11 POINT ESTIMATE RESULTS

This chapter summarizes the doses and risks calculated for each of the four hypothetical individuals (family members) comprising each of the seven exposure scenarios as described in Chapter 3. Each family consists of:

- An adult female.
- An adult male.
- A male child born in 1955.
- A male child born in 1964.

The chapter is organized into two main sections:

Section 11.1 is an introduction and overview of results. The introduction (Section 11.1.1) summarizes the exposure routes and pathways considered for each exposure scenario. The overview of results (Section 11.1.2) summarizes the range of radiation doses and cancer risks calculated for all hypothetical members of all scenarios, and identifies those exposure pathways and radionuclides that consistently caused the largest doses and cancer risks among the hypothetical family members.

Section 11.2 presents radiation doses and cancer risks for each member of each family exposure scenario. It is divided into seven subsections – one for each exposure scenario. Each subsection addresses:

1. Effective dose and cancer risks for each family member, summed over the 39 years covered by this study.
2. Annual effective dose for each family member.
3. Radionuclides that dominated the radiation dose.
4. Effective dose for each family member from external exposure to radiation, and from ingesting and inhaling radionuclides.
5. The principal exposure pathways (e.g., eating contaminated foods) that led to the radiation dose.

Effective doses and cancer risks are presented in two significant figures. This format was chosen because it facilitates comparison of doses and risks that are far apart as well as those that are similar but not identical. Effective doses presented as the percent of the entire effective dose received over 39 years are shown to the nearest 0.1% although the calculations are likely not that accurate. Introduction and Overview of Results.

11.1 Introduction and Overview

11.1.1 Introduction

Radiation dose in this chapter is presented as effective dose. Effective dose represents the sum of equivalent doses calculated for up to 23 bodily tissues and organs (e.g., lungs, bone, thyroid) as weighted by a set of factors (Chapter 10) that have been recommended by the International Commission on Radiation Protection (ICRP) (1). These weighting factors account for the different sensitivity of different bodily tissues to radiation-induced cancers and genetic effects. Results are generally presented in units of millis (mSv). A milli is one-one thousandth of a (Sv), the recommended international unit for radiation dose. We also often present equivalent results in units of millirem (mrem), the radiation dose unit most

commonly used in the United States. A millirem is 0.01 millisv.[1] The cancer incidence and cancer fatality risks presented in this chapter represent the sum of risks calculated for 14 organs (or cancer sites) of the body (see Chapter 10). Both cancer incidence and fatality risks, as presented here, result solely from exposure to radionuclides released from SRS activities. These risks are in addition to those risks of cancer that the person would have without this radiation exposure. We present cancer incidence and fatality risks in units of percent: For example, a person with a 1% cancer incidence risk would face a one-in-one hundred lifetime risk of developing cancer due to the radiation exposures discussed here.

Exposures, tabulated for 18 exposure pathways in Chapter 9, are used to compute doses and risks by the methods outlined in Chapter 10. Table 11-1[2] summarizes each pathway, provides a shorthand description of each pathway, distinguishes whether the pathway resulted from radionuclides released by SRS into either the air or into surface water, and identifies the exposure route resulting from each exposure pathway.

Table 11-1 Exposure Routes and Pathways for Air and Water Pathways

Exposure Route & Pathway	Shorthand Description	Air Releases	Water Releases
External radiation:			
Immersion in a plume of contaminated air	Air Immersion	X	
Exposure to soil contaminated with radionuclides deposited from the air	Ground Contamination	X	
Exposure to a shoreline contaminated with radionuclides deposited from water	Shoreline		X
Exposure to contaminated water while swimming	Swimming		X
Exposure to contaminated water while boating	Boating		X
Ingestion:			
Leafy vegetable consumption	Leafy Vegetables	X	
Root vegetable consumption	Root Vegetables	X	
Fruit consumption	Fruit	X	
Grain consumption	Grain	X	
Beef consumption*	Beef	X	
Poultry consumption*	Poultry	X	
Milk consumption	Milk	X	
Egg consumption	Eggs	X	
Inadvertent soil consumption	Soil	X	
Fish consumption	Fish		X
Inadvertent ingestion of water while swimming	Inadvertent Swimming		X

[1] One is equal to 100 rems. One milli (1 mSv) = 1/1,000 Sv = 100 millirems (100 mrem). See Appendix D for additional information.
[2] We present radiation doses and risks for individual receptors as summed over all applicable pathways, as well as radiation doses received by each receptor from each pathway.

Exposure Route & Pathway	Shorthand Description	Air Releases	Water Releases
	Ingestion		
Inhalation:			
Inhalation of contamination in a plume of air	Air Inhalation	X	
Inhalation of contamination resuspended from soil after deposition from the air	Resuspended Soil	X	

*Beef consumption is a surrogate for consumption of all types of beef, including venison acquired through deer hunting on or near SRS. See Chapter 8 for an explanation of the reasons for this. Poultry consumption is a surrogate for consumptions of chicken and other fowl, including that acquired through bird hunting on or near SRS.

As shown, thirteen of these eighteen exposure pathways are associated with release of radionuclides by SRS into the air (*air pathways*), while five are associated with release into surface water (*water pathways*). Each hypothetical member of each exposure scenario may have received radiation exposures from some or all of these exposure pathways. Members of Rural Family One, Rural Family Two, the Urban/Suburban Family, and the Migrant Worker Family all received radiation exposures only from the air pathways. Members of the Delivery Person Family, the Outdoors Person Family, and the Family Living Near the River all received radiation exposures from the water as well as the air pathways.

11.1.2 Overview of Dose Results

Table 11-2 presents the effective dose received by each member of each hypothetical exposure scenario, as summed over the 39 years covered by this study. Doses for each scenario are presented for all air pathways; for all water pathways, and for air and water pathways combined.

The smallest radiation dose from all air pathways was received by the Child Born in 1964 of Rural Family One, while the largest radiation doses from all air pathways was received by the Child Born in 1955 of the Outdoors Person Family. The smallest radiation dose from all water pathways was received by the Child Born in 1955 of the Outdoors Person Family, while the largest radiation dose from all water pathways was received by the two adults of the Delivery Person Family. Considering combined air and water pathways, the smallest dose by any member of any exposure scenario was received by the Child Born in 1964 of the Rural Family Scenario, while the largest dose was received by the Child Born in 1955 of the Outdoors Person Family.

For any exposure scenario, most of the dose (i.e. from about 50 percent to more than 90 percent) received through all air pathways by the two adults and the Child Born in 1955 came from drinking milk and eating beef containing ^{131}I. Doses from tritium and ^{41}Ar were also important for these three family members. Most doses from tritium came from drinking milk and eating beef containing this radionuclide, while most doses from ^{41}Ar came from the air immersion pathway. ^{131}I, tritium, and ^{41}Ar were mostly released into the air during the very early days of SRS operation. In fact, about 99% of all ^{131}I released over 39 years had been released by the end of 1961.

