestyles or diets that should be considered separately from the standard consumption/exposure pathways.

3.3.2 *Onsite-Hunter Deer, Hog, and Turkey Consumption Pathway*

Controlled hunts of deer and feral hogs are conducted at SRS for approximately six weeks each year. Hunt participants are volunteers who are chosen by a lottery. Before any harvested animal is released to a hunter, SRS personnel perform a field analysis for cesium-137 concentrations. Like fish, deer and hogs have a high bioaccumulation factor for cesium. Since 1992, the estimated dose from the consumption of the harvested deer and hog meat has been determined for each hunter. The hunter-dose calculation is based on the assumption that the hunter individually consumes the entire edible portion of the animals he harvested from SRS. A background concentration of 5 pCi/g is subtracted out before the hunter dose is calculated. This background value was established in the early 1990's and was based on deer concentrations measured at other large government facilities in GA and SC (Fort Stewart and Fort Jackson), which are similar to SRS in that the global fallout from weapons testing remains somewhat unmitigated by farming and other anthropogenic activities. However, because the physical half-life of cesium-137 is 30-y and its effective (physical plus ecological) half-life in the SRS area has been shown to be about 14-15 y (Paller et al. 2008), it is recommended that a SRS-specific background concentration be re-established and confirmed on a periodic basis.

The maximum onsite-hunter doses from 2001 through 2010 are shown in Table 3-5. The 30-y projected risk for this pathway (5.6E-04) is based on the 10-y average. However, it should be noted that the same hunter seldom receives the maximum potential dose for more than one year. The maximum annual dose from the onsite-hunter deer and hog consumption pathway typically exceeds all standard MEI pathways combined and, as shown in Table 3-5, exceeds all other sportsman dose scenarios. Therefore, deer consumption by the onsite hunter is the critical exposure pathway for SRS.

Since 2006, a special turkey hunt for the mobility impaired has been held onsite. In 2010, this hunt resulted in the harvest of 42 turkeys (SRS 2011). Because of the relatively small size of the turkeys (as compared to deer and hogs) and because the cesium-137 concentrations measured in the field are usually around the regional background of 1.0 pCi/g, the doses from the turkey consumption pathway are much lower than from deer and hog. The maximum doses from the turkey hunts have not been reported in the annual SRS environmental report. It is recommended that, for completeness, these doses be documented in future reports and that a regional background concentration be re-established and confirmed on a periodic basis.

3.3.3 *Offsite-Hunter Deer and Hog Consumption Pathway*

This pathway assumes that deer and hogs that had resided on SRS moved offsite prior to being harvested. The estimated doses are based on the maximum annual meat consumption rate of 81 kg/y (Jannik et al. 2010) and on the average concentration of cesium-137 in all of the deer and hogs harvested during the annual onsite hunts. A background concentration of 1 pCi/g is subtracted out before the off-site hunter dose is calculated. This background value was established in the early 1990's and was based on deer concentrations measured at control locations in the four quadrants approximately 80-km from the center of the site. Because it has been about 20-y since this background value was established, it is recommended that a regional background concentration be re-established and confirmed on a periodic basis.

The maximum deer and hog offsite hunter doses from 2001 through 2010 are shown in Table 3-5. The 30-y projected risk for this pathway (1.5E-04) is based on the 10-y average. This pathway typically exceeds all standard MEI pathways combined.

Table 3-5. Maximum Sportsman Doses and Projected 30-y Risks (2001-2010).

Year	Onsite Hunter (mrem)	Offsite Hunter (mrem)	Sav. Swamp (Offsite) Hunter (mrem)	Creek Mouth Fisherman (mrem)	Sav. Swamp (Offsite)Fisherman (mrem)
2001	14.0	0.5	4.9	0.26	0.64
2002	39.5	12.2	16.6	0.35	0.62
2003	15.6	1.2	5.6	0.58	0.66
2004	70.8	17.3	21.7	0.97	0.71
2005	8.8	5.4	8.3	0.24	0.52
2006	22.0	8.9	9.6	0.24	0.52
2007	9.0	2.3	4.8	0.24	0.50
2008	13.0	7.7	8.6	0.11	0.37
2009	8.4	1.5	4.4	0.35	0.38
2010	12.4	0.4	3.3	0.22	0.40
30-y Risk (unitless)	5.6E-04	1.5E-04	2.3E-04	9.3E-06	1.4E-05

3.3.4 *Savannah River Swamp Hunter Soil Exposure Pathway*

The potential dose to an offsite recreational hunter exposed to SRS legacy contamination in Savannah River Swamp soil on the privately owned Creek Plantation is estimated using the RESRAD code (Yu et al. 2001). It was assumed that this recreational sportsman hunted for 120 hours during the year (eight 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, 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 is estimated and added to the maximum offsite hunter to obtain the combined "Savannah River Swamp Offsite Hunter" dose. The maximum doses from 2001 through 2010 for this pathway are shown in Table 3-5. The 30-y projected risk for this pathway (1.5E-04) is based on the 10-y average. This pathway typically exceeds all standard MEI pathways combined and is the second most critical pathway at SRS.

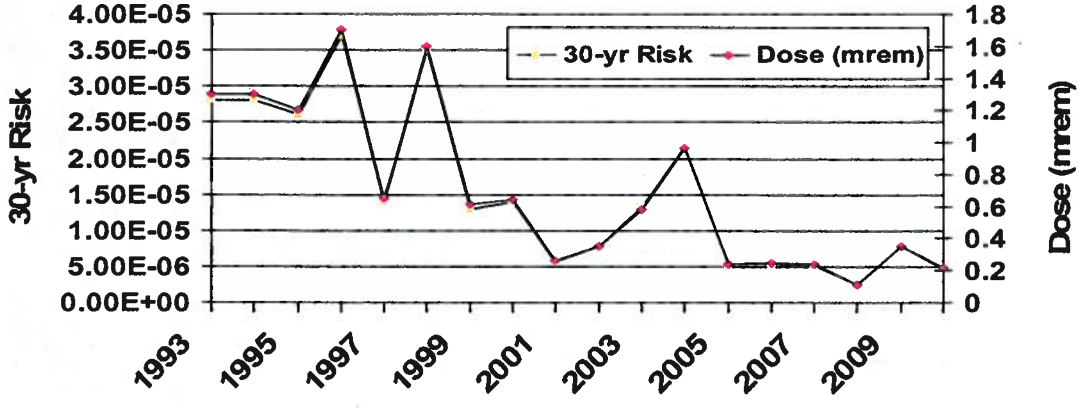
3.3.5 *Fish Consumption Pathway*

In EPA (1991), two fish-consumption pathways are considered – the recreational and the subsistence fisherman scenarios. In Burger et al. (1999), it was shown that some people who fish on the Savannah River reportedly eat a subsistence level (>50 kg/y) of fish each year, but not necessarily fish caught exclusively from the Savannah River. Also, a majority of the fisherman interviewed in Burger et al. (1999) were located above SRS, especially around the New Savannah Bluff Lock and Dam near Augusta, Georgia. In the 2002 and 2008 GA Department of Natural Resources Creel Surveys (summaries included in the CD attached to this report), the average success rate for catching fish in the lower Savannah River is about 0.25 kg of whole fish per hour, which equates to over 14 hours per kg of edible fish. Therefore, because of 1) SRS's relatively remote location and 2) the relatively low productivity of the lower Savannah River (especially for game fish), the recreational fisherman, as opposed to the subsistence fisherman, is considered the more reasonable scenario and should continue to be used for MEI and fisherman dose assessments at SRS.

