9 EXPOSURE ROUTES AND PATHWAYS

This chapter discusses how the hypothetical receptors receive a radiation dose from SRS releases by coming into contact with contaminated media (air, water, soil, and food). The models used to derive doses from exposure to contaminated media are discussed in a semi-quantitative fashion, because the details of these models are fully explained in the Software Design Document (Chapter 10) for the GENII[1] code (1). These models do not calculate dose directly, but instead calculate "intake of radionuclides by each ingestion and inhalation exposure pathway, and exposure to radionuclides from external exposure pathways." Chapter 10 explains how these radionuclide intakes and exposures produce receptor doses.

This chapter also summarizes the values for the variables chosen to obtain the point-estimates of radiation dose and risk. Variable values related to receptor activities, in accordance with the scenarios discussed in Chapter 3, are summarized here; the complete rationale for their selection is given in Appendix E. Other variable values not related to receptor activities are detailed in Appendix F.

9.1 Introduction

Radionuclide releases from SRS facilities into the air (Chapter 5) and water (Chapter 7) are transported, by advection and dispersion in air (Chapter 6) and water (Chapter 7), to various exposure locations. These transported radionuclide releases produce contaminated media at the exposure locations (Chapter 3). Air, water, soil, and food are the contaminated media investigated in this study. Contamination of soil and foodstuffs by contaminated air and water is discussed in Chapter 8. At the various exposure locations the hypothetical receptors engage in activities specified in accordance with the scenarios described in Chapter 3, such as swimming, breathing, boating, and eating; these activities bring the receptors into contact with different kinds of contaminated media, which causes radiation exposure. The three radiation exposure routes considered in this study are:

1. INHALATION of contaminated air and contamination resuspended from soil.
2. INGESTION of contaminated food, water, and soil.
3. DIRECT EXPOSURE to contaminated air, water, and soil (including river sediment).

Although additional exposure routes may be important under some circumstances, they were not considered important for this dose reconstruction. For example, absorption of radionuclides through skin exposed to contaminated air or water is a possible exposure route, but is typically less than other exposure routes for the same contaminated media. Thus direct exposure from air immersion and water immersion is generally more significant than dermal absorption respectively in air and water for most beta-gamma emitters, such as Ar-41. Direct exposures by air and water immersion were included in this study, but dermal exposures were not included. Ingestion of contaminated drinking water was not included in this study; only inadvertent ingestion of water while swimming was modeled. The main rationale for this is that the main body of water directly contaminated by liquid releases from the SRS, the Savannah River, was not used for drinking water in any of the exposure scenarios. The Savannah River is used for municipal water supplies far downstream (e.g., Port Wentworth and Beaufort-Jasper), but this was not part of any scenario. Some contamination of local reservoirs near the SRS probably arose from deposition of airborne radionuclides into the surface-water basins feeding the reservoirs. However, a model for this type of contaminant transport was not readily available and the contamination level measured was found to be small and may not all have originated from the SRS (e.g., in 1981 the measured concentrations at the North Augusta Water Plant for undifferentiated alpha activity was 0.4 pCi/L and for undifferentiated beta activity was 3 pCi/L) (2).

[1] All references to GENII in this chapter refer to version 2 of GENII.

A total of eighteen potential exposure pathways were modeled in this study, as shown in Table 9-1. The Table is organized according to the exposure route (direct exposure, ingestion, and inhalation) and exposure pathway; it indicates for each exposure pathway whether the release was to water or air and the contaminated medium (air, water, soil, or foodstuffs) causing the exposure. The total dose is obtained by summing the incremental dose from each exposure pathway.

Table 9-1 Exposure Routes and Pathways for Air and Water Pathways

Exposure Route & Pathway	Air Release	Water Release	Contaminated Medium
Direct Exposure (External radiation):			
• Immersion in a plume of air	X		Air
• Exposure to contaminated soil	X		Soil
• Exposure to a contaminated shoreline		X	Soil (sediment)
• Exposure to contaminated water while swimming		X	Water
• Exposure to contaminated water while boating		X	Water
Ingestion:			
• Leafy vegetable consumption	X		Food
• Root vegetable consumption	X		Food
• Fruit consumption	X		Food
• Grain consumption	X		Food
• Beef consumption	X		Food
• Poultry consumption	X		Food
• Milk consumption	X		Food
• Egg consumption	X		Food
• Inadvertent soil consumption	X		Food
• Fish consumption		X	Food
• Inadvertent ingestion of water while swimming		X	Food
Inhalation:			
• Inhalation of contamination in the air	X		Air
• Inhalation of contamination resuspended from soil	X		Air

9.2 General Exposure Formula

Given the concentration of a radionuclide in a contaminated medium, the exposure models represent how the receptor comes into contact with radiation in a way that ultimately produces a radiation dose in the receptor. In particular the end point of these exposure models is to calculate "intake" of either 1) radioactive material through ingestion or inhalation routes or 2) radiation exposure from direct external radiation.

The exposure models determine different information depending upon the exposure route, as shown in Table 9-2.

Table 9-2 Intake for Direct Exposure, Ingestion, and Inhalation Exposure Routes

Exposure Route	Intake Calculated
Direct Exposure	Annual exposure [immersion in air (Bq/m^3) or water (Bq/L); proximity to soil or sediment (Bq/kg) or water (Bq/L); ground plane exposure (Bq/m^2)].
Ingestion	Annual radionuclide activity ingested (Bq in a year).
Inhalation	Annual radionuclide activity inhaled (Bq in a year).

As will be described in Chapter 10, these intake values will be multiplied by an appropriate dose conversion factor to obtain an incremental dose; i.e.,

$$\text{Dose} = \text{Intake} * \text{Dose Conversion Factor} \qquad (9\text{-}1)$$

However, the dose conversion factor depends upon the exposure route, the radionuclide, and sometimes other factors, such as solubility or lung clearance class. In addition, dose conversion factors are, in general, dependent on the age of the receptor. Because the scenario specifications clearly expressed a concern with the interaction of the age of the receptors and the time-history of releases from the site, doses were calculated using age-dependent dose conversion factors. This age dependency was represented by grouping the dose conversion factors into four age groups, as shown in Table 9-3:

Table 9-3 Age Groups Used for Dose Conversion Factors and Risks

Receptor Age Group	Age Group*
Infant/ Preschooler	0 – 5 year
School Age Child	5 – 15 year
Teenager/Young Adult	15 – 25 year
Adult	25 – 70 year

*Based on the Federal Guidance Report 13 (FRG-13) Cancer Risk Coefficients for Environmental Exposure to Radionuclides (3).

More details on dose conversion factors are presented in Chapter 10.

The exact nature of both the intake and the formula used to calculate the intake depend upon both the exposure route and the specific pathway described. The general formula for calculating the intake is:

$$I = C_m \cdot CR \cdot ED \cdot DAF \cdot AAF \qquad (9\text{-}2)$$

Where, I is the intake;

C_m is the concentration in the medium;
CR is the contact rate or uptake rate;
ED is the exposure duration;
DAF is the daily activity factor;
AAF is the annual activity factor.

Table 9-4 describes each factor in the general intake equation and shows some examples of units for these various factors.

Table 9-4 Terms of the General Intake Equation*

General Term	Variable Abbreviation	Description	Example Units
Medium Concentration	C_m	Radionuclide concentration in the exposure medium.	Bq/L water Bq/m^3 air Bq/kg soil
Intake/Contact Rte	CR	Ingestion, inhalation, or exposure rate.	L water/d m^3 air/d
Exposure Duration	ED	Number of years over which the exposure is defined.	Y – (For this study, all exposures were calculated on an annual basis, so this was always 1Y.)
Daily Activity Factor	DAF	Daily activity pattern parameter (e.g. exposure events per day, hours of exposure per day).	hr/d events/d · h/event
Annual Activity Factor	AAF	Annual activity pattern parameter (e.g. days per year that exposure occurs).	days/year

*Based on Table 10.1 of the GENII SDD (1).