The Child Born in 1964 was born after the largest releases into the air from SRS. For this reason, his doses received through the air pathways were consistently smaller than those received by any other member of any family exposure scenario. The Child Born in 1964 received most of his dose from the air pathways from ingestion or inhalation of tritium, followed by external exposure to ^{41}Ar. The two ingestion pathways of most importance for this family member were the milk and beef ingestion pathways. ^{131}I was consistently the third most important radionuclide for this family member, mainly from eating milk and beef.

Table 11-2 39-Year Effective Dose (mSv) for Each Member of Each Scenario

Scenario	Pathways	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Rural Family One	Air	0.30	0.42	1.6	0.072
	Water	___	___	___	_____
	All	0.30	0.42	1.6	0.072
Rural Family Two	Air	0.70	0.97	3.8	0.14
	Water	___	___	___	___
	All	0.70	0.97	3.8	0.14
Urban/Suburban Family	Air	0.33	0.73	2.7	0.11
	Water	___	____	___	___
	All	0.33	0.73	2.7	0.11
Migrant Worker Family	Air	0.45	0.62	2.2	0.083
	Water	____	____	___	____
	All	0.45	0.62	2.2	0.083
Delivery Person Family	Air	0.40	0.57	2.1	0.12
	Water	5.7	5.7	3.1	2.0
	All	6.1	6.3	5.2	2.1
Outdoors Person Family	Air	1.6	2.5	8.3	0.36
	Water	1.5	1.7	1.2	1.5
	All	3.0	4.2	9.4	1.8
Near Water Family	Air	0.31	0.42	1.7	0.088
	Water	1.8	1.8	1.4	1.7
	All	2.1	2.2	3.1	1.8

Small discrepancies are caused by rounding errors.

The dose received by any family member from all air pathways was highly dependent on that family member's assumed exposure locations, particularly the locations where the family member obtained food, lived, or worked. For example, the dose received by the Adult Female from all air pathways ranged across all seven scenarios from 0.30 to 1.6 mSv, or a factor of about five. This range in dose was notably larger than the range in dose that could be accounted for considering the differences in activities performed by the Adult Female in each scenario (e.g., a larger fraction of her foods was contaminated in some scenarios than in others). Radionuclide concentrations in the exposure locations depended on the meteorological parameters that influenced calculations of radionuclide dispersion in air. Among these parameters were the distances from the release points and the distributions of average wind speeds and atmospheric stability conditions.

Almost the entire dose received by any family member from all water pathways came from eating fish containing radionuclides. The three radionuclides that contributed the most to these doses were ^{137}Cs, ^{32}P, and ^{90}Sr. The relative importance of any radionuclide depended on whether the fish came from the Savannah River or from Lower Three Runs Creek.

11.2 Detailed Results for Each Scenario

11.2.1 Rural Family One

This hypothetical family lived in Girard, GA, and spent much of their work, home activities, and recreation time outdoors (see Figure 11-1). The Adult Male was a farmer, and the Adult Female worked at home. The family hunted, fished, and swam around the Girard area and in the nearby area of Briar Creek. The family did no boating. The children attended grade school in Girard and high school in Waynesboro, GA. Otherwise, the children stayed in Girard and became farmers when they grew up.

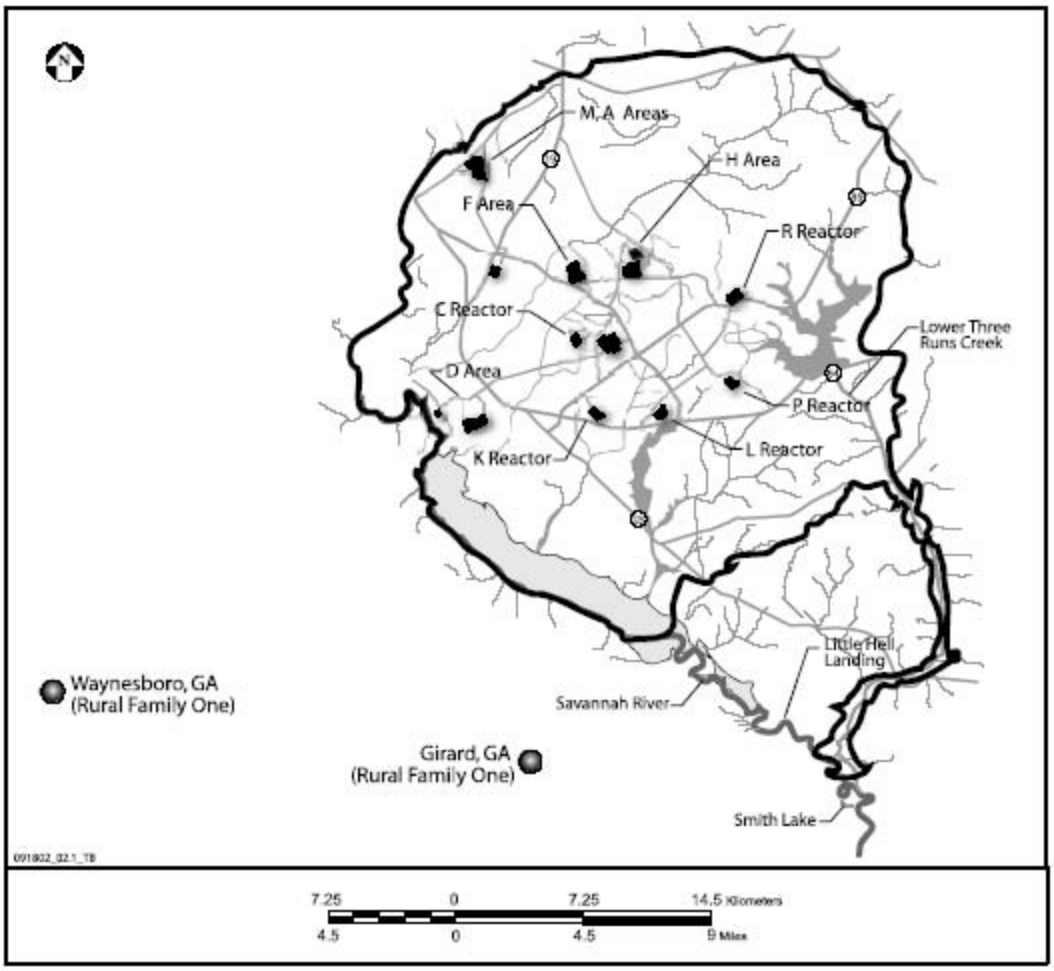

Figure 11-1 Exposure Locations for Rural Family One

All the family's milk and eggs came from cows and hens located in Girard. The fish eaten by the family was caught in Briar Creek or other nearby locations. Because Briar Creek is not located hydrologically downstream from SRS, none of the fish eaten by the family were affected by SRS release of radionuclides to surface water.