During 1991 and 1992, a U.S. House of Representatives Appropriations Committee requested that SRS develop a plan to evaluate risk to the public from fish collected from the Savannah River. In response to this request, SRS developed—in conjunction with EPA, GDNR, and SCDHEC—the SRS Fish Monitoring Plan, which is reviewed and updated as needed every year. 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 (SRS 2010).

In the dose and risk calculations performed as part of the SRS Fish Monitoring Plan, it is conservatively assumed that the recreational "Creek Mouth Fisherman" fishes for a single species of fish from the mouth of the worst-case SRS stream. Since 1992, samples of fish have been systematically taken from the mouths of the five SRS streams, and the subsequent recreational fisherman doses and 30-y risks have been estimated using a maximum consumption rate of 19 kg/y. The results are shown graphically in **Figure 3-7**. The doses from this pathway for the past 10-y (2001-2010) are provided in the Table 3-5 column labeled "Creek Mouth Fisherman."

Figure 3-7. Maximum Fisherman Doses and Projected 30-y Risks (1992-2010).



To be conservative, and according to the SRS Fish Monitoring Plan, all non-negative radioanalytical results (even those below the minimum detectable activity) are included in the average radionuclide concentrations used for the dose/risk calculations. Originally (beginning in 1992) edible and non-edible portions were composited by species for each location and analyzed for gross alpha/beta, tritium, strontium-90, cesium-137 (and other gamma emitters), plutonium-238, and plutonium-239. However, during the 1990's and early 2000's, the fisherman doses and risks were dominated by cesium-137 (typically >90%).

In subsequent years, several other radionuclides have been added to the radioanalytical suite for the SRS Fish Monitoring Plan. These include iodine-129, uranium isotopes, technetium-99, americium-241, curium-244, and neptunium-237. By continuing to conservatively include all non-negative analytical results, these added radionuclides have distorted the importance of cesium-137. For example, in 2010, cesium-137 accounted (on average) for slightly less than 50% of the dose/risk. Iodine-129 now accounts (on average) for about 40% of the dose/risk even though just three out of the 90 edible composited samples analyzed contained significant (detectable) concentrations of iodine-129. Therefore, it is recommended that in the future the non-negative concentrations be included in the averages only if at least one of the three composites (by species) is significant.

As mentioned, the SRS Fish Monitoring Plan requires that edible and non-edible portions of the composited fish samples be analyzed for the various radionuclides. No fish species (such as smelt) exist in the Savannah River that are commonly eaten whole. No known critical sub-populations occur in the SRS area that routinely eat whole fish as a common practice. In Burger et al. (1999), a majority of the Savannah River fisherman interviewed reportedly have eaten "whole fish." However, "whole fish" was not defined, nor was the frequency of this practice. However, for the species commonly fished for in the Savannah River (see GDNR Creel Surveys), the non-edible portion is in fact non-edible and avoided most of the time. Therefore, the dose/risk from the fish consumption pathway will continue to be based only on the edible portion of the fish. Consideration should be given to eliminating the analysis of the non-edible portions of fish, or, at least reducing it to only measuring for strontium-90 in fish bones.

As shown in Table 3-5, the 30-y projected Creek Mouth Fisherman fish consumption pathway risk, which is based on the 10-y average dose, is 9.6E-06, which is more than the 3.1E-06 projected risks for the standard MEI liquid pathways combined (Table 3-3).

3.3.6 *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 in soil 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 is estimated and added to the maximum offsite fisherman dose to obtain the combined "Savannah River Swamp Offsite Fisherman" dose. The maximum doses from 2001 through 2010 for this pathway are shown in Table 3-5. The 30-y projected risk for this pathway (1.4E-05) is based on the 10-y average. This pathway typically exceeds all standard MEI pathways combined and is the fourth most critical pathway at SRS.

3.3.7 *Other Non-typical Wildlife Consumption Pathways*

Other SRS aquatic, terrestrial, and riparian animals, such as waterfowl, amphibians, raccoons, beavers, rabbits, and reptiles, may leave the site and be consumed by people in the surrounding areas. All of these animals have been extensively studied over the years at SRS by researchers at the Savannah River Ecology Laboratory (SREL). Refer to the SREL website: (http://www.srel.edu) for a complete listing of related publications.

However, because they travel over much larger ranges and are widely hunted and consumed by people, waterfowl are typically of most concern to SRS stakeholders. In 1986, in support of the site's Comprehensive Cooling Water Study, SREL issued a final report of a multiyear study of waterfowl at SRS (Mayer et al. 1986). This study concluded that offsite consumption of waterfowl posed a minor risk to offsite hunters. Part of the reason for this conclusion is that waterfowl have been shown to have a relatively rapid elimination rate for cesium upon leaving a contaminated area. In Fendley et al. (1976), the biological half-life for wood ducks was shown to average 5.6 d with a range of 3.2 to 9.3 d.

In addition, insufficient data exist to accurately or practically determine reasonable maximum consumption rates and concentrations to calculate potential doses from non-typical wildlife consumption pathways. However, doses and risks from these less common consumption pathways are considered to be bounded by those determined from the deer/hog consumption pathways.

3.3.8 *Goat Milk Consumption Pathway*

Goats are raised on some farms in the SRS vicinity. It has been shown that the annual MEI dose would increase about 10% if goat milk were substituted for the customary cow milk pathway (SRS 2011). Most of this difference is from tritium oxide because the transfer factor (fraction of the daily intake of the nuclide that appears in each liter of milk) for tritium oxide is 17 times more for goat milk than for cow milk (NRC 1977b). However, because goat milk consumption is far less common and seldom a complete substitute for cow milk, cow milk will remain the primary parameter for the milk consumption pathway.

3.4 SRS Performance Assessments and Composite Analysis

In response to DOE (1999), several Performance Assessments and a Comprehensive Composite Analysis have recently been completed at SRS. These reports document the potential pathways and likely radionuclides of concern at SRS. The critical radionuclides and pathways identified in these comprehensive reports are discussed.

3.4.1 *Performance Assessments*

Recently, four major Performance Assessments (PAs) have been completed at SRS (WSRC 2008; LWO 2009; SRR 2010; SRR 2011). These assessments are very conservative in that they must consider a hypothetical intruder living on the waste site and the concentrations in groundwater at 100 m. In addition to the hypothetical intruder, the PAs have a point of compliance at the site boundary for potential airborne releases from the facilities. However, neither of these pathways is directly applicable to the near-term MEI doses documented in the SRS environmental report, but they do give an indication of the critical radionuclides in the distant future (100-10,000 y).