As stated previously, the methods for calculating the concentrations in contaminated media are described in other Chapters: Chapter 5 describes the calculation for air; Chapter 7 describes the calculation for water; Chapter 8 describes the calculation for food chain media, i.e., soil, plants, and animals. These concentrations depend upon the time history of releases from the site and their migration in and uptake by the various media. The other four factors (variables) in Equation 9-2 depend upon the behavior of the receptors, as specified by the scenarios. The contact rate for the ingestion route is the ingestion rate, kg of a particular food ingested per year. The contact rate for inhalation is the inhalation rate, m^3 of air inhaled per day. The contact rate for direct exposure is unity. For this study the exposure duration was one year, since the release rate (Bq/y) was adjusted for each year and since dose and risk conversion factors were adjusted for the ages of the receptors. The daily activity factor and annual activity factor varied depending on the exposure pathway. For example, for school children, attendance at school was characterized by a daily activity factor of 7 hours/day spent at school on a school day and an annual activity factor of 180 days/year of school attendance. Those variables that depend on receptor behavior, (e.g., time spent in a particular exposure location), are sometimes called usage factors. Values for these variables, along with a rationale for the choice of each value for the point estimate calculation, are listed in Appendix E.

Dose to each receptor could have been calculated by specifying the appropriate variables in Equation 9-2 for every applicable exposure pathway. However, such a calculation would have been very laborious and could not be easily automated. As Equation 9-2 indicates, the increment of dose from any exposure pathway is calculated by multiplying a number of factors; this property was used to perform an efficient, file-driven calculation. For each pathway, doses were calculated for an adult on the basis of a unit contact rate (e.g., 1 kg ingested per year) and/or a unit exposure duration (e.g., one hour). Then each dose based on unit inputs was scaled up by a factor representing the actual contact rates and exposure durations for a particular receptor; in addition, doses were scaled by adjustment factors accounting for the age-dependent dose conversion factors. The derivation and computational use of these exposure factors and adjustment

factors are described in Appendices E and G, respectively. This approach made the calculation of doses more efficient, but had no effect on the values of the computed doses or the precision of those estimates.

The following sections briefly discuss the intake models and variables for each of the three exposure routes modeled.

9.3 Direct Exposure Pathways

Direct exposure pathways modeled in this study include:

1. Immersion in a plume of air.
2. Exposure to contaminated soil.
3. Exposure to a contaminated shoreline.
4. Immersion in contaminated water while swimming.
5. Exposure to contaminated water while boating.

As shown in Table 9-1, the first two exposure pathways are associated only with radionuclide releases to air, while the last three exposure pathways are associated only with radionuclide releases to water. Soil was considered to be contaminated by deposition of airborne radionuclides. Soil was not considered to be contaminated by deposition of water-borne radionuclides, because farmers in vicinity of the SRS did not use the Savannah River and Lower Three Runs Creek for irrigation (as explained in Chapter 3). The Savannah River and Lower Three Runs Creek were the only two water bodies contaminated by liquid releases from the SRS and accessible to the public. For exposure to a contaminated shoreline, the contaminated medium is shoreline sediment, deposited by one of the two water bodies receiving liquid releases from the SRS.

9.3.1 Immersion in a Plume of Air

External exposures from immersion in a contaminated plume of air result from the receptor absorbing radiation emitted by radionuclides in the plume. Gamma rays produce most of the immersion dose, although beta and alpha radiation may also contribute. The receptor is assumed to be at the center of a hemispherical cloud of radionuclides at a uniform concentration. Radiation emitted by atoms farther away from the receptor is more likely to be absorbed by the air and contaminants between the receptor and the emitting atoms. Therefore, nearby atoms contribute most to the dose and the dose calculated is not very sensitive to large-scale variations in concentration. Note that for this study, the use of a sector average model means the concentration is assumed to be constant in an entire 22.5º sector (360° divided by 16 sectors) at a given radius.

Key variables in determining the exposure from immersion in a contaminated plume of air are 1) the concentration of each radionuclide at a particular exposure location and 2) the time of exposure for a particular receptor at a particular location. In general shielding of a receptor may also be important, but it was conservatively assumed that indoor air concentrations equaled outdoor air concentrations. The approach used to calculate yearly air concentrations at various exposure locations is described in Chapter 5. The time spent by each receptor at various locations is provided in Table 9-5.

Table 9-5 Exposure Times (hours/year) for the Air Immersion Pathway

Individual	Adult Male	Adult Female	Child Born in 1955		Child Born in 1964	
			*Thru 1972**	*Starting 1973*	*Thru 1981*	*Starting 1982*
Rural Family One						
Girard	8,760	8,760	7,500	8,760	7,500	8,760
Waynesboro	0	0	1,260	0	1,260*	0
Rural Family Two						
Williston	8,760	8,760	8,760	8,760	8,760	8,760
Urban/Suburban Family						
Augusta	6,760	8,760	8,760	6,760	8,760	6,760
Onsite SRS	2,000	0	0	2,000	0	2,000
Delivery Family						
Martin	306	306	306	306	306	306
Onsite SRS	400	0	0	400	0	400
Allendale	1,600	0	0	1,600	0	1,600
Barnwell	6,454	8,454	8,454	6,454	8,454	6,454
Outdoors Person Family						
Onsite SRS	2,000	0	0	2,000	0	2,000
Jackson	6,760	8,760	8,760	6,760	8,760	6,760
Family Near River						
Martin	8,760	8,760	8,760	8,760	8,760	8,760
Migrant Worker Family						
New Ellenton	4,380	4,380	4,380	4,380	4,360	4,380

*During the indicated years (1969-1972 for the Child Born in 1955, and 1978-81 for the Child Born in 1964), the children born in 1955 and 1964 are classed as teenagers.

9.3.2 Exposure to Contaminated Soil

External exposures from being on a contaminated surface result from the receptor absorbing radiation emitted by radionuclides in the contaminated surface. Gamma rays produce most of this dose from a contaminated surface, also called ground-plane dose. The receptor is assumed to be standing on a slab of material contaminated at a uniform concentration. Radiation emitted by atoms on the surface of the slab is partially absorbed by the air between the receptor and emitting atoms; radiation emitted by atoms within the slab is partially absorbed by the intervening air and slab material (usually considered to be soil). More distant decaying atoms generally contribute less to dose than those closer to the receptor. The model also considers excitation of intervening atoms and secondary emission of radiation. Therefore nearby atoms contribute most to the dose and the dose calculated is not very sensitive to large-scale variations in concentration. Note that for this study, the use of a sector average model means the concentration is assumed to be constant in an entire 22.5º sector at a given radius.

Key variables in determining the intake for exposure to contaminated soil are:

1. Concentration of each radionuclide in the soil at a particular exposure location.
2. Time of exposure for a particular receptor at a particular location.
3. Shielding of a receptor provided by buildings.
4. Fractions of time spent indoors and outdoors at each exposure location.