During the 1950s, half of the beef, poultry, leafy and root vegetables, and fruit eaten by the family was grown or produced on the family farm. The remaining half came from other sources such as stores in

Girard. Half of this food was locally grown or produced, and the remaining half came from sources away from the SRS area. Beginning in 1960, only 25% of their beef, poultry, vegetables, and fruit was grown or produced on the family farm. The remaining 75% came from other sources such as stores. Half of this remaining food was grown or produced in Girard, and half came from sources outside the SRS area.[3] All of the locally-produced grain eaten by the family was corn.[4]

Drinking water and water used to irrigate any food grown and eaten by the family came from ground- or surface-water sources assumed to be unaffected by SRS releases.

11.2.1.1 Effective Dose and Total Risks

Table 11-3 lists the effective dose and cancer risks for each member of Rural Family One, as summed over the 39 years covered in this study. All of these doses and risks came from exposure to radionuclides that had been released by SRS into the air.

Table 11-3 39-Year Effective Dose and Cancer Risks for Rural Family One

Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)	0.30	0.42	1.6	0.072
Cancer Incidence Risk (%)	0.00083	0.0011	0.016	0.0011
Cancer Fatality Risk (%)	0.00030	0.00038	0.0025	0.00069

The Child Born in 1955 received the largest dose and risks. He received an effective dose of 1.6 mSv (160 mrem), a cancer incidence risk of 0.016%, and a cancer fatality risk of 0.0025%. The Child Born in 1964 received the smallest dose and risks. The effective dose for the Child Born in 1964 was 4% of that for the Child Born in 1955.

Since dose is calculated in a risk-weighted fashion (effective dose), one would expect that the ratio of risk to dose would be a constant. For the adults, this seems to be so. However, as explained in Chapter 10, especially Section 10.2.2 and 10.3, internal conversion coefficients for dose and risk were considered to be age dependent. As a consequence, for the children the ratio of risk to dose is higher, which accounts for 1) the greater dose for a unit intake at younger ages and 2) the higher risk from childhood exposures, related partly to the longer latency period. However, the ratio of risk to dose for the children depends in a complex fashion on the time history of exposure and the particular radionuclides causing the exposure.

11.2.1.2 Effective Dose by Year

Figure 11-2 shows the percent of the entire 39-year effective dose received each year by each family member.[5] Figure 11-3 shows the annual dose received by each family member from 1954 through 1992. Note that the vertical axis (y-axis) of this figure is in units of s (rather than millis) and that its scale is logarithmic. A logarithmic scale is used because the annual doses range by a factor of more than 1000.[6]

[3] It was assumed that locally-grown food was produced at the same location in Girard as the family residence. It was also assumed that all locally-grown vegetables and fruit, whether grown on the family farm or obtained by Girard stores from local farms, contained radionuclides from SRS operations. Similarly, it was assumed that all locally-produced beef and poultry was raised in Girard, and therefore contained radionuclides from SRS operations.

[4] This assumption was made for all receptors and scenarios. As discussed in Appendix F, although individuals in the SRS vicinity would have eaten grain products such as breads, pasta, or flours, almost all such grain products was likely grown or produced out of the SRS vicinity and was therefore unaffected by SRS operations. But individuals in the SRS vicinity could plausibly have eaten locally-grown corn. This could have occurred for persons living in a suburban as well as a rural environment. Therefore, corn was treated as a grain surrogate for purposes of the dose reconstruction assessment.

Table 11-4 combines the information in these two figures. It lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose.