3.4.1.1 E-Area Low Level Waste Facility

The critical radionuclides identified in the E-Area LLW Facility PA (WSRC 2008) were iodine-129, tritium, carbon-14, and technetium-99, mainly from the drinking water pathway.

3.4.1.2 Saltstone Disposal Facility

The critical radionuclides identified in the Saltstone Disposal Facility PA (LWO 2009) were radium-226, iodine-129, technetium-99, neptunium-237, and protactinium-231, with radium-226 and iodine-129 being the principal contributors to the projected dose within 10,000 y. Water ingestion (47%), fish ingestion (16%), and vegetable ingestion (37%) were identified as the critical pathways in this assessment.

3.4.1.3 F-Tank Farm

The critical radionuclides identified in the F-Tank Farm PA (SRR 2010) were radium-226, technetium-99, neptunium-237, and cesium-135, with radium-226 and neptunium-237 being the principal contributors to the projected dose greater than 10,000 y. Water ingestion (64%) and vegetable ingestion (29%) were identified as the critical pathways leading to the highest dose within 10,000 y.

3.4.1.4 H-Tank Farm

The critical radionuclides identified in the H-Tank Farm PA (SRR 2011) were radium-226, technetium-99, niobium-93m, neptunium-237, carbon-14, and cesium-135, with technetium-99 being the principal contributor to the projected dose greater than 10,000 y. Water ingestion (73%) and vegetable ingestion (20%) were identified as the critical pathways leading to the highest dose within 10,000 y.

3.4.2 *Composite Analysis*

A sitewide Composite Analysis (CA) also is required by DOE (1999). DOE views a CA as a planning tool relative to the end state radiological protection of the public. As such a CA is not a tool to evaluate current or near term (<2025) compliance but rather a long-term management and planning tool.

The CA includes the following three additional exposure pathways that are not included in the SRS site environmental report (SER): ingestion of garden soil, external irradiation from garden soil, and inhalation of garden dust. These additional CA exposure pathways were found to be insignificant contributors to the overall CA dose (SRNL 2010). A comparison of the types of dose projections provided by the SER and CA is provided in Table 3-6.

Table 3-6. Comparison of SER and CA Dose Pathways.

CA Exposure Pathway	SER MEI	SER Irrigation	SER Creek-Mouth Fisherman
Ingestion of surface water	X		
Ingestion of vegetables, beef, and milk		X	
Ingestion of garden soil			
External irradiation from garden soil			
Inhalation of garden dust			
Ingestion of fish	X		X
External irradiation from shoreline	X		
External irradiation while boating	X		
External irradiation while swimming	X		

As shown in Table 3-7 (taken from SRNL 2011), the near-term (30-y) critical radionuclides and associated pathways identified in the CA are cesium-137 (fish consumption), tritium (water consumption), iodine-129 (food consumption), and chlorine-36 (food consumption).

The critical radionuclides in the distant future (>100 y) were identified as iodine-129, chlorine-36, technetium-99, niobium-94, niobium-93m (daughter of zirconium-93), neptunium-237, radium-226, and nickel-59. Because of recommendations in Jannik (1997), several of these long-lived radionuclides (iodine-129, technetium-99, and neptunium-237) were recently added to the EMS radionuclide analytical suite and are currently being measured at the applicable SRS effluent and environmental surveillance locations. The others have not been routinely analyzed for, mainly because they are not projected to reach human exposure locations for many years. However, consideration should be given to at least periodically analyzing for these radionuclides as well as for cesium-135, carbon-14, and protactinium-231, which are the additional long-lived radionuclides identified as important in the four PA's discussed.

In Table 3-7, chlorine-36 is shown as a fairly near term dose contributor, however all of the chlorine-36 is associated with the reactor buildings which will undergo in-situ disposal, which consists of grouting up and sealing the reactor buildings. These barriers were conservatively not accounted for in the CA modeling. In the future, all of the long-lived radionuclides listed in Table 3-7 may become more important on a percentage of dose/risk basis, but as shown, the total dose consequence should remain small.

Table 3-7. CA Primary Radionuclides/Sources Contributing to Peak Dose.

(Those producing a maximum dose ≥0.01 mrem/y)

Radionuclide	Source	Peak Dose (mrem/y)	Timing of Peak
Cs137	LTR Streambed	4.110	2011
Cs137	FMB Streambed	2.740	2011
Cs137	SC/PB Streambed	0.420	2011
Cs137	UTR Streambed	0.100	2011
Cs137	SR Swamp	0.043	2011
H3	K-Area GOU	0.150	2011
H3	FMB GOU	0.015	2011
H3	P-Reactor (concrete)	0.015	2032
H3	264-H	0.015	2039
H3	HAMN	0.061	2041
H3	E-Area CIG	0.021	2043
H3	232-H	0.011	2045
H3	HAOM	0.020	2060
I129	ORWBG fast	0.014	2011
I129	Old F-Area Seepage Basin	0.025	2021
I129	ORWBG slow	0.160	2024
I129	P-Reactor (surface)	0.012	2033
I129	E-Area Slit Trench Central	0.013	2049
I129	Z-Area Vault 4	0.027	2050
I129	LLRWDF FMB	0.018	2085
I129	MWMF	0.130	2115
I129	LLRWDF UTR	0.018	2125
I129	H-Area Seepage Basin	0.100	2240
Cl36	P-Reactor (surface)	0.099	2032
Cl36	L-Reactor (surface)	0.072	2038
Cl36	R-Reactor (surface)	0.045	2043
Cl36	K-Reactor (surface)	0.053	2055
Cl36	C-Reactor (surface)	0.057	2145
Tc99	Z-Area Vault 4	0.048	2115
Nb94	C-Reactor SS	0.150	2155
Nb94	NRCDA Pad 2	0.035	2215
Nb93m	TPBAR	0.021	2310
Np237	H-Area Canyon	1.040	2815
Ra226	E-Area ILV	0.016	4750
Ni59	ORWBG	0.028	5000
Nb93m	NRCDA Pad 1	0.066	12050

4.0 CONCLUSIONS

During the operational history of SRS, many different radionuclides have been released from site facilities. However, as shown in this analysis (Tables 3.1 and 3.3), only a relatively small number of the released radionuclides have been significant contributors to doses/risks to offsite people.

When comparing radiological risks, it should be noted that if a potential risk is determined to be less than 1.0E-06 (i.e., one additional case of severe detriment in a group of 1,000,000 people), then the risk is considered minimal. If a calculated risk is greater than 1.0E-04, then some form of corrective action or remediation usually is required. However, if a calculated risk falls between 1.0E-06 and 1.0E-04, the risk is considered acceptable if it is kept as low as reasonably achievable.