The approach used to calculate yearly soil concentrations at various exposure locations is described in Chapter 8. The time spent by each receptor at various locations is provided in Table 9-6. (Note that the exposure times in Table 9-6 are smaller than in Table 9-4 because receptors were assumed not to be exposed to radiation from ground contamination when they were swimming or boating.) The outdoor shielding factor was set equal to 1.0 for all scenarios, exposure locations, individuals, and years; the indoor shielding factor was set to 0.7 (Appendix E). The hours spent indoors and outdoors were determined based on data from The Exposure Factors Handbook (4) and the scenario specifications provided by CDC (5). From the times spent indoors and outdoors at each location for each receptor, the fraction of time spent indoors and outdoors was calculated (these fractions must sum to unity); indoor and outdoor fractions are summarized in Table 9-7. In addition, Appendix E lists the hours spent indoors and outdoors for each receptor and exposure location, and the indoor and outdoor fractions calculated from these hours.

Table 9-6 Exposure Times (hours/year) for Ground Contamination External Exposure Pathway

Individual	Adult Male	Adult Female	Child Born in 1955		Child Born in 1964	
			*Thru 1972**	*Starting 1973*	*Thru 1981*	*Starting 1982*
Rural Family One						
Girard	8,739	8,739	7,479	8,739	7,479	8,739
Waynesboro	0	0	1,260	0	1,260*	0
Rural Family Two						
Williston	8,739	8,739	8,739	8,739	8,739	8,739
Urban/Suburban Family						
Augusta	6,643	8,643	8,643	6,643	8,643	6,643
Onsite SRS	2,000	0	0	2,000	0	2,000
Delivery Family						
Martin	189	189	189	189	189	189
Onsite SRS	400	0	0	400	0	400
Allendale	1,600	0	0	1,600	0	1,600
Barnwell	6,454	8,454	8,454	6,454	8,454	6,454
Outdoors Person Family						
Onsite SRS	1,740	0	0	1,740	0	1,740
Jackson	6,643	8,643	8,643	6,643	8,643	6,643
Family Near River						
Martin	8,447	8,447	8,447	8,447	8,447	8,447
Migrant Worker Family						
New Ellenton	4,370	4,370	4,370	4,370	4,370	4,370

*During the indicated years (1969-1972 for the Child Born in 1955, and 1978-81 for the Child Born in 1964), the children born in 1955 and 1964 are classed as teenagers.

Table 9-7 Indoor and Outdoor Fractions for Ground Contamination Pathway

Member	Location	Outdoor Fraction	Indoor Fraction	Member	Location	Outdoor Fraction	Indoor Fraction
Rural Family One				***Urban/Suburban Family***			
Infant	Girard	0.15	0.85	Infant	Augusta	0.14	0.86
Preschooler	Girard	0.15	0.85	Preschooler	Augusta	0.14	0.86
School Child	Girard	0.18	0.82	School Child	Augusta	0.17	0.83
Teen	Girard	0.13	0.87	Teen	Augusta	0.14	0.86
Teen	Waynesboro	0.29	0.71	Adult Male	Augusta	0.13	0.87
Adult Male	Girard	0.31	0.69	Adult Male	SRS	0.13	0.87
Adult Female	Girard	0.14	0.86	Adult Female	Augusta	0.13	0.87
Rural Family Two				***Family Near River***			
Infant	Williston	0.15	0.85	Infant	Martin	0.14	0.86
Preschooler	Williston	0.15	0.85	Preschooler	Martin	0.14	0.86
School Child	Williston	0.18	0.82	School Child	Martin	0.18	0.82
Teen	Williston	0.15	0.85	Teen	Martin	0.15	0.85
Adult Male	Williston	0.31	0.69	Adult Male	Martin	0.13	0.87
Adult Female	Williston	0.14	0.86	Adult Female	Martin	0.13	0.87
Delivery Person Family				***Outdoor Person***			
Infant	Martin	0.45	0.55	Infant	Jackson	0.15	0.85
Infant	Barnwell	0.14	0.86	Preschooler	Jackson	0.15	0.85
Preschooler	Martin	0.45	0.55	School Child	Jackson	0.18	0.82
Preschooler	Barnwell	0.14	0.86	Teen	Jackson	0.15	0.85
School Child	Martin	0.45	0.55	Adult Male	Jackson	0.14	0.86
School Child	Barnwell	0.18	0.82	Adult Male	SRS	1.0	0
Teen	Martin	0.45	0.55	Adult Female	Jackson	0.14	0.86
Teen	Barnwell	0.15	0.85	***Migrant Worker Family***			
Adult Male	Martin	0.45	0.55	Infant	New Ellenton	0.15	0.85
Adult Male	Barnwell	0.13	0.87	Preschooler	New Ellenton	0.15	0.85
Adult Male	SRS	0.50	0.50	School Child	New Ellenton	0.18	0.82
Adult Male	Allendale	0.16	0.84	Teen	New Ellenton	0.15	0.85
Adult Female	Martin	0.45	0.55	Adult Male	New Ellenton	0.31	0.69
Adult Female	Barnwell	0.13	0.87	Adult Female	New Ellenton	0.14	0.86

9.3.3 Exposure to a Contaminated Shoreline

External exposure from being on the shore of a river or stream is similar to external exposure from contaminated soil. The principal differences for this study are: 1) the contamination on the shoreline results from contaminated sediment deposited there by contaminated water, rather than from contaminated air; 2) the deposited sediment geometry is comprised of two relatively narrow strips on either side of the river or stream; and 3) the time spent at the shoreline is much less than the time spent on contaminated ground. As with external exposure from contaminated soil, the concentration of radionuclides in the narrow strips is assumed to be constant for a given year.

Key variables for determining the intake for exposure to contaminated sediments on the shoreline are:

1. Concentration of each radionuclide in the sediment at a particular shoreline location.
2. Shoreline width factor.
3. Shoreline use daily event frequency (frequency of shoreline use per day) at the shoreline location.
4. Duration of each shoreline use (hours per event).
5. Shoreline use annual event frequency (number of days per year the shoreline is used).

The approach used to calculate yearly average radionuclide concentrations in sediment at various shoreline exposure locations is described in Chapter 8. The shoreline width factor is taken to be 0.2 for all locations. Because the source of radiation is comprised of two strips rather than an infinite plane, the radiation level is only a fraction of the infinite plane value, which is accounted for by this factor. This is the default value used in the GENII code, the value recommended by the NRC for river shorelines (6), and the value used in past environmental analyses for SRS (7), (8), (9). Variables 3), 4), and 5) multiplied together equal the total time per year spent on the shoreline; values for these total times are provided in Table 9-7. Note that only the Delivery Family, Outdoors Family, and Near-River Family have any shoreline exposure. Although other scenarios may participate in shoreline activities, the shorelines are on bodies of water that receive no waterborne releases from the SRS; in these cases it was assumed that the water and shorelines were uncontaminated by SRS activities. Thus the shoreline exposure times for Rural Family One, Rural Family Two, the Urban/Suburban Family, and the Migrant Worker Family were all assumed to be zero.

For the remaining receptors, exposure times were determined as follows:

- All members of the Delivery Person Family split their shoreline use equally between Lower Three Runs Creek near Martin and the Savannah River at Smith Lake. Shoreline exposure rates are estimated using the following factors based on South Carolina recreational patterns cited in Hamby 1991 [pp.6 and 24](10):

  - Average number of shoreline usage events/year – 19.15
  - Average hours/shoreline usage event – 4.44

  85 hr/yr is the product of these values.

- The Outdoors Person Adult Male (and children when they become working adults) used the shoreline on the Savannah River downstream of SRS; this location represented job-related exposures associated with employment onsite at the SRS. This time includes time spent fishing and hunting. The exposure level assumes the adult male was “on the river” 8 hours/day (40 hours/week) during the summer (13 weeks)(5). It further assumes that half the time spent “on the river” was spent on the shoreline, and the other half was spent on a boat. This results in an exposure time of 260 hours/year on the shoreline for the adult male.