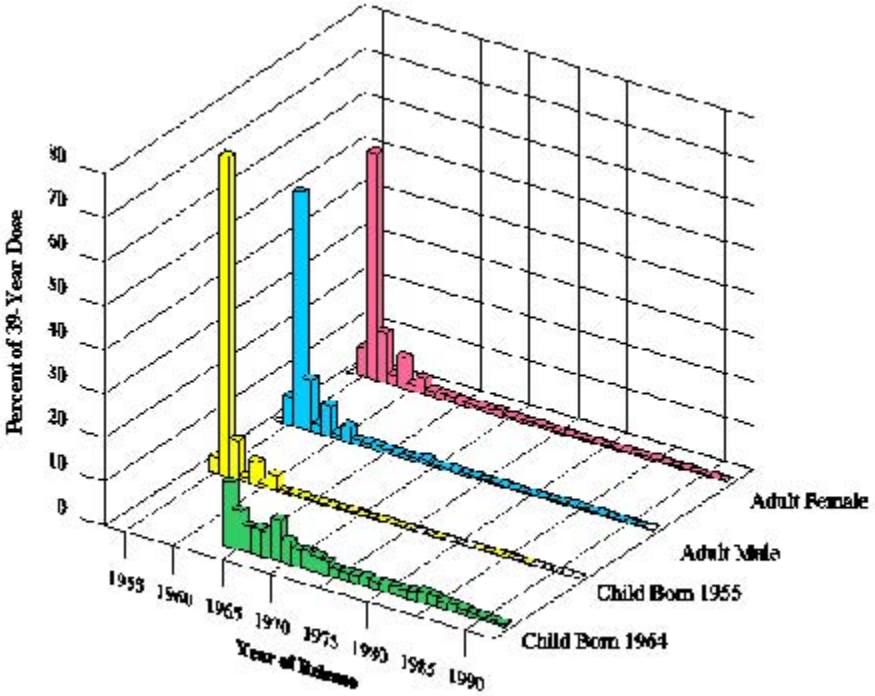

Figure 11-2 Percent of 39-Year Effective Dose by Year for Rural Family One

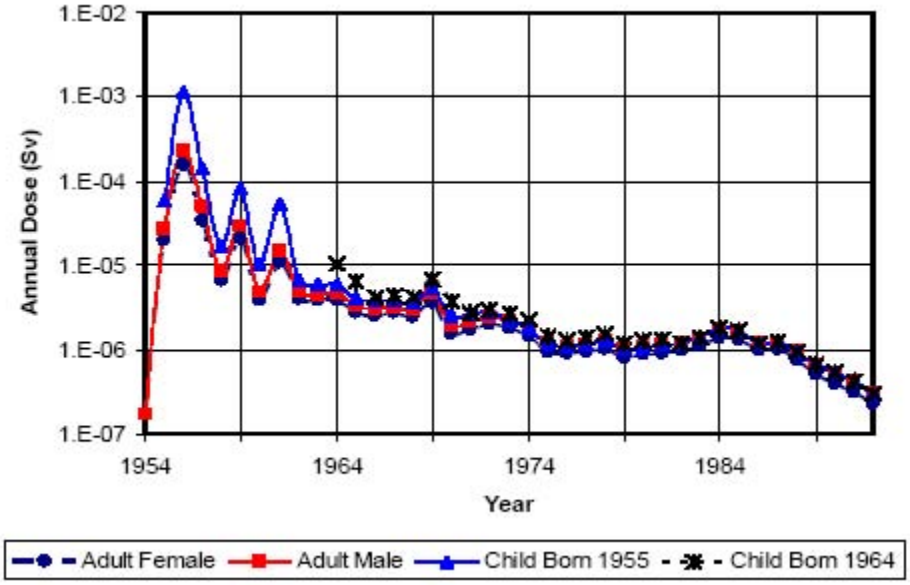

Figure 11-3 Annual Effective Dose (Sv) for Rural Family One

[5] Graphs and tables showing cancer incidence and fatality risks by year are available Appendix I.

[6] Each of the units on the scale of the vertical axis is ten times as large or as small as the next unit. As shown in Figure 11-3, for example, the Child Born in 1955 received an effective dose of 0.000058 Sv (0.058 mSv) in 1955 and an effective dose of 0.0012 Sv (1.2 mSv) in 1956. The dose received in 1956 was 21 times larger than the dose received in 1955.

Table 11-4 Annual Effective Dose (mSv) for Rural Family One

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1954	$1.7x10^{-04}$	0.1	$1.7x10^{-04}$	<0.1				
1955	0.020	6.6	0.027	6.5	0.058	3.6		
1956	0.16	51.6	0.23	53.6	1.2	72.8		
1957	0.034	11.3	0.049	11.6	0.14	8.9		
1958	0.0066	2.2	0.0086	2.0	0.017	1.1		
1959	0.021	7.0	0.030	7.0	0.082	5.2		
1960	0.0039	1.3	0.0048	1.1	0.010	0.6		
1961	0.011	3.6	0.015	3.5	0.055	3.4		
1962	0.0040	1.3	0.0048	1.1	0.0066	0.4		
1963	0.0038	1.3	0.0046	1.1	0.0059	0.4		
1964	0.0039	1.3	0.0048	1.1	0.0059	0.4	0.011	14.7
1965	0.0027	0.9	0.0033	0.8	0.0040	0.3	0.0064	8.9
1966	0.0026	0.9	0.0031	0.7	0.0039	0.2	0.0043	5.9
1967	0.0027	0.9	0.0032	0.8	0.0038	0.2	0.0044	6.1
1968	0.0024	0.8	0.0030	0.7	0.0036	0.2	0.0042	5.9
1969	0.0036	1.2	0.0047	1.1	0.0053	0.3	0.0068	9.4
1970	0.0016	0.5	0.0020	0.5	0.0025	0.2	0.0038	5.2
1971	0.0017	0.6	0.0021	0.5	0.0026	0.2	0.0027	3.8
1972	0.0020	0.7	0.0025	0.6	0.0029	0.2	0.0030	4.2
1973	0.0018	0.6	0.0022	0.5	0.0022	0.1	0.0026	3.6
1974	0.0015	0.5	0.0018	0.4	0.0018	0.1	0.0022	3.1
1975	$9.4x10^{-04}$	0.3	0.0012	0.3	0.0012	0.1	0.0015	2.0
1976	$9.1x10^{-04}$	0.3	0.0011	0.3	0.0011	0.1	0.0013	1.8
1977	$9.4x10^{-04}$	0.3	0.0012	0.3	0.0012	0.1	0.0014	1.9
1978	0.0010	0.3	0.0013	0.3	0.0013	0.1	0.0015	2.1
1979	$8.1x10^{-04}$	0.3	0.0010	0.2	0.0010	0.1	0.0012	1.7
1980	$8.7x10^{-04}$	0.3	0.0011	0.3	0.0011	0.1	0.0013	1.8
1981	$9.1x10^{-04}$	0.3	0.0011	0.3	0.0011	0.1	0.0014	1.9
1982	$9.7x10^{-04}$	0.3	0.0012	0.3	0.0012	0.1	0.0012	1.7
1983	0.0011	0.4	0.0014	0.3	0.0014	0.1	0.0014	2.0
1984	0.0014	0.5	0.0018	0.4	0.0018	0.1	0.0018	2.5
1985	0.0013	0.4	0.0017	0.4	0.0017	0.1	0.0017	2.4
1986	$9.9x10^{-04}$	0.3	0.0012	0.3	0.0012	0.1	0.0012	1.7
1987	0.0010	0.3	0.0013	0.3	0.0013	0.1	0.0013	1.7
1988	$7.4x10^{-04}$	0.2	$9.5x10^{-04}$	0.2	$9.5x10^{-04}$	0.1	$9.5x10^{-04}$	1.3
1989	$5.2x10^{-04}$	0.2	$6.8x10^{-04}$	0.2	$6.8x10^{-04}$	<0.1	$6.8x10^{-04}$	0.9
1990	$4.0x10^{-04}$	0.1	$5.3x10^{-04}$	0.1	$5.3x10^{-04}$	<0.1	$5.3x10^{-04}$	0.7
1991	$3.2x10^{-04}$	0.1	$4.2x10^{-04}$	0.1	$4.2x10^{-04}$	<0.1	$4.2x10^{-04}$	0.6
1992	$2.3x10^{-04}$	0.1	$3.1x10^{-04}$	0.1	$3.1x10^{-04}$	<0.1	$3.1x10^{-04}$	0.4
Total	0.30	100	0.42	100	1.6	100	0.072	100

Most of the dose was received during the first years of site operation. In 1956, the Child Born in 1955 received 1.2 mSv (120 mrem), or 73% of his entire dose, the Adult Female received 0.16 mSv (16 mrem), or 52% of her entire dose, and the Adult Male received 0.23 mSv (23 mrem), or 54% of his entire dose. Doses received during 1955, 1957, 1959, and 1961 were also relatively large. By the end of 1961, all of these three family members had received at least 84% of their entire radiation dose.

The Child Born in 1964 received his largest annual dose in 1964, when he received 0.011 mSv (1.1 mrem) or 15% of his entire dose. It represented about 1% of the largest annual dose received by the Child Born in 1955.