For the airborne pathway, only iodine-131, tritium, argon-41, iodine-129, plutonium-239, and carbon-14 were determined to exceed a risk of 1.0E-06 on a cumulative MEI risk basis. However, no radionuclides exceeded a cumulative risk of 1.0E-04. The most critical pathways associated with the airborne pathway MEI cumulative risks were food consumption, inhalation, and plume shine.

For the liquid pathway, cesium-137, phosphorus-32, strontium-90, zinc-65, tritium, iodine-131, unidentified beta, and sulfur-35 were determined to exceed a risk of 1.0E-06 on a cumulative MEI risk basis. Only cesium-137 exceeded a cumulative risk of 1.0E-04. The most critical pathways associated with the liquid pathway MEI cumulative risks were fish consumption and drinking water ingestion.

For the next 30 years, if site missions and operations remain constant, only tritium is projected to exceed an atmospheric pathway MEI risk of 1.0E-06 and only iodine-129 is projected to exceed a risk of 1.0E-07. All other airborne radionuclides are projected to have negligible (<1.0E-07) 30-y risks. The critical pathways associated with the airborne pathway MEI projected risks are inhalation and vegetation consumption, with milk consumption becoming more important as iodine-129 becomes a higher percentage of the dose.

On a 30-y risk basis, no liquid pathway radionuclides are projected to exceed a risk of 1.0E-06. However, tritium and cesium-137 are close (8.5E-07 and 8.4E-07, respectively) and iodine-129, unidentified alpha and beta, technetium-99, and strontium-90 all exceed 1.0E-07. All other liquid pathway radionuclides have negligible (<1.0E-07) projected 30-y risks. By considering the irrigation of foodstuffs with Savannah River water, the most critical pathway associated with the liquid pathway MEI projected risk is the consumption of irrigated food, followed by fish consumption and drinking water ingestion.

The SRS-specific, nontypical exposure pathways are not included in the standard MEI dose/risk calculations because they apply to relatively low-probability (creek-mouth fisherman) or unique (onsite deer and hog hunters) exposure scenarios. However they are assessed separately.

The maximum annual dose from the onsite-hunter deer/hog consumption pathway typically exceeds all standard MEI pathways combined and it exceeds all other sportsman dose scenarios. The 30-y projected risk (assuming the maximum dose occurs to the same hunter) from this pathway is 5.6E-04. Therefore, deer/hog consumption by the onsite hunter is the critical exposure pathway for SRS with cesium-137 being the critical radionuclide.

The offsite deer/hog hunter and the associated Savannah River Swamp offsite hunter are the next most critical exposure pathways at SRS. The projected 30-y risks for these pathways are 1.5E-04 and 2.3E-04, respectively. The creek mouth fisherman and the associated Savannah River Swamp (Steel Creek) offsite fisherman are the next most critical pathways at SRS. The projected 30-y risks for these pathways are 9.3E-06 and 1.4E-05, respectively.

The following recommendations and considerations were identified during this assessment:

- In Jannik (1997), the irrigation pathway was not included in the analyses. However, the potential for agricultural irrigation does exist, especially on a small scale for the MEI exposure scenario. Therefore, this pathway is included in this report and it is recommended that it be included in the official MEI and population doses that are reported in the annual SRS environmental report for documenting compliance with DOE Order 458.1 (DOE 2011).
- The SRS-specific cesium-137 background concentrations used for onsite deer, hogs, and turkeys have not been updated or validated since the early 1990's. In addition, the regional background concentrations used for offsite deer and hogs also have not been updated or validated since that time. It is recommended that these values be reestablished and then validated on a periodic basis.
- Since 2006, a special turkey hunt for the mobility impaired has been held onsite. The maximum hunter doses from these hunts have not been reported in the annual SRS environmental report. Even though these doses are bounded by the deer/hog hunter doses, it is recommended that, for completeness, these doses be documented in future reports.
- To be conservative, and according to the SRS Fish Monitoring Plan, all non-negative radioanalytical results (even those below the minimum detectable activity) are included in the average radionuclide concentrations used for the dose/risk calculations. This has served to inflate the fisherman dose and to lessen the importance of cesium-137 in this pathway. It is recommended that in the future the non-negative concentrations be included in the averages only if at least one of the three composites (by species) is significant.
- There are no species of fish (such as smelt) in the Savannah River that are commonly eaten whole and there are no known critical sub-populations in the SRS area that routinely eat whole fish as a common practice. Therefore, the dose/risk from the fish consumption pathway will continue to be based only on the edible portion of the fish. Consideration should be given to eliminating the analysis of the non-edible portions of fish. Or, at least reducing it to measuring only for strontium-90 in fish bones.
- In the recent SRS PA's and CA, the following long-lived radionuclides were identified as being important in the long-term dose projections (>100 y): chlorine-36, niobium-94, niobium-93m (daughter of zirconium-93, radium-226, and nickel-59, cesium-135, carbon-14, and protactinium-231. These radionuclides have not been routinely analyzed for in effluent or environmental samples. Consideration should be given to at least periodically analyzing for these radionuclides.