- The Family Living Near the River used the shoreline on the Savannah River downstream of the SRS; an exposure time of 365 hours a year assumed an average of one hour per day shoreline exposure for every day of the year

Locations and exposure times for shoreline external exposure are summarized in Table 9-8.

Table 9-8 Exposure Times (hours/year) for Shoreline External Exposure Pathway

Scenario	Shoreline Usage Location	Exposure Time (hours/year)
Rural Family One	Briar Creek near Girard	0 (all years and individuals)*
Rural Family Two	Savannah River upstream of SRS and farm ponds around Williston	0 (all years and individuals)*
Urban/Suburban Family	Savannah River at Augusta	0 (all years and individuals)*
Delivery Person	Lower Three Runs Creek (LTRC) at Martin (50%) and the Savannah River down stream of the LTRC confluence (50%).	For all years and individuals: 42.5 on LTRC shoreline at Martin 42.5 on Savannah
Outdoors Person	Savannah River: Upstream of SRS for the adult female and children. Downstream of SRS for the adult male.	260 for the adult male on the Savannah River downstream of the SRS; also used for children after they reach age 18.
Family Living Near the River	Savannah River Downstream of SRS for all individuals.	365 (all years and individuals)
Migrant Worker Family	Savannah River upstream of SRS and farm ponds around New Ellenton	0 (all years and individuals)*

*The dose from shoreline external exposure is assumed to be zero, because the exposure location received no waterborne releases from the SRS; in these cases it was assumed that the water was uncontaminated by SRS activities.

9.3.4 Immersion in Contaminated Water While Swimming

In this study doses from swimming were modeled through two separate but related exposure pathways: 1) external exposure by immersion in contaminated water, discussed here, and 2) inadvertent ingestion of contaminated water, discussed in Section 9.4.

External exposures from immersion in a contaminated body of water are similar in nature to exposures from immersion in a contaminated plume of air, as discussed in Section 9.3.1. A significant difference is that radiation is attenuated more rapidly in water because of its higher density.

Key variables in determining the exposure for immersion in a contaminated body of water are:

1. Concentration of each radionuclide in the water at a location used for swimming.
2. Swimming daily event frequency (frequency of swimming per day) at the particular swimming location.
3. Duration of each swimming event (hours per event).
4. Swimming event annual frequency (number of days per year swimming occurs).

The approach used to calculate annual radionuclide concentrations in water at two exposure locations is described in Chapter 8. Variables 2), 3), and 4) multiplied together equal the total time per year spent swimming and therefore immersed in contaminated water; values for these total times are provided in Table 9-8.

Note that only the Delivery Family and Near-River Family have any exposure due to swimming in contaminated water. Although other scenarios may participate in swimming activities, that swimming was specified to take place in bodies of water that receive no waterborne releases from the SRS; for these scenarios it was assumed that the water was uncontaminated by SRS activities. Thus the swimming exposure times for Rural Family One, Rural Family Two, the Urban/Suburban Family, the Outdoors Person Family, and the Migrant Worker Family were all assumed to be zero.

Consistent with the scenarios described in Chapter 3, swimming locations were: 1) Lower Three Runs Creek near Martin, SC, for the Delivery Person Family and 2) the Savannah River downstream of SRS for the Family Living Near the River. Time spent swimming were based on South Carolina recreational patterns cited in Hamby 1991 [p.6 and 24] (10). The Hamby values are based on "Outdoor Recreation Assessment and Policy Plan 1989," in the Georgia Recreation Planning Process, GA Department of Natural Resources, Atlanta, GA, 1990. Swimming times, not differentiated by age, represent warm-water fishing activity:

- Average number of lake swimming events/year – 8.12
- Average hours/lake swimming event – 2.61

This results in an exposure rate of 21.2 hours/year, which is applied to all individuals in the Delivery Person Family. For the Family Living Near the River, it was assumed that all members of the family spent one hour per day during the summer swimming in the river; this is more consistent with the characterization of this family as "always outdoors and in contact with the river" (5)

Locations and total time immersed in contaminated water while swimming summarized in Table 9-9.

Table 9-9 Exposure Locations and Times (hours/year) for Swimming External Exposure (Water Immersion) Pathway

Scenario	Swimming Location	Exposure Time (hours/year)
Rural Family One	Briar Creek near Girard	0 (all years and individuals)*
Rural Family Two	farm ponds around Williston	0 (all years and individuals)*
Urban/Suburban Family	Savannah River at Augusta	0 (all years and individuals)*
Delivery Person	Lower Three Runs Creek (LTRC) at Martin	21.2 (all years and individuals)
Outdoors Person	Savannah River upstream of SRS	0 (all years and individuals)*
Family Living Near the River	Savannah River Downstream of SRS	91 (all years and individuals)
Migrant Worker Family	Savannah River upstream of SRS and farm ponds around New Ellenton	0 (all years and individuals)*

* The dose from swimming external exposure (water immersion) is assumed to be zero, because the exposure location received no waterborne releases from the SRS; in these cases it was assumed that the water was uncontaminated by SRS activities.

9.3.5 Exposure to Contaminated Water While Boating

External exposure from being in a boat on a contaminated body of water is similar to external exposure from contaminated soil. The differences are that: 1) the contaminated water, not soil, is the source of radiation and 2) the boat, not buildings, partially shields the receptor from the radiation

Key variables for determining the intake for exposure to contaminated water while boating are:

1. Concentration of each radionuclide in the water at a location used for boating.
2. Shielding factor for boating exposures.
3. Boating daily event frequency (frequency of boating per day) at the particular boating location.
4. Duration of each boating event (hours per event).
5. Boating event annual frequency (number of days per year boating occurs).

The approach used to calculate annual radionuclide concentrations in water at two exposure locations is described in Chapter 8. The shielding factor accounts for the shielding from external radiation provided by the structure and composition of the boat; the shielding factor was assumed to have a value of 1.0 for all scenarios and receptors; this conservatively assumes the boat provides no shielding. Variables (3), (4), and (5) multiplied together equal the total time (in hours) per year spent boating and therefore exposed to direct radiation from contaminated water; values for these total times are provided in Table 9-10.

Table 9-10 Exposure Times (hours/year) and Locations for Boating External Exposure Pathway

Scenario	Boating Exposure Location	Exposure Time (hours/year)
Rural Family One	No boating activity	0 (all years and individuals)
Rural Family Two	No boating activity	0 (all years and individuals)
Urban/Suburban Family	Savannah River at Augusta	0 (all years and individuals)*
Delivery Person	Savannah River Downstream of SRS.	96 (all years and individuals)
Outdoors Person	Savannah River Downstream of SRS.	356 for adult male and children age 18 and over; 96 for adult female and children under age 18.
Family Living Near the River	Savannah River Downstream of SRS.	192 (all years and individuals)
Migrant Worker Family	No boating activity.	0 (all years and individuals)

* The dose from boating external exposure is assumed to be zero, because the exposure location received no waterborne releases from the SRS; in this and similar cases it was assumed that the water was uncontaminated by SRS activities.

The scenarios specified no boating activity for Rural Family One, Rural Family Two, and the Migrant Worker Family. For the Delivery Person Family, the Family Living Near the River, and the Outdoors Person boating occurred on the Savannah River downstream of SRS. Boating times are estimated using the factors for boating based on South Carolina recreational patterns cited in Hamby 1991 (10) and shown below in Table 9-11. These values are based on "Outdoor Recreation Assessment and Policy Plan 1989," in the Georgia Recreation Planning Process, GA Department of Natural Resources, Atlanta, GA, 1990. The numbers apply to all age groups and include two categories – canoeing and boating/sailing.