After 1961, the annual dose received by the family members gradually decreased from roughly 0.004 - 0.006 mSv per year to roughly 0.0003 mSv per year. This point is shown in Figure 11-3. When each of the children reached age 18 (in 1973 and 1982, respectively), their annual doses equaled the Adult Male's. This occurred because their radiation exposures were modeled to be the same as the Adult Male's. Annual doses for the Adult Female were always smaller than those for the Adult Male because she always ate less food and inhaled less air.

11.2.1.3 Dominant Radionuclides, Exposure Routes, and Pathways

Figure 11-4 lists the radionuclides that caused the largest doses over 39 years for each family member.

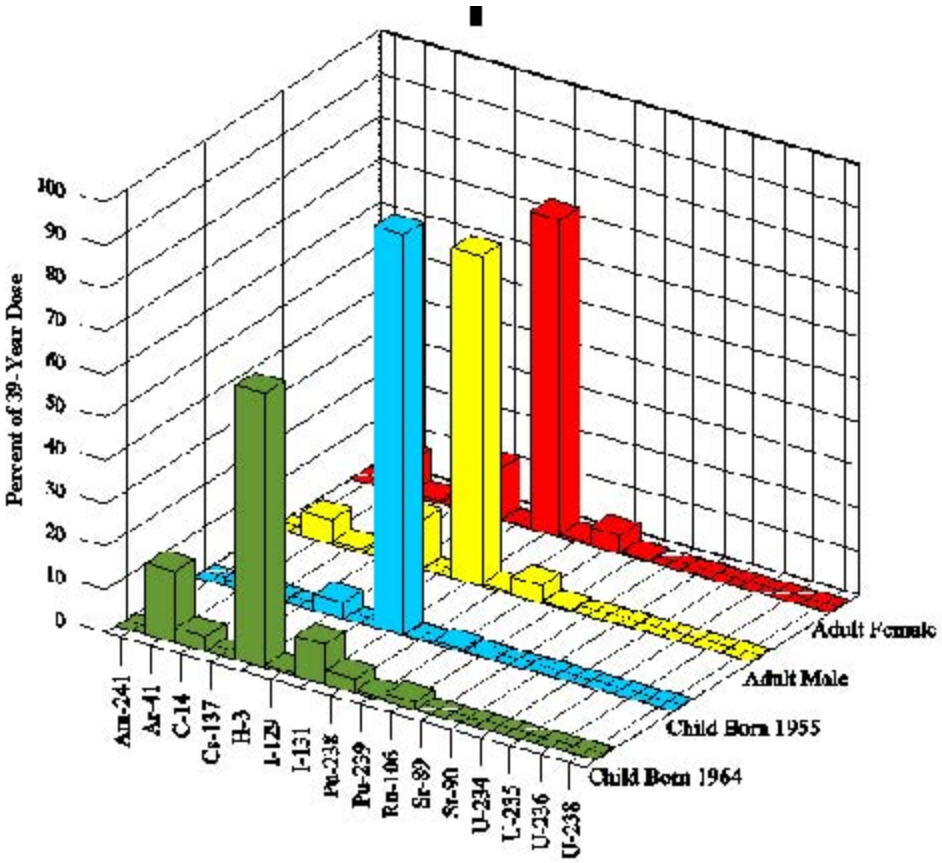

Figure 11-4 Percent of 39-Year Effective Dose by Dominant Isotopes for Rural Family One

The two adults and the Child Born in 1955 were exposed to largely the same quantities and distributions of radionuclides.[7] ^{131}I caused radiation doses mainly from eating beef and milk. It was also a major contributor to inhalation doses and a secondary contributor to doses from external radiation. Tritium caused radiation doses from ingestion and inhalation. ^{41}Ar was the largest contributor to doses from external radiation, while ^{239}Pu (along with ^{131}I) was a major contributor to doses from inhalation. ^{14}C caused doses mainly through ingestion.

The Child Born in 1964 did not experience the very large releases of ^{131}I that occurred in the 1950s and early 1960s. Hence, ^{131}I dropped to third in order of importance for this child. Tritium accounted for most of his dose, primarily through ingestion and inhalation. ^{131}I was a secondary contributor to ingestion dose, followed by ^{14}C. ^{41}Ar caused nearly his entire external radiation dose. ^{238}Pu was an important contributor to inhalation dose.

Most of the radiation dose received by this family came from eating food containing radionuclides (Figure 11-5). Ingestion contributed from 70 to 93 percent of the dose. External exposure to radiation contributed from 2 to17 percent of the dose. Inhalation contributed from 5 to 14 percent of the dose.

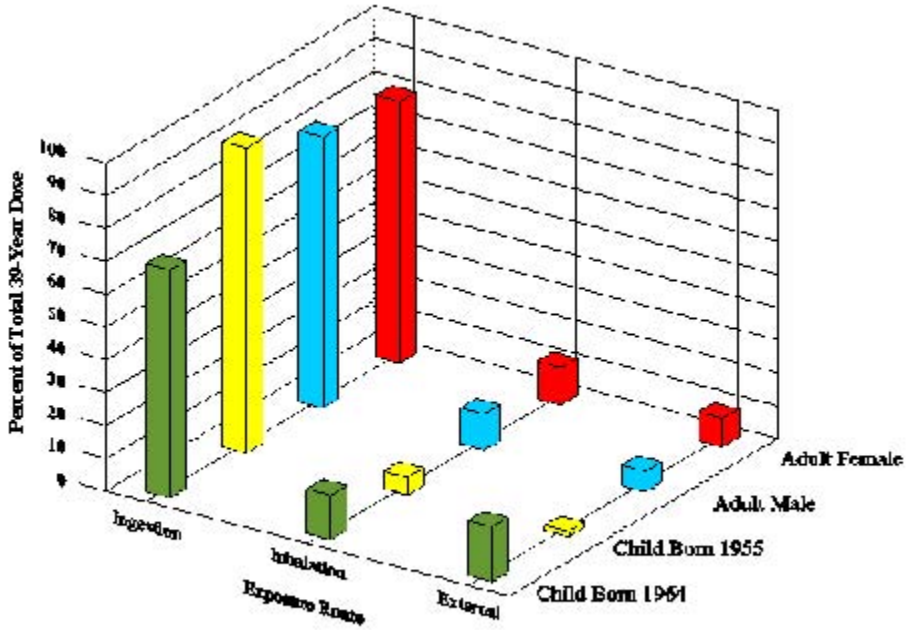

Figure 11-5 Percent of 39-Year Effective Dose by Exposure Route for Rural Family One

Compared to other family members, the Child Born in 1964 received a smaller dose from ingestion and a larger dose from external exposure to radiation and from inhalation. Again, this resulted from his missing the large releases of iodine and other radionuclides during the 1950s and early 1960s.