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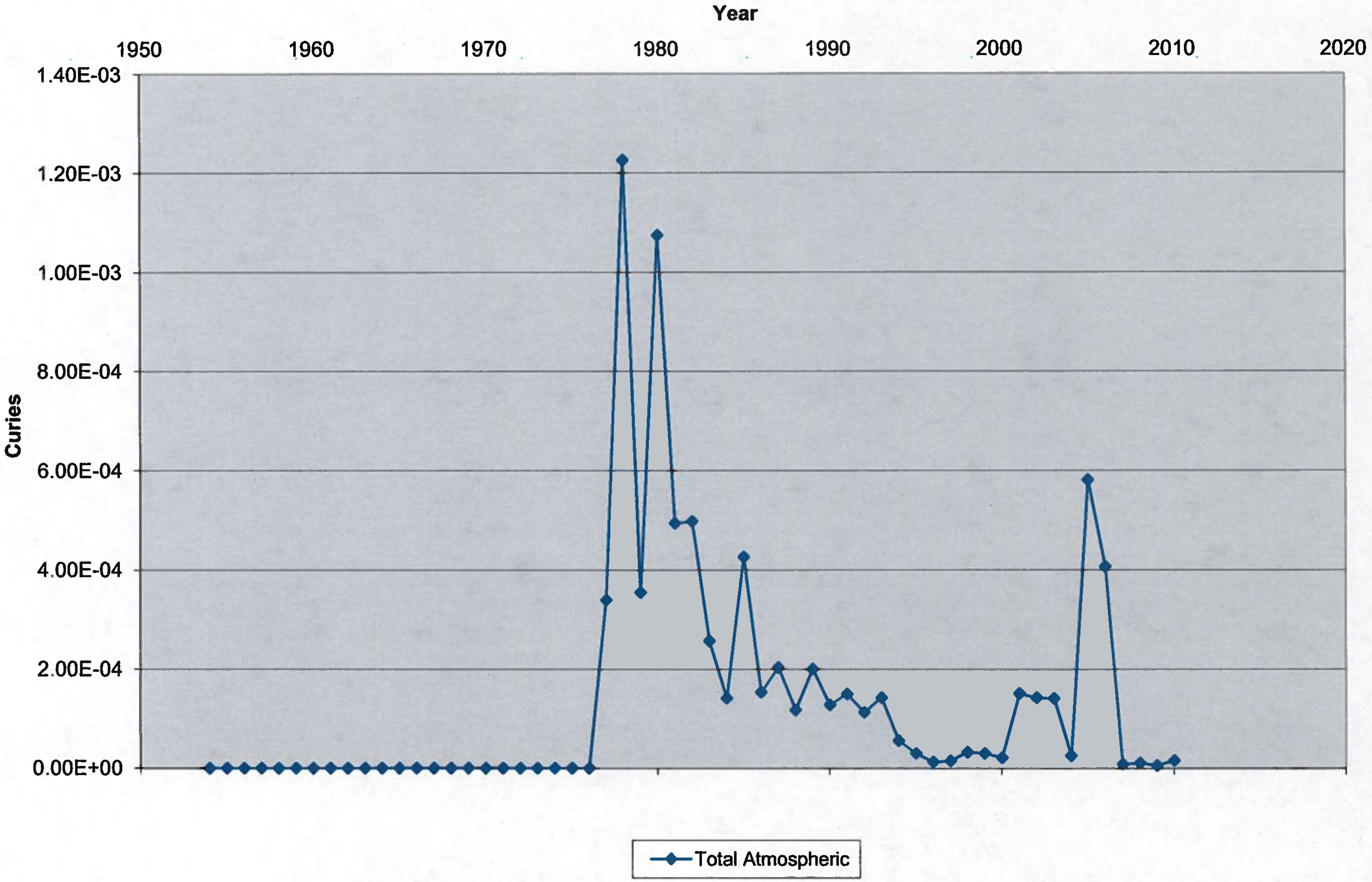