Table 9-11 South Carolina Boating Usage Rates (adapted from Hamby 1991)

Boating Usage	Canoe Trails	Boating / Sailing
Events / Year (average)	6.13	18.77
Hours / Event (average)	2.25	4.38
Hours / Year	13.8	82.2
Total	96 hours/year	

The total rate (96 hours/year) was applied to all individuals in the Delivery Person Family. Twice this exposure time was assumed for the Family Living Near the River, because their contact with the water was specified as higher than normal. For the Outdoors Person family, all family members, but the Adult Male, were assumed to have the regional average exposure time, the same as the Delivery Person Family. However the Adult Male had both occupational and recreational exposure; the average recreational exposure of 96 hours/year was added to an occupational exposure of 260 hours/year for a total of 356 hours/year. For the Adult Male's occupational exposure the amount of time spent boating was assumed to be half the time spent "on the river," and the time spent "on the river" was cited in Lockridge 2002 (5) as 8 hours/day (i.e., 40 hours/week) during the summer (i.e., 13 weeks) (0.5 x 40 x 13 = 260 hours/year).

9.4 Ingestion Exposure Route

Ingestion exposure pathways modeled in this study include:

- Ingestion of plants by humans, including:
  Leafy vegetables
  Root vegetables
  Fruit
  Grain
- Ingestion of animal products by humans, including:
  Beef
  Poultry
  Milk
  Eggs
  Fish
- Inadvertent consumption of contaminated soil
- Inadvertent consumption of contaminated water while swimming.

As shown in Table 9-1, the all these exposure pathways are associated only with radionuclide releases to air, with the exception of ingestion of fish and inadvertent ingestion of water while swimming; these last two pathways are associated only with radionuclide releases to water. With the exception of fish, contamination of plants and animals resulted from the contamination of soil by deposition of airborne radionuclides. Soil was not considered to be contaminated by deposition of water-borne radionuclides, because farmers in vicinity of the SRS did not use the Savannah River and Lower Three Runs Creek for irrigation (as explained in Chapter 3). In this study, ingestion of beef was used to represent consumption of all types of meat and meat products, except poultry.

9.4.1 Food-Chain Ingestion Exposures

The general intake equation (9-2) can be simplified for ingestion of foodstuffs to be:

$$I = C_f \cdot U \cdot ED \cdot T \qquad (9\text{-}3)$$

Where, I is the intake;

C_f is the radionuclide concentration in the contaminated food;
U is the consumption rate of the food, i.e., the contact rate for ingestion;
ED is the exposure duration, set to one year, since this study examines doses on an annual basis;
T is a special form of the annual activity factor representing the fraction of the food consumed that was produced in the vicinity of SRS and therefore was considered contaminated.

The general food intake equation (9-3) was adapted further for this study to reflect the receptor behaviors specified by the CDC scenarios. In particular, the scenarios specified the locations from which the receptors obtained their food. This was an important aspect of the scenario specifications, since different locations potentially experienced different contamination levels from SRS releases, because of differing distances from the sources and the inhomogeneous air dispersion patterns at the SRS. In general the radionuclide concentration in the food (C_f·), the ingestion rate (U), and the fraction contaminated (T) may all be a function of the location where the food was produced. A more precise rendering of equation (9-3) is:

$$I_{total} = \sum I_L = C_{fL} \cdot U_L \cdot ED \cdot T_L \qquad (9\text{-}4)$$

Where all the variables are defined as before, but the index "L" refers to location and I_{total} represents the total intake of a particular radionuclide for a particular receptor for a particular food. For example, as shown in Table 9-16 and Table 9-17 the Outdoors Person Family consumed as much meat (modeled as beef) as most other scenarios. A large fraction (75%) of this meat came from the SRS, while the remainder (25%) came from Jackson. The fraction of contamination of the meat from Jackson was set to 0.5 to reflect production of meat products distant from the SRS (e.g., hot dogs, lunch meats, and other processed meats); the fraction of contamination of meat from the SRS was set to 1.0 to reflect consumption of game taken from the site.

The source location of various terrestrial foods for each scenario is shown in Table 9-12. In general, both the amount of food consumed from each source location and the fraction of the food contaminated varies with the location and type of food. Note that for four scenarios all foods originate at a single location unique to that scenario: Rural Family #1, Rural Family #2, Near River Family, and the Migrant Worker Family.

Chapter 8 describes how the concentrations in food were calculated. The following subsections briefly provide the values chosen for consumption rate, U, and fraction contaminated, T, for the nine types of food considered, as well as the rationale for these choices.

Table 9-12 Source Locations for Various Terrestrial Food Types (and Soil Ingestion) for Each Scenario*

CDC SCENARIO	FOOD TYPE								
	Beef	Poultry	Milk	Eggs	Leafy Veg.	Root Veg.	Fruit	Grain	Soil
Rural Family #1	G	G	G	G	G	G	G	G	G
Rural Family #2	W	W	W	W	W	W	W	W	W
Urban/Suburban	A	A	A/NE	A	A	A	A	A	A
Delivery Person	B/M	B/M	B/M	B/M	B/M	B/M	B/M	B/M	B/M
Outdoors Person	J/SRS	J	J	J	J	J	J	J	J
Near River	M	M	M	M	M	M	M	M	M
Migrant Worker	NE	NE	NE	NE	NE	NE	NE	NE	NE

*Key to locations: G – Girard; W – Williston; A – Augusta; NE – New Ellenton; B – Barnwell; M – Martin; J – Jackson; SRS – Onsite SRS.

9.4.1.1 Ingestion of Leafy and Root Vegetables and Fruit

The Exposure Factors Handbook (4) was used to determine consumption rates of leafy vegetables, root and other vegetables, and fruit. This reference is based on data from U.S. Department of Agriculture studies, including the periodic National Food Consumption Surveys (NFCS) and the Continuing Surveys of Food Intakes by Individuals (CSFII).

Ingestion rates determined for leafy and root vegetables and fruit are listed in Table 9-13. Exposure factors reflect the assumptions that: 1) half the leafy vegetables, root vegetables, and fruit consumed by the Delivery Person Family were obtained from the Barnwell area and half from the Martin area, and 2) the Migrant Worker Family was in the SRS vicinity for only half of any year.

The fractions of foodstuffs contaminated (adjustment factors) are listed in Table 9-14. Note that for Rural Families One and Two the values change after 1959, but that values for all other scenarios are constant for the entire 39-year study period. The time dependencies of these values for different scenarios were mandated by the scenario specifications (5).

Table 9-13 Ingestion Rates (kg/yr) for Three Produce Categories

Individual	All Other Scenarios‡			Delivery Person Family (Barnwell/Martin)†			Migrant Worker Family		
	LV*	RV*	F*	LV	RV	F	LV	RV	F
Adult M	16.7	79.2	55.2	8.35/ 8.35	39.6/ 39.6	27.6/ 27.6	8.35	39.6	27.6
Adult F	16.7	57.2	56.6	8.35/ 8.35	28.6/ 28.6	28.3/ 28.3	8.35	28.6	28.3
1955 Child:									
Infant 1955	1.2	26.6	61.7	0.6/ 0.6	13.3/ 13.3	30.85/ 30.85	0.6	13.3	30.85
Preschool 1965-68	4.1	31.1	50.7	2.05/ 2.05	15.55/ 15.55	25.35/ 25.35	2.1	15.55	25.35
School 1960-66	8.1	41.9	52.0	4.05/ 4.05	20.95/ 20.95	26.0/ 26.0	4.05	20.95	26.0
Teen 1967-73	10.6	63.2	49.4	5.3/ 5.3	31.6/ 31.6	24.7/ 24.7	5.3	31.6	24.7
Adult 1974-92	16.7	79.2	55.2	8.35/ 8.35	39.6/ 39.6	27.6/ 27.6	8.35	39.6	27.6
1964 Child:									
Infant 1964	1.2	26.6	61.7	0.6/ 0.6	13.3/ 13.3	30.85/ 30.85	0.6	13.3	30.85
Preschool 1965-68	4.1	31.1	50.7	2.05/ 2.05	15.55/ 15.55	25.35/ 25.35	2.1	15.55	25.35
School 1969-75	8.1	41.9	52.0	4.05/ 4.05	20.95/ 20.95	26.0/ 26.0	4.1	20.95	26.0
Teen 1976-82	10.6	63.2	49.4	5.3/ 5.3	31.6/ 31.6	24.7/ 24.7	5.3	31.6	24.7
Adult 1983-92	16.7	79.2	55.2	8.35/ 8.35	39.6/ 39.6	27.6/ 27.6	8.4	39.6	27.6