Table 11-5 lists the effective dose received over 39 years by each family member through each exposure pathway. Figure 11-6 illustrates the percent of effective dose. Tables of effective dose by radionuclide for each route and pathway are provided in Appendix K.

[7] Although the two adults received radiation doses during the year 1954, the Child Born in 1955 did not. But because the quantities of radionuclides discharged into the air were small compared to following years, the two adults and the Child Born in 1955 were each affected by nearly the same radionuclide source term.

Table 11-5 Year Effective Dose (mSv) by Exposure Pathway for Rural Family One

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.024	8.0	0.024	5.7	0.024	1.5	0.012	16.6
	Ground Contamination	0.0024	0.8	0.0025	0.6	0.0024	0.1	9.3×10^{-5}	0.1
Ingestion	Beef	0.15	50.7	0.24	57.1	0.69	43.2	0.011	15.3
	Eggs	0.0014	0.5	0.0023	0.6	0.0021	0.1	0.0014	2.0
	Fruit	0.011	3.6	0.0105	2.5	0.043	2.7	0.0054	7.5
	Grain	0.0011	0.4	0.0013	0.3	0.0036	0.2	6.3×10^{-4}	0.9
	Leafy Vegetables	0.018	5.9	0.018	4.2	0.030	1.9	9.7×10^{-4}	1.3
	Milk	0.049	16.1	0.065	15.3	0.70	43.9	0.026	35.4
	Poultry	0.0010	0.3	0.0012	0.3	0.0013	0.1	8.1×10^{-4}	1.1
	Root Vegetables	0.0073	2.4	0.010	2.4	0.014	0.9	0.0044	6.1
	Soil*	4.9×10^{-7}	<0.1	4.9×10^{-7}	<0.1	7.4×10^{-6}	<0.1	8.1×10^{-8}	<0.1
Inhalation	Air Inhalation	0.031	10.1	0.041	9.7	0.082	5.1	0.0091	12.6
	Resuspended Soil	0.0040	1.3	0.0054	1.3	0.0037	0.2	7.9×10^{-4}	1.1
Total		0.30	100	0.42	100	1.59	100	0.0721	100

*Doses from the soil ingestion pathway were no more than 0.0005% of any family member's entire 39-year dose.

Family members received most of their dose from eating beef and milk. At least 50 percent of the dose received by the two adults came from eating beef, while 15 to 16 percent of their dose came from drinking milk. The Child Born in 1955 received most of his dose from drinking milk (44%) and from eating beef (43%). Beef and milk pathways contributed 51% of the dose received by the Child Born in 1964.

The next largest doses were generally from eating fruits and vegetables – i.e., from 6 to 15 percent of the entire dose over 39 years. Doses from eating grain, poultry, and eggs ranged from 0.4 to 4 percent of the entire dose. Except for the Child Born in 1964, eggs contributed less than 1% of the entire dose.

Differences in doses for the two adults arose because of differences in their eating patterns. For example, the Adult Male and Adult Female each ate the same quantities of leafy vegetables, and each received the same radiation dose from this pathway. But the Adult Male ate 1.6 times as much beef as the Adult Female (see Appendix F), and thus received 1.6 times the dose from this pathway.

The Child Born in 1955 received a larger ingestion dose than did the two adults, especially from drinking milk. His dose from drinking milk was ten times larger than the doses received by the two adults. His doses from most of the other pathways were also somewhat larger. Differences came primarily from changes, as the Child Born in 1955 aged, in his annual rates of eating foods, and, while growing from a child to an adult, his larger effective dose per quantity of radionuclide ingested (see Appendix D).

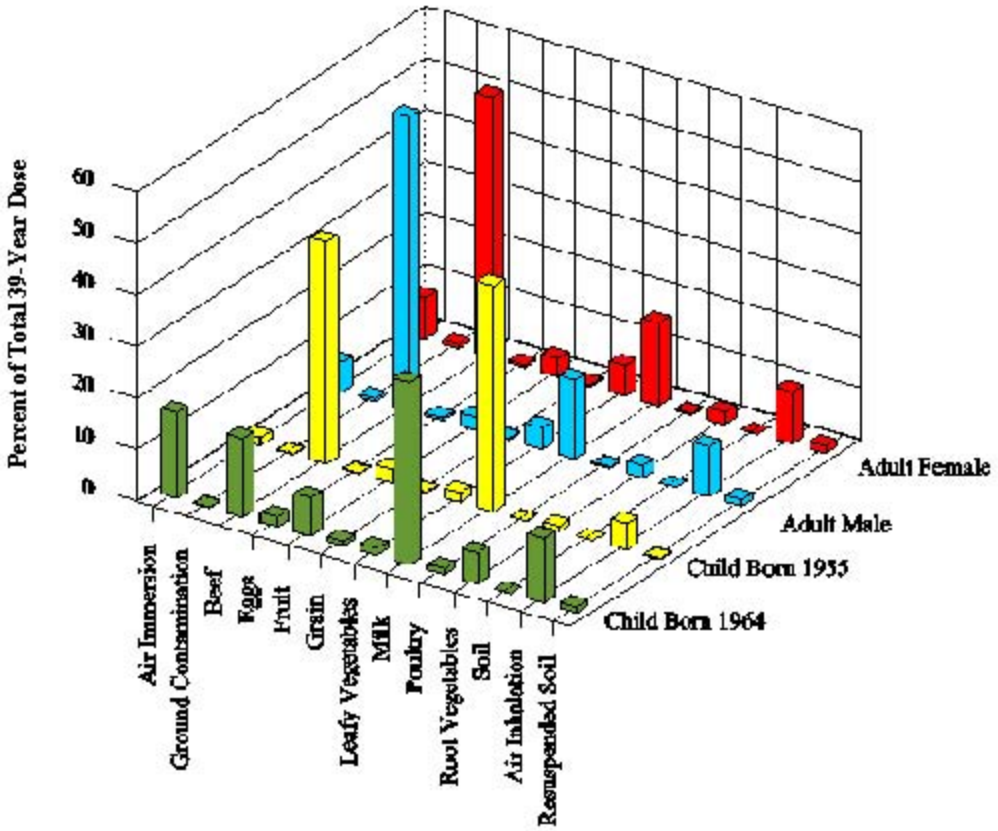

Figure 11-6 Percent of 39-Year Effective Dose by Exposure Pathway for Rural Family One

The Child Born in 1964 received a smaller ingestion dose than did any of the other family members. The distribution of dose among ingestion pathways was also different. The ingestion dose for the Child Born in 1964 was mostly caused by drinking milk and by eating beef containing tritium (see Appendix K).

Of the two external exposure pathways, at least ten times as much dose was received from exposure to radionuclides in the air than from radionuclides that had been deposited on soil or other surfaces.