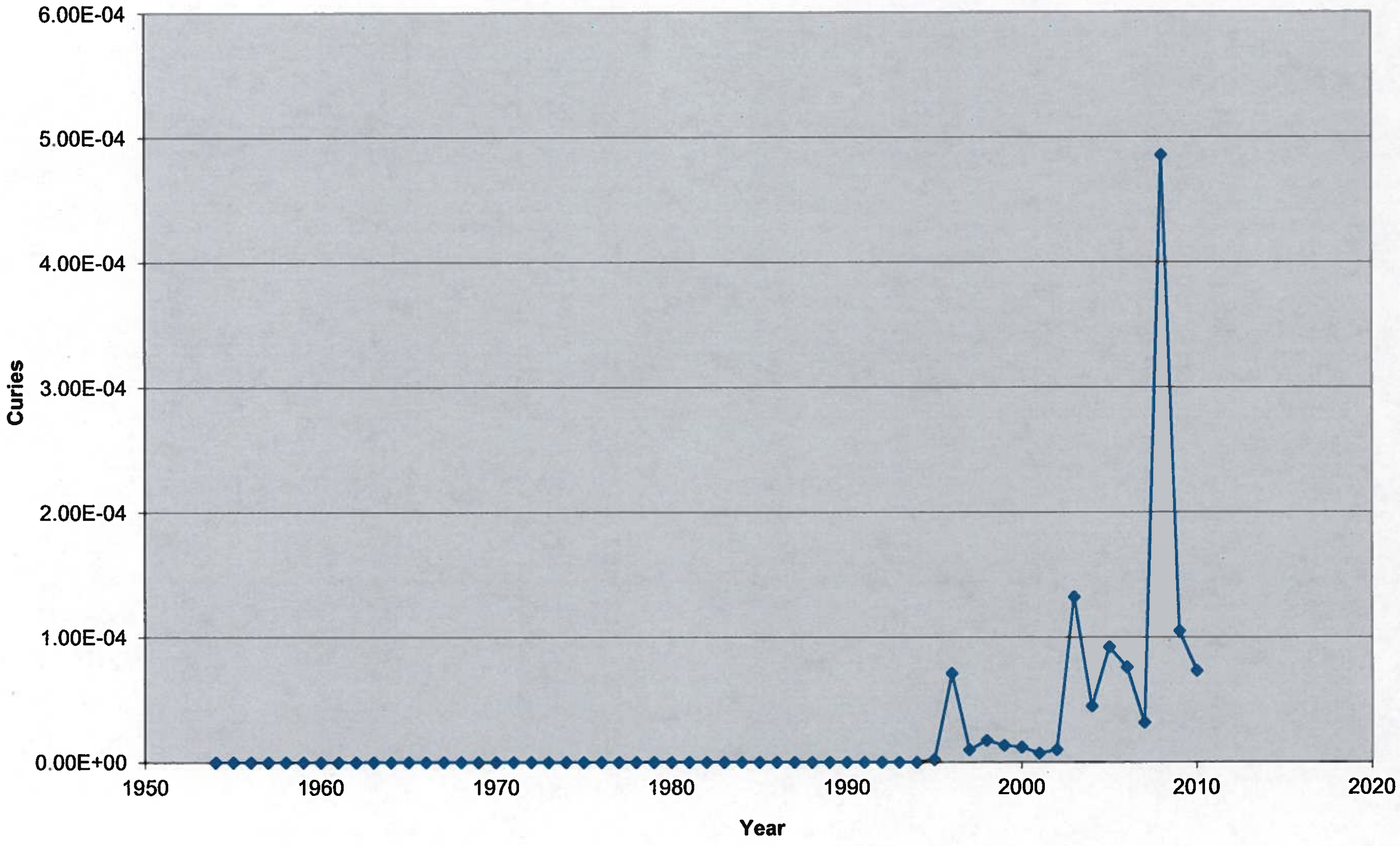
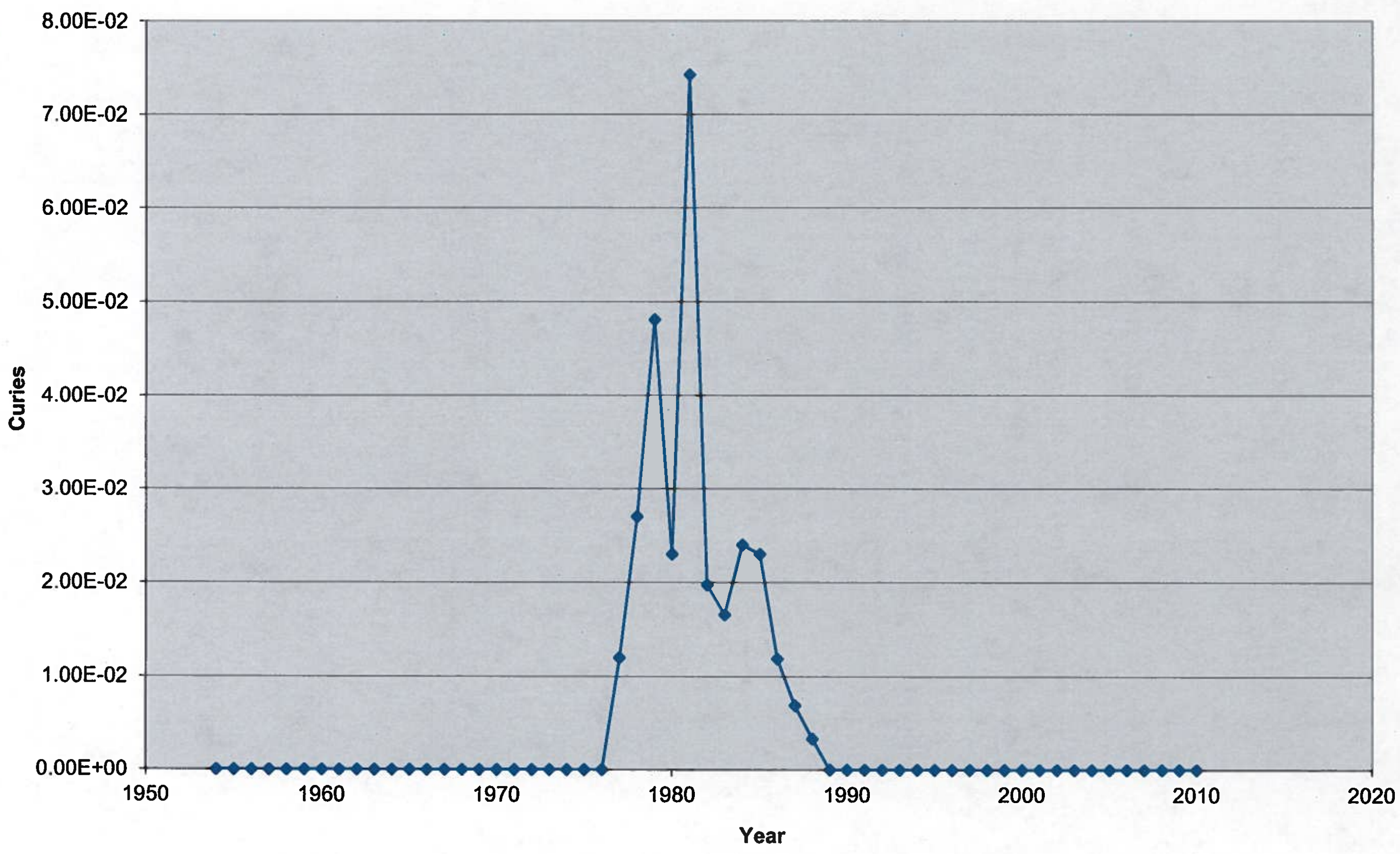
Appendix A