*LV: Leafy Vegetables; RV: Root Vegetables; F: Fruit.
†The Delivery Person Family obtains half its produce from Martin and half from Barnwell; table entries represent this portion.
‡Rural Families One and Two, Urban/Suburban Family, Outdoors Person Family, Near Water Family

Table 9-14 Ingestion Rates (kg/y) and Fraction Contaminated (Adjustment Factor) for Leafy Vegetable, Root Vegetable, and Fruit Ingestion Exposure Pathways

Individual	Rural Families One And Two	All Other Scenarios*
Adult Male:		
Thru 1959	0.75	0.50
1960 & on	0.625	0.50
Adult Female:		
Thru 1959	0.75	0.50
1960 & on	0.625	0.50
1955 Child:		
Thru 1959	0.75	0.50
1960 & on	0.625	0.50
1964 Child:	0.625	0.50

* Urban/Suburban Family, Delivery Person Family, Outdoors Person Family, Near River Family, Migrant Worker Family

9.4.1.2 Ingestion of Grain

For the grain ingestion pathways, consumption rate data from the Exposure Factors Handbook (4) was used, as shown in Table 9-15. No data on local consumption was identified. These data were interpreted by assuming that most grain and grain products consumed by receptors in the vicinity of the SRS (i.e. breads, pastas, flours, etc.), would originate outside the local region. However, corn was expected to be consumed as a vegetable (e.g., corn on the cob). For purposes of modeling radionuclide uptake, corn is considered a grain rather than a vegetable. The Exposure Factors Handbook data is presented in terms of g/kg-day of consumption and was converted into kg/y by using Tables 7-2 and 7-3 from the same source to determine mean body mass as a function of age and gender. The Exposure Factors Handbook also presents consumption rates based on geographic region; however, differentiation by age and gender was not given by geographic region and differences between regions were small, so regional data were not used.

The contaminated fraction for the Migrant Worker Family was set to 0.5 to account for the fact that the family was completely absent from the SRS vicinity for one-half the year. For all the remaining scenarios, the contaminated fraction was set equal to 1.0.

Table 9-15 Ingestion Rate of Corn (kg/y)

Individual	All Other Scenarios	Delivery Person Family	
		Martin	Barnwell
Adult Male	4.1	2.05	2.05
Adult Female	3.5	1.75	1.75
1955 Child:			
Infant 1955	1.2	0.6	0.6
Preschool 1956-59	2.9	1.45	1.45
School 1960-66	3.9	1.95	1.95
Teen 1967-73	3.6	1.8	1.8
Adult 1974-92	4.1	2.05	2.05
1964 Child:			
Infant 1964	1.2	0.6	0.6
Preschool 1965-68	2.9	1.45	1.45
School 1969-75	3.9	1.95	1.95
Teen 1976-82	3.6	1.8	1.8
Adult 1983-92	4.1	2.05	2.05

9.4.1.3 Ingestion of Beef

Beef was used to represent all non-poultry and non-fish meat that was eaten by the hypothetical receptors. As explained in the White Paper, "Treatment of Radionuclide Concentrations in Wild Game in Dose Reconstruction Modeling" (11) beef was used as a surrogate for venison from locally-hunted deer. The principal source of information on meat consumption was the Exposure Factors Handbook (4).

Values used to characterize the consumption of beef reflects the scenario specifications; in particular the scenarios specified that: 1) the Delivery Person Family ate beef obtained from both the Martin and Barnwell areas; 2) the Migrant Worker Family is in the SRS vicinity for only half the year; and 3) three-quarters of the "beef " eaten by the Outdoors Person Family was venison from deer taken on the SRS site and one-quarter came from Jackson as farm-raised beef or other meat. Beef consumption rates are listed for each receptor in Table 9-16.

The fraction of the beef consumed that was considered to be contaminated (adjustment factor) took into account a number of assumptions that are discussed and referenced in Appendix E. For several scenarios 50% of beef purchased at local groceries was considered locally grown and therefore contaminated. The fraction of beef that is contaminated is listed for each receptor in Table 9-17.

Table 9-16 Consumption Rate (kg/y) of Beef (Meat)

Individual	Rural Families One and Two, Urban/ Suburban Family, Near River Family	Delivery Person Family		Outdoors Person Family		Migrant Worker Family
		Martin	Barn-well	Jackson	SRS Onsite	New Ellenton
Adult Male	78.1	39.05	39.05	19.52	58.58	39.05
Adult Female	49.7	24.85	24.85	12.42	37.28	24.85
1955 Child:						
Infant 1955	25.2	12.6	12.6	6.3	18.9	12.6
Preschool 1956-59	31.4	15.7	15.7	7.85	23.55	15.7
School 1960-66	50.6	25.3	25.3	12.65	37.95	25.3
Teen 1967-73	75.6	37.8	37.8	18.9	56.7	37.8
Adult 1974-92	78.1	39.05	39.05	19.52	58.58	39.05
1964 Child:						
Infant 1964	25.2	12.6	12.6	6.3	18.9	12.6
Preschool 1965-68	31.4	15.7	15.7	7.85	23.55	15.7
School 1969-75	50.6	25.3	25.3	12.65	37.95	25.3
Teen 1976-82	75.6	37.8	37.8	18.9	56.7	37.8
Adult 1983-92	78.1	39.05	39.05	19.52	58.58	39.05

Table 9-17 Fraction of Beef and Poultry that is Contaminated (Adjustment Factors)

	SCENARIO							
	Rural Family One/ Two	Urban-Suburban Family	Delivery Person Family		Outdoors Person Family		Near River Family	Migrant Worker Family
Production Location →	Williston/Girard	Augusta	Martin	Barnwell	Jackson	SRS Onsite	Martin	New Ellenton
Adult Male:								
1955-1959	0.75	0.5	0.625	0.5	0.5	1.0	0.5	0.5
1960-1992	0.625	0.5	0.625	0.5	0.5	1.0	0.5	0.5
Adult Female:								
1955-1959	0.75	0.5	0.625	0.5	0.5	1.0	0.5	0.5
1960-1992	0.625	0.5	0.625	0.5	0.5	1.0	0.5	0.5
1955 Child:								
1955-1959	0.75	0.5	0.625	0.5	0.5	1.0	0.5	0.5
1960-1992	0.625	0.5	0.625	0.5	0.5	1.0	0.5	0.5
1964 Child:	0.625	0.5	0.625	0.5	0.5	1.0	0.5	0.5

9.4.1.4 Ingestion of Poultry

For the poultry ingestion pathway, consumption rates for specific age and gender categories from the Exposure Factors Handbook [Table 11-10] (4) were adapted to the age and gender categories used in the modeling by using the same approach as was used for beef consumption. The rates that result from this adjustment are shown in Table 9-18 for each scenario. The fraction of poultry that is considered to be contaminated for each scenario is based on the descriptions provided by the SRSHES (4) and are the same fractions contaminated as used for beef ingestion. These fractions contaminated are shown for each scenario in Table 9-17.