External doses from air immersion were slightly larger for the two adults than for the Child Born in 1955. Because external radiation doses were determined as if all family members were always adults,[8] the small difference in dose between the two adults and this child resulted from: 1) differences in annual levels of exposure during the years the child attended high school in Waynesboro (the two adults always stayed in Girard); and 2) the additional year of radiation exposure (1954) experienced by the two adults.

For the two adults and the Child Born in 1955, the small differences in doses from external exposure to contaminated ground surfaces were largely caused by differences in the fractions of their time spent indoors and outdoors. Structures provided radiation shielding against exposures from contaminated ground surfaces. Because the Adult Male spent more time outdoors than the Adult Female, he received larger doses. But the Child Born in 1955 spent more time inside in his early years than he did after he grew (see Appendix D). The outcome of these competing influences was that his dose was slightly larger than that for the Adult Female and slightly smaller than that for the Adult Male.

[8] External radiation dose coefficients are given in FGR-13U (2) only for adults, an approximation that the authors of [FGR-13U] concluded would result in relatively small errors. Consequently, doses from external radiation sources were calculated as if all family members were always adults (see Appendix D).

Doses from inhalation pathways resulted from: 1) breathing radionuclides that were in the air before being deposited on the ground, and 2) breathing radionuclides that had been resuspended from soil after being deposited on the ground. Clearly most inhalation doses resulted from the first pathway. Only 4 to 12 percent of all inhalation doses came from inhalation of radioactive particles after they had been resuspended from soil.

- For the air inhalation pathway, the Adult Male received a somewhat larger dose than did the Adult Female because he had a larger breathing capacity (see Appendix E). However, the Child Born in 1955 received about twice as much dose as the two adults. This resulted from two competing influences: The breathing rate of the Child Born in 1955 was small as an infant but increased as he grew to manhood; conversely, the dose received per unit quantity of radionuclide inhaled was generally larger during his earlier years.[9]

- For the soil resuspension pathway, the inhalation doses for the Adult Male were again larger than those for the Adult Female. However, inhalation doses for the Child Born in 1955 were smaller than those for the two adults. This pattern is different than that seen for the air inhalation pathway. This occurred because the quantities and distributions of radionuclides affecting these individuals were different for this pathway than for the air inhalation pathway, in addition to competing influences such as those described above.[10]

11.2.2 Rural Family Two

This hypothetical family was similar to Rural Family One, except that this family lived in Williston, SC, instead of Girard, GA (Figure 11-7). They spent much of their work, home activities, and recreation time outdoors. The Adult Male was a farmer and the Adult Female worked at home. The family hunted, fished, and swam in the Williston area. This family did no boating. The children attended grade and high school in Williston. When they grew up, the children became farmers, adopting the same activities as did their adult male parent.

All of the family's milk and eggs came from cows and hens located in Williston (on the family farm or nearby). All the fish eaten by the family was caught in streams and ponds in or near Williston. Because these streams and ponds are not located hydrologically downstream from SRS, none of the fish eaten by the family were affected by SRS release of radionuclides to surface water.

During the 1950s, half of the beef, poultry, leafy and root vegetables, and fruit eaten by the family was grown or produced on the family farm. The remaining half came from other sources such as stores in Williston. Half of this remaining food (i.e., food not grown or raised on the family farm) was grown or produced in Williston and the other half came from outside the SRS area. Beginning in 1960, only 25% of their beef, poultry, vegetables, and fruit was grown or produced on the family farm. The remaining

[9] From [FGR-13U], for example, the effective dose coefficients for ^{131}I inhaled as a vapor are as follows in units of Sv per Bq inhaled: Infant (1.30×10^{-7}), 1-Year-Old (1.27×10^{-7}), 5-Year-Old ($7\ 34 \times 10^{-8}$); 10-Year-Old (3.71×10^{-8}), 15-Year-Old (2.43×10^{-8}), and Adult (1.54×10^{-8}). Doses per unit quantity of ^{131}I inhaled decrease for each successive age group.

[10] The Child Born in 1955 received a larger dose than the two adults for the air inhalation pathway but a smaller dose than the two adults for the resuspension pathway. This probably occurred because the family members were exposed to different quantities and distributions of radionuclides for the air inhalation pathway than for the resuspension pathway. For the air inhalation pathway, radionuclides were inhaled from a plume of radionuclides in air surrounding each family member. But radionuclides inhaled due to the resuspension pathway had to be first deposited on the soil and then dispersed back into the air due to wind or activities such as farming that disturbed the soil. Different radionuclides were deposited onto soil at different rates depending on their physical form (e.g., whether they existed as gasses or particulates). In addition, the concentrations of radionuclides in air from resuspension of radioactive particles from soil were 100 times smaller in Waynesboro, where the children attended high school, than in Girard (see Chapter 9).

75% was obtained from other sources such as stores in Williston. Half of this remaining food was locally-grown or produced, and half came from outside the SRS area.

All locally-grown grain eaten by the family was corn. Drinking water and water used to irrigate any food grown and eaten by the family came from ground- or surface-water sources assumed to be unaffected by SRS releases.