AM-241 Total Atmospheric



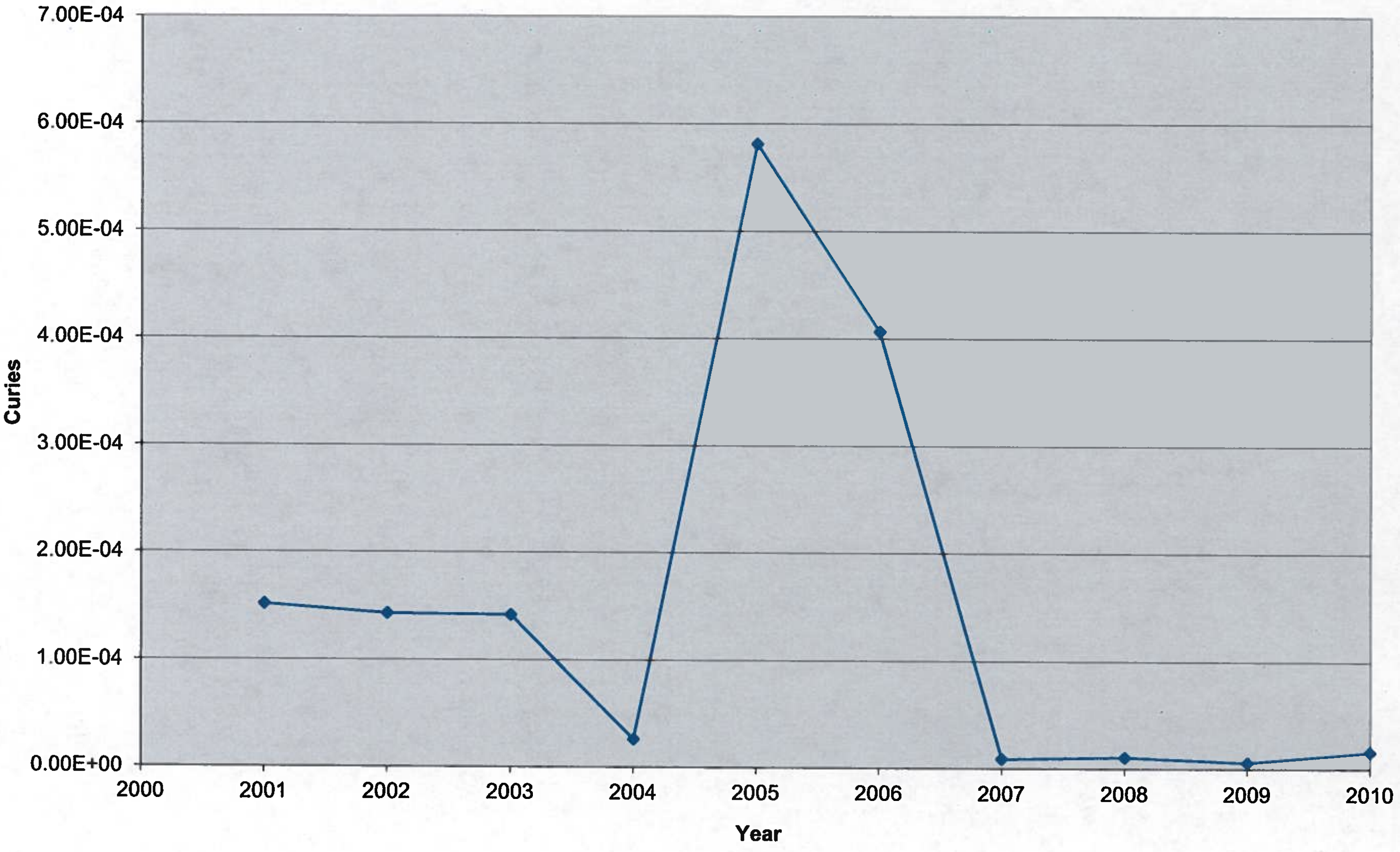
AM-241Total Liquid To Stream

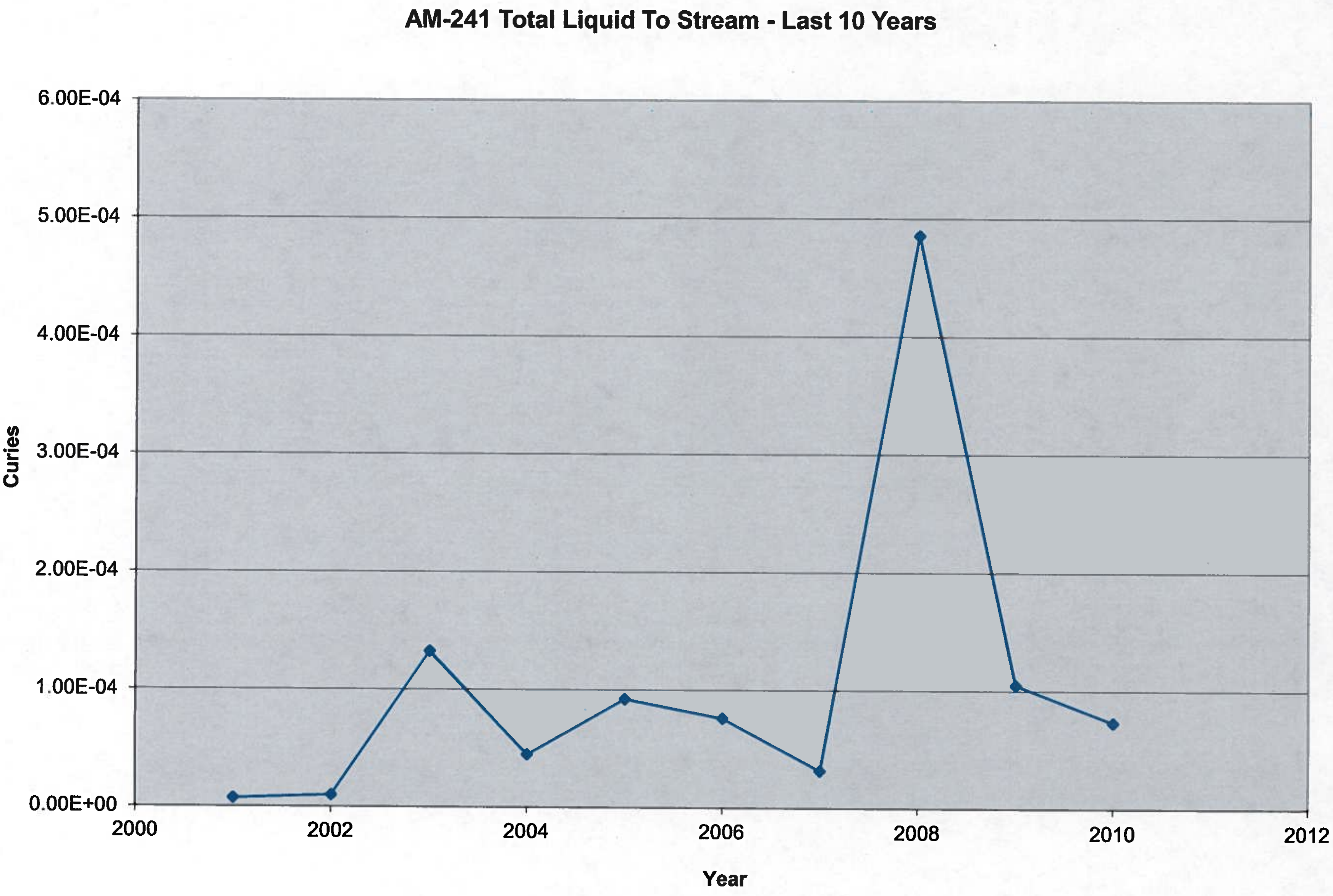




AM-241 Total Liquid To Seepage Basin

AM-241 Total Atmospheric - Last 10 Years




AM-241 Total Liquid To Stream - Last 10 Years
Curies
6.00E-04
5.00E-04
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
2000
2002
2004
2006
2008
2010
2012
Year

Appendix B-1

Radionuclide	Cumulative Dose (mrem)	Cumulative Risk	Radionuclide
Cs-137	2.0E+02	1.8E-04	H-3
P-32	9.0E+01	7.8E-05	Cs-137
Sr-90	4.2E+01	3.6E-05	I-129
Zn-65	1.8E+01	1.6E-05	Alpha
H-3	1.8E+01	1.6E-05	Beta
I-131	6.6E+00	5.7E-06	Tc-99
Beta	6.1E+00	5.3E-06	Sr-90
S-35	2.5E+00	2.2E-06	Pu-238
Sr-89	7.4E-01	6.5E-07	Am-241
Co-60	6.9E-01	6.0E-07	Pu-239
Alpha	5.1E-01	4.4E-07	U-234
Ba-La-140	4.5E-01	3.9E-07	Co-60
I-129	4.3E-01	3.7E-07	Zn-65
Y-91	4.2E-01	3.7E-07	Cm-244
Np-239	4.2E-01	3.6E-07	U-235
Ce-141,144	3.1E-01	2.7E-07	Np-237
Cs-134	2.8E-01	2.4E-07	Ba-La-140
Cr-51	2.6E-01	2.2E-07	Ce-141,144
Zr-Nb-95	1.7E-01	1.5E-07	Cr-51
Tc-99	8.2E-02	7.2E-08	Cs-134
Cm-244	7.6E-02	6.6E-08	I-131
Pm-147	4.9E-02	4.2E-08	Mn-54
Pu-238	4.7E-02	4.1E-08	Mo-99
Pu-239	7.7E-03	6.7E-09	Np-239
Mo-99	4.4E-03	3.8E-09	P-32
U-234	3.3E-03	2.8E-09	Pm-147
Mn-54	1.6E-03	1.4E-09	Ru-106
Am-241	8.0E-04	6.9E-10	S-35
U-235	2.8E-04	2.4E-10	Sb-124,125
Sb-124,125	8.7E-05	7.6E-11	Sr-89
Ru-106	6.1E-05	5.3E-11	Y-91
Np-237	1.2E-07	1.1E-13	Zr-95