Table 9-18 Ingestion Rate of Poultry (kg/y)

	All Other Scenarios	Delivery Person Family		Outdoors Person Family	
		Martin	Barnwell	Onsite SRS	Jackson
Adult Male	11.9	11.9	11.9	11.9	11.9
Adult Female	9.1	9.1	9.1	9.1	9.1
1955 Child:					
Infant 1955	1.5	1.5	1.5	1.5	1.5
Preschool 1956-59	6.4	6.4	6.4	6.4	6.4
School 1960-66	8.0	8.0	8.0	8.0	8.0
Teen 1967-73	11.7	11.7	11.7	11.7	11.7
Adult 1974-92	11.9	11.9	11.9	11.9	11.9
1964 Child:					
Infant 1964	1.5	1.5	1.5	1.5	1.5
Preschool 1965-68	6.4	6.4	6.4	6.4	6.4
School 1969-75	8.0	8.0	8.0	8.0	8.0
Teen 1976-82	11.7	11.7	11.7	11.7	11.7
Adult 1983-92	11.9	11.9	11.9	11.9	11.9

9.4.1.5 Ingestion of Milk

For the milk ingestion pathway, consumption rates were adapted from The Exposure Factors Handbook (4); these milk consumption rates are listed in Table 9-19. Note that of the milk consumed by the Urban/Suburban Family, half came from cows in Augusta, GA, and half came from cows in New Ellenton, SC. Similarly, for the Delivery Person Family the milk supply was split evenly between Barnwell and Martin. Because the scenarios specified that all milk was obtained from sources local to SRS, the fraction contaminated was set to unity for all scenarios.

Table 9-19 Consumption Rates (kg/y) for Milk

Individual	Rural Families One and Two, Outdoors Person Family, Near River Family	Urban/ Suburban Family	Delivery Person Family	Migrant Worker Family
		Augusta/New Ellenton	Barnwell/ Martin	New Ellenton
Adult Male	73.7	36.85/36.85	36.85/36.85	36.9
Adult Female	55.5	27.75/27.75	27.75/27.75	27.8
1955 Child:				
Infant 1955	131.8	65.9/65.9	65.9/65.9	65.9
Preschool 1956-59	130.2	65.1/65.1	65.1/65.1	65.1
School 1960-66	146.5	73.25/73.25	73.25/73.25	73.3
Teen 1967-73	169.5	84.75/84/75	84.75/84/75	84.8
Adult 1974-92	73.7	36.85/36.85	36.85/36.85	36.9
1964 Child:				
Infant 1964	131.8	65.9/65.9	65.9/65.9	65.9
Preschool 1965-68	130.2	65.1/65.1	65.1/65.1	65.1
School 1969-75	146.5	73.25/73.25	73.25/73.25	73.3
Teen 1976-82	169.5	84.75/84/75	84.75/84/75	84.8
Adult 1983-92	73.7	36.85/36.85	36.85/36.85	36.9

9.4.1.6 Ingestion of Eggs

For the egg ingestion pathway, consumption rates were adapted from The Exposure Factors Handbook (4); these egg consumption rates are listed in Table 9-20. Note that of the eggs consumed by the Urban/Suburban Family all came from hens in Augusta, GA, even though some foodstuffs came from New Ellenton, SC. For the Delivery Person Family the egg supply was split evenly between Barnwell and Martin. The quantity of eggs consumed by the Migrant Worker Family was set to one-half the quantity consumed by other scenarios, since they were absent from the SRS vicinity for one-half of each year modeled. Because the scenarios specified that all eggs were obtained from sources local to SRS, the fraction contaminated was set to unity for all scenarios.

Table 9-20 Consumption Rates (kg/y) for Eggs

Individual	Rural Families One and Two, Outdoors Person Family, Near River Family	Urban/ Suburban Family Augusta/New Ellenton	Delivery Person Family Barnwell/ Martin	Migrant Worker Family New Ellenton
Adult Male	13.9	13.9/0	6.95/6.95	6.95
Adult Female	8.4	8.4/0	4.2/4.2	4.2
1955 Child:				
Infant 1955	1.8	1.8/0	0.90/0.90	0.90
Preschool 1956-59	7.7	7.7/0	3.85/3.85	3.85
School 1960-66	8.0	8.0/0	4.0/4.0	4.0
Teen 1967-73	10.8	10.8/0	5.4/5.4	5.4
Adult 1974-92	13.9	13.9/0	6.95/6.95	6.95
1964 Child:				
Infant 1964	1.8	1.8/0	0.90/0.90	0.90
Preschool 1965-68	7.7	7.7/0	3.85/3.85	3.85
School 1969-75	8.0	8.0/0	4.0/4.0	4.0
Teen 1976-82	10.8	10.8/0	5.4/5.4	5.4
Adult 1983-92	13.9	13.9/0	6.95/6.95	6.95

9.4.1.7 Ingestion of Fish

Radiation exposure through the aquatic food consumption pathway was modeled as occurring entirely from consumption of fish. Freshwater crustaceans (e.g., crayfish) and mollusks (e.g., fresh water mussel) that grew in waters contaminated by liquid releases from the SRS were not considered to be consumed in sufficient quantities to warrant modeling. Crabs, shrimp, oysters, and clams from estuarine waters were certainly consumed in significant quantities; however, because the habitat for these crustaceans and mollusks is located a significant distance downriver in brackish or salt water, far away from the SRS, the levels of radiation in those waters and animals, traceable to the SRS releases, would be quite small. Modeling these small doses was therefore not included in the study. Several references were consulted to determine fish consumption rates, including (4), (10), (12), (13), and (14). None of these studies of fish consumption, however, were local to South Carolina and Georgia; therefore consumption rates were based on the Exposure Factors Handbook (4). For the Delivery Person Family, the source of the catch was assumed to be split evenly between Lower Three Runs Creek and the Savannah River. The consumption rate for the Migrant Worker Family reflected their presence in the SRS vicinity for only one-half of each year. The consumption rates for fish are summarized in Table 9-21.

Table 9-21 Ingestion Rate (kg/yr) for Fish

Scenario:	Rural Family One	Rural Family Two	Urban/ Suburban Family	Delivery Person Family		Outdoors Person Family	Family Near the River	Migrant Worker Family
Location:	Briar Creek	Creeks, ponds local to Williston	Savannah River near Augusta	Lower Three Runs Creek	Savannah River (Smith Lake)	Savannah River (various locations)	Savannah River (various locations)	Creeks, ponds of New Ellenton
Individual								
Adult M	9.9	9.9	9.9	4.95	4.95	9.9	9.9	4.95
Adult F	9.9	9.9	9.9	4.95	4.95	9.9	9.9	4.95
Children:								
Infant	4.2	4.2	4.2	2.1	2.1	4.2	4.2	2.1
Preschool	4.2	4.2	4.2	2.1	2.1	4.2	4.2	2.1
School	5.0	5.0	5.0	2.5	2.5	5.0	5.0	2.5
Teen	4.5	4.5	4.5	2.25	2.25	4.5	4.5	2.25
Adult	9.9	9.9	9.9	4.95	4.95	9.9	9.9	4.95

All fish consumed by the two Rural Families, the Urban/Suburban Family, and the Migrant Worker Family were assumed to come from bodies of water uncontaminated by SRS releases to surface water. However, all fish consumed by the Delivery Person Family, the Outdoors Person Family, and the Family Near the River were assumed to come from bodies of water contaminated by SRS releases to surface water. Therefore the contaminated fraction (adjustment factor) was set to unity for the Delivery Person Family, the Outdoors Person Family, and the Near River Family; all others were set to zero.