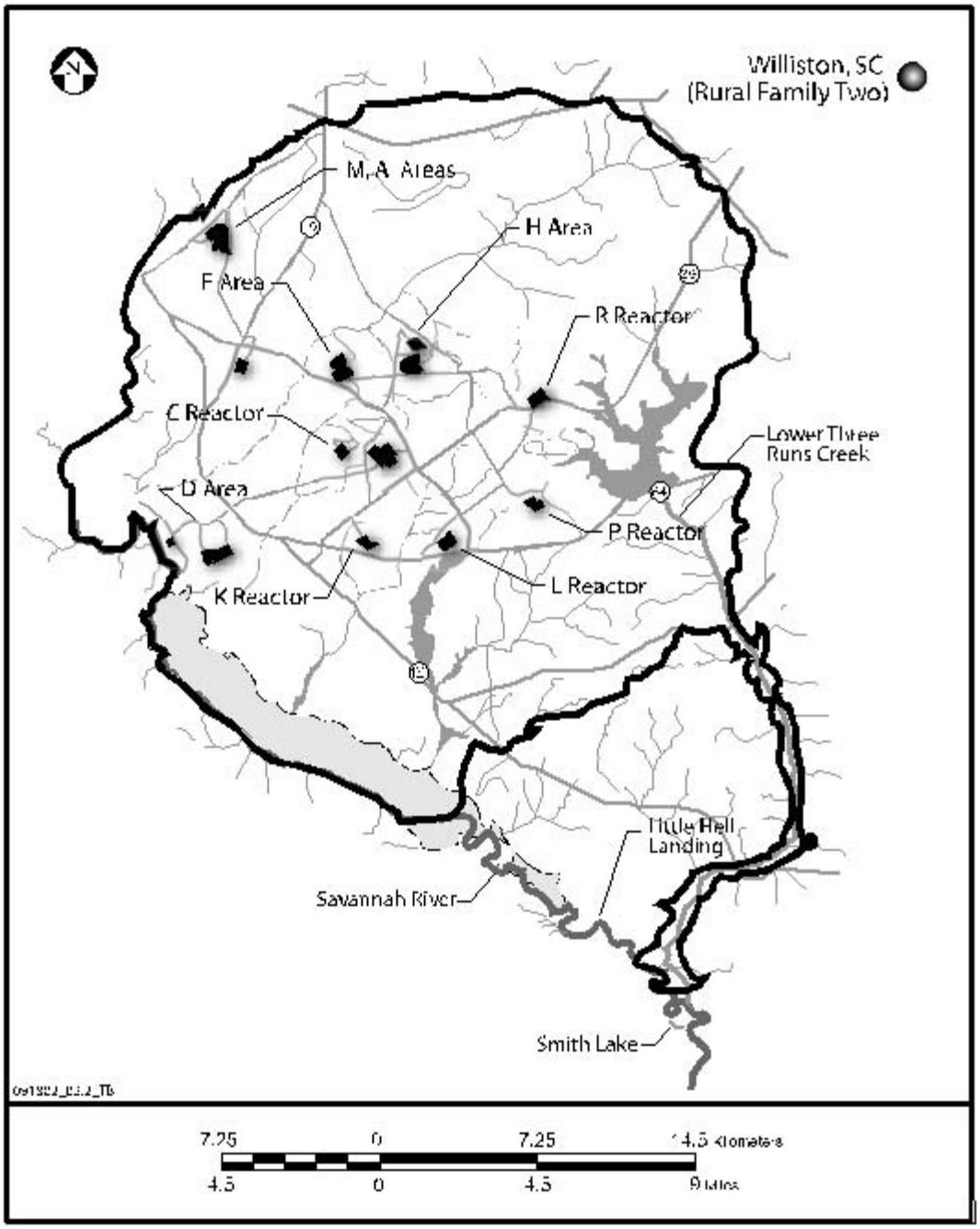

Figure 11-7 Exposure Location for Rural Family Two

11.2.2.1 Effective Dose and Total Risks

Table 11-6 lists the effective dose and cancer risks for each member of Rural Family Two over 39 years of SRS operation. All doses and risks resulted from exposure to radionuclides that had been released into the air.

Table 11-6 39-Year Effective Dose and Cancer Risks for Rural Family Two

Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)	0.70	0.97	3.8	0.14
Cancer Incidence Risk (%)	0.0019	0.0025	0.037	0.0021
Cancer Fatality Risk (%)	0.00064	0.00080	0.0056	0.0013

Doses and risks were about double those for Rural Family One (Table 11-3), which mainly resulted from the different exposure location (Williston vs. Girard and Waynesboro). The Child Born in 1955 received the largest dose and risks. He received an effective dose over 39 years of 3.8 mSv (380 mrem), a cancer incidence risk of 0.037%, and a cancer fatality risk of 0.0056%. The Child Born in 1964 again received the smallest dose and risks. The dose for the Child Born in 1964 was about 4% of that for the Child Born in 1955.

11.2.2.2 Effective Dose by Year

Figure 11-8 shows the percent of the entire 39-year effective dose received each year by each family member, while Figure 11-9 shows the annual effective dose (in units of s) received by each family member. Again, the vertical axis (y-axis) of Figure 11-9 is in logarithmic scale. The shapes of each figure are similar to corresponding figures for Rural Family One (Figure 11-2 and Figure 11-3). More detailed information is contained in Table 11-7 which lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose in millis.

Most of the dose was received during the early days of site operation. In 1956, the Child Born in 1955 received 2.8 mSv (280 mrem), or 74% of his entire dose over 39 years. During this year the Adult Female received 0.37 mSv (37 mrem), or 54% of her entire dose, and the Adult Male received 0.54 mSv (54 mrem), or 56% of his entire dose. The Child Born in 1964 received his largest dose in 1964 when he received 0.020 mSv (2 mrem), or 15% of his entire dose over 39 years.

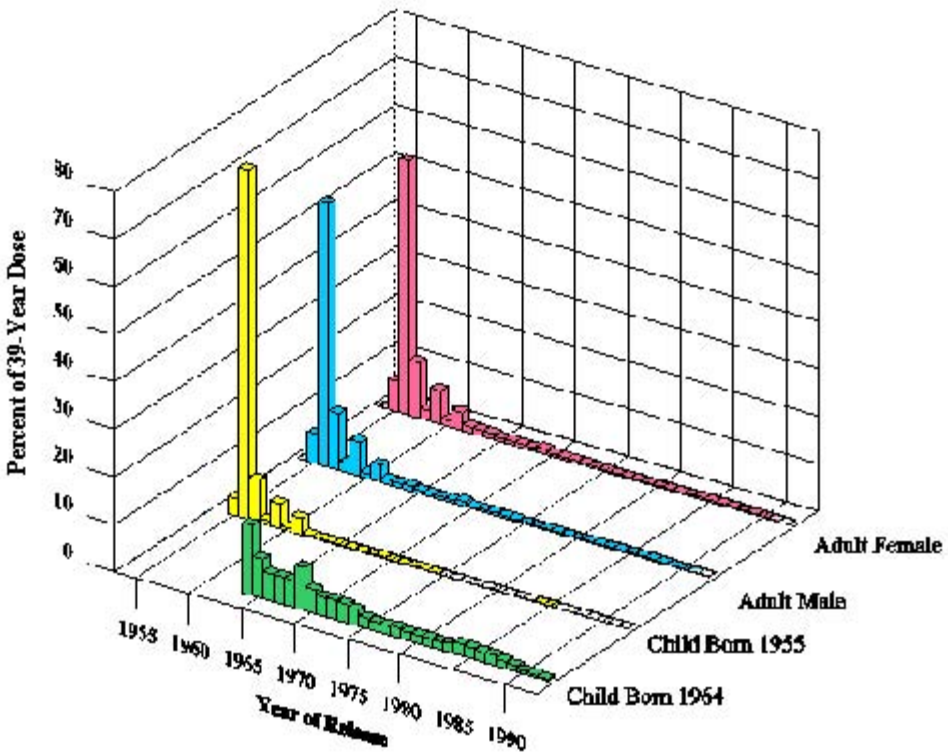

Figure 11-8 Percent of 39-Year Effective Dose by Year for Rural Family Two