Radionuclide	Cumulative Dose	Cumulative Risk	Radionuclide
I-131	4.3E+01	3.8E-05	H-3
H-3	4.2E+01	3.6E-05	I-129
Ar-41	1.1E+01	1.0E-05	Alpha
I-129	3.4E+00	2.9E-06	Pu-238
Pu-239	3.3E+00	2.9E-06	Pu-239
C-14	2.0E+00	1.8E-06	Beta
UN-ID-B+G	1.0E+00	8.7E-07	Cs-137
Kr-88	7.7E-01	6.7E-07	Kr-85
Pu-238	7.2E-01	6.3E-07	Am-241
Ru-106	2.7E-01	2.3E-07	Sr-90
Xe-135	1.2E-01	1.0E-07	C-14
UN-ID-ALPHA	1.0E-01	8.8E-08	U-238
Kr-85	1.0E-01	8.7E-08	Tc-99
Cs-137	7.6E-02	6.6E-08	U-234
Xe-133	5.6E-02	4.8E-08	Th-232
Cm-244	5.2E-02	4.6E-08	Cm-244
Kr-85m	4.4E-02	3.8E-08	Co-60
Sr-90	3.6E-02	3.2E-08	Np-237
Ru-103	2.0E-02	1.7E-08	U-235
Kr-87	1.5E-02	1.3E-08	Ce-144
Am-241	7.1E-03	6.1E-09	Cs-134
Ce-144	2.8E-03	2.4E-09	U-232
Co-60	1.5E-03	1.3E-09	Ru-106
Cs-134	1.5E-03	1.3E-09	Sb-124
Nb-95	1.4E-03	1.2E-09	Eu-154
Zr-95	1.2E-03	1.1E-09	Cm-242
Ce-141	1.0E-03	8.7E-10	Ru-103
U-238	5.0E-04	4.3E-10	Zn-65
U-234	3.2E-04	2.8E-10	Co-58
Xe-131m	3.0E-04	2.6E-10	Ce-141
Tc-99	2.7E-04	2.4E-10	Nb-95
U-235	2.7E-04	2.3E-10	Mn-54
Cm-242	2.5E-04	2.1E-10	I-131
Th-232	1.7E-04	1.5E-10	Np-239
Np-237	5.3E-05	4.7E-11	Zr-95
U-232	1.0E-05	9.1E-12	I-133
Os-185	1.0E-05	9.1E-12	Xe-135
Sb-124	5.8E-06	5.0E-12	Cr-51
Eu-154	4.6E-06	4.0E-12	Pm-147
I-133	4.5E-06	3.9E-12	Sr-89
I-135	3.1E-06	2.7E-12	Eu-155
Zn-65	2.6E-06	2.3E-12	Co-57
Co-58	1.5E-06	1.3E-12	Y-91
Se-75	6.7E-07	5.9E-13	Xe-133
Mn-54	5.8E-07	5.0E-13	Ar-41
Np-239	2.1E-07	1.9E-13	I-135

Cr-51	4.7E-08	4.1E-14	Kr-85m
Pm-147	2.9E-08	2.6E-14	Kr-87
Sr-89	1.9E-08	1.7E-14	Kr-88
Eu-155	1.3E-08	1.2E-14	Os-185
S-35	6.2E-09	5.4E-15	S-35
Co-57	5.6E-10	4.8E-16	Sb-125
Y-91	5.6E-12	4.8E-18	Se-75
Sb-125	6.8E-17	5.9E-23	Xe-131m
			Total

Appendix B-2

Past 10-Y Total Dose	30-Y Projected Risk	Plume	Ground	Vegetable
6.2E-01	1.6E-06	0.0E+00	0.0E+00	2.1E-01
6.7E-02	1.7E-07	0.0E+00	1.7E-05	4.2E-02
1.1E-02	2.9E-08	0.0E+00	1.9E-08	1.5E-03
9.3E-03	2.4E-08	0.0E+00	4.2E-08	1.3E-03
7.8E-03	2.0E-08	0.0E+00	1.4E-08	1.1E-03
5.5E-03	1.4E-08	0.0E+00	4.1E-07	4.7E-03
3.5E-03	9.2E-09	0.0E+00	5.9E-04	1.5E-03
2.0E-03	5.1E-09	2.0E-03	0.0E+00	0.0E+00
1.4E-03	3.6E-09	0.0E+00	2.3E-07	1.8E-04
1.3E-03	3.3E-09	0.0E+00	9.4E-08	1.1E-03
5.1E-04	1.3E-09	0.0E+00	0.0E+00	2.7E-04
3.0E-04	7.8E-10	0.0E+00	1.1E-08	9.6E-05
2.7E-04	7.1E-10	0.0E+00	2.9E-08	2.3E-04
2.7E-04	7.1E-10	0.0E+00	1.1E-08	8.1E-05
1.7E-04	4.4E-10	0.0E+00	8.2E-10	3.8E-05
1.1E-04	2.8E-10	0.0E+00	8.7E-10	1.3E-05
6.7E-05	1.8E-10	2.0E-03	6.1E-04	2.6E-01
5.3E-05	1.4E-10	**0.27%**	**0.08%**	**35.37%**
3.1E-05	8.0E-11			
2.2E-05	5.8E-11			
1.7E-05	4.4E-11			
1.0E-05	2.7E-11			
6.1E-06	1.6E-11			
5.8E-06	1.5E-11			
3.9E-06	1.0E-11			
3.8E-06	1.0E-11			
1.8E-06	4.8E-12			
1.5E-06	3.8E-12			
1.4E-06	3.8E-12			
6.9E-07	1.8E-12			
5.9E-07	1.5E-12			
5.8E-07	1.5E-12			
4.9E-07	1.3E-12			
2.1E-07	5.6E-13			
1.5E-07	3.9E-13			
1.5E-07	3.8E-13			
5.6E-08	1.5E-13			
3.5E-08	9.2E-14			
2.7E-08	7.2E-14			
1.9E-08	5.0E-14			
8.0E-09	2.1E-14			
3.8E-10	1.0E-15			
5.6E-12	1.5E-17			
5.7E-13	1.5E-18			
0.0E+00	0.0E+00			
0.0E+00	0.0E+00			

0.0E+00	0.0E+00
0.0E+00	0.0E+00
0.0E+00	0.0E+00
0.0E+00	0.0E+00
0.0E+00	0.0E+00
0.0E+00	0.0E+00
0.0E+00	0.0E+00
0.0E+00	0.0E+00
7.3E-01	**1.9E-06**

Meat	Cow Milk	Inhalation	Total Atmospheric Pathway	
0.0E+00	1.2E-01	2.9E-01	6.2E-01	85.07%
8.4E-03	1.7E-02	1.9E-04	6.7E-02	9.09%
4.9E-08	1.1E-06	9.1E-03	1.1E-02	1.44%
4.3E-08	9.6E-07	8.0E-03	9.3E-03	1.27%
3.6E-08	8.0E-07	6.7E-03	7.8E-03	1.06%
1.8E-04	4.4E-04	1.6E-04	5.5E-03	0.75%
9.7E-04	5.0E-04	1.4E-05	3.5E-03	0.48%
0.0E+00	0.0E+00	0.0E+00	2.0E-03	0.27%
2.8E-06	5.7E-09	1.2E-03	1.4E-03	0.19%
4.2E-05	1.0E-04	3.6E-05	1.3E-03	0.17%
1.2E-04	1.3E-04	0.0E+00	5.1E-04	0.07%
1.1E-06	1.3E-05	1.9E-04	3.0E-04	0.04%
2.3E-05	1.9E-05	4.4E-06	2.7E-04	0.04%
9.5E-07	1.1E-05	1.8E-04	2.7E-04	0.04%
2.7E-07	1.4E-08	1.3E-04	1.7E-04	0.02%
1.6E-08	2.0E-08	9.3E-05	1.1E-04	0.01%
9.7E-03	1.4E-01	3.2E-01	7.341E-01	
1.32%	**19.30%**	**43.66%**		
				2.08%