9.4.2 Inadvertent Soil Ingestion

The total mass of contaminated soil consumed over each year (kg/y) was based on the Exposure Factors Handbook (4). Daily rates of 100 milligrams per day for children and 50 milligrams per day for adults were apportioned among the exposure locations according to the amount of time that each receptor spent at each location. Note that unlike most foodstuffs, the consumption rate of soil is higher for children than for adults. These soil ingestion rates are summarized in Table 9-22. A higher rate of soil ingestion might be appropriate for persons spending a lot of time outdoors working with soil (such as the adult males in Rural Family #1, Rural Family #2, and the Migrant Family). The Exposure Factors Handbook (4) reports values as high as 480 mg/d, but characterizes them as “conjectural”. However, note that such soil-intensive outdoor activity would not be expected to occur every day, but only during relatively short periods of cultivating, planting, and harvesting.

Table 9-22 Soil Ingestion Rates (kg/year) for Each Scenario by Location of Soil Ingestion; Children's Ingestion Rates are Shown by Age

Scenario→		Rural Family One		Rural Family Two	Urban/ Suburban		Delivery Person				Outdoors Person		Near River	Migrant Worker
Location→		Girard	Wayne -sboro	Willi-ston	Augusta	Onsite SRS	Martin	Onsite SRS	Allen-dale	Barn-well	Onsite SRS	Jackson	Martin	New Ellenton
Person	Age													
Adult M	All	0.0183	0	0.0183	0.0141	0.00418	0.000693	0.000836	0.00334	0.0135	0.00418	0.0141	0.0183	0.009125
Adult F	All	0.0183	0	0.0183	0.0183	0	0.000393	0	0	0.0177	0	0.0183	0.0183	0.009125
Children Born in 1955 and 1964	Infant <1	0.0365	0	0.0365	0.0365	0	0.00128		0	0.0352	0	0.0365	0.0365	0.01825
	Pre-school 1-4	0.0365	0	0.0365	0.0365	0	0.00128	0	0	0.0352	0	0.0365	0.0365	0.01825
	School-child 5-11	0.0365	0	0.0365	0.0365	0	0.00128	0	0	0.0352	0	0.0365	0.0365	0.01825
	Teen 12-17	0.0313	0.00525	0.0365	0.0365	0	0.00128	0	0	0.0352	0	0.0365	0.0365	0.01825
	Adult M ≥18	0.0183	0	0.0183	0.0141	0.00418	0.00693	0.000836	0.0034	0.0135	0.00418	0.0141	0.0183	0.009125

9.4.3 Inadvertent Water Consumption while Swimming

The hourly ingestion rate of water, while swimming, was set equal to 0.05 L/hr, which is the EPA default value (see Appendix E). Based on the scenario specifications, swimming exposures were set to zero for all receptors except the Delivery Family and the Near River Family, because only these families swam in water contaminated by liquid releases from the SRS. The Delivery Person family swam on Lower Three Runs Creek near Martin, and the Family Near the River swam on the Savannah River downstream of the site. Swimming times were 21.2 hours/year for the Delivery Person Family, and 91 hours per year for the Family Near the River. Hence, the total amount of contaminated water ingested while swimming was 1.06 L/year for all members of the Delivery Person Family and 4.6 L/year for all members of the Family Near the River.

9.5 Inhalation Exposure Route

The inhalation exposure route consists of: 1) inhalation of air contaminated directly by releases to the atmosphere from the SRS and 2) inhalation of radionuclides that have been resuspended from soil after initial deposition from contaminated air. The general intake equation (9-2) can be simplified for inhalation to be:

$$I = C_a \cdot U \cdot ED \cdot T \qquad (9\text{-}5)$$

Where, I is the intake;

C_a is the radionuclide concentration in air resulting either directly from releases or from resuspension;

U is the breathing rate (m^3/h), i.e., the contact rate for inhalation;

ED is the exposure duration, set to one year, since this study examines doses on an annual basis;

T is the fraction of time spent at a particular location giving rise to the specified air concentration of radionuclides.

Chapter 5 describes how the concentrations in air resulting directly from atmospheric releases from the SRS were calculated. Chapter 8 describes how concentrations in soil were calculated and how concentrations of radionuclides in air from resuspended soil were calculated. The following subsections briefly provide the values for chosen for breathing rate, U, and fraction of time spent at different locations with contaminated air or soil, T.

9.5.1 Air Inhalation

Inhalation rates by age were based on data from the Exposure Factors Handbook (4). Breathing rates in the Exposure Factors Handbook were averaged over several age intervals to obtain age-interval-weighted breathing rates for the age groupings used in this dose calculation. Inhalation rates (units of m^3 per year) were created for each receptor at each exposure location by multiplying a constant daily inhalation rate, appropriate for the age and gender of the receptor, by the number of days in a year that the receptor was at a particular exposure location.

For this phase of the dose reconstruction it was not considered appropriate to refine the calculation by modeling the potential differences between indoor and outdoor radionuclide concentrations. Instead indoor concentrations were considered to be equal to outdoor concentrations, which is likely to be a pessimistic assumption. Furthermore this may better reflect conditions early in the site history, when air

conditioning and tightly sealed buildings were not as common as today. Table 9-23 lists the volume of air breathed per year at various exposure locations for each scenario; these inhalation volumes are also related to the age and gender of the various receptors.

9.5.2 Resuspended Soil

The same exposure variables that were used to calculate intake of radionuclides by breathing air contaminated directly by SRS releases to the atmosphere were used to calculate intake of radionuclides by breathing air contaminated by resuspension of contaminated soil. The only difference is that the air concentration used in equation (9-5) is the concentration based on resuspended radioactivity. As explained in Chapter 8, air concentration from resuspension is related to the soil concentration by a simple linear factor, the resuspension factor. For this study, higher values of the resuspension factor (producing higher air concentrations) were used for rural locations (Girard, New Ellenton, and Williston), while lower values were used for all other locations, which were assumed to have urban or suburban characteristics.

Table 9-23 Breathing Rates (m3/y) for the Family Members of Each Scenario by Location of Exposure; Children's Breathing Rates are Shown by Age

Scenario→		Rural One		Rural Two	Urban/Suburban		Delivery Person			Outdoors Person			Near River	Migrant Worker
Location →		Girard	Waynes-boro	Williston	Augusta	Onsite SRS	Martin	Onsite SRS	Allen-dale	Barnwell	Onsite SRS	Jackson	Martin	New Ellenton
Person	Age*													
Adult M	All	5,548	0	5,548	4,281	1,267	194	253	1,013	4,088	1,267	4,281	5,548	2,774
Adult F	All	4,125	0	4,125	4,125	0	144	0	0	3,980	0	4,125	4,125	2,062
Child Born in 1955 or 1964	Infant <1	1,643	0	1,643	1,643	0	57	0	0	1,585	0	1,643	1,643	821
	Pre-school 1-4	2,811	0	2,811	2,811	0	98	0	0	2,712	0	2,811	2,811	1,405
	School-child 5-11	4,380	0	4,380	4,380	0	153	0	0	4,227	0	4,380	4,380	2,190
	Teen 12-17	5,045	848	5,892	5,892	0	206	0	0	5,686	0	5,892	5,892	2,946
	Adult M ≥18	5,548	0	5,548	4,281	1,267	194	253	1,013	4088	1,267	4,281	5,548	2,774

*Note that the year the breathing rate is to be applied may be calculated by summing the age and the birth year of the child.

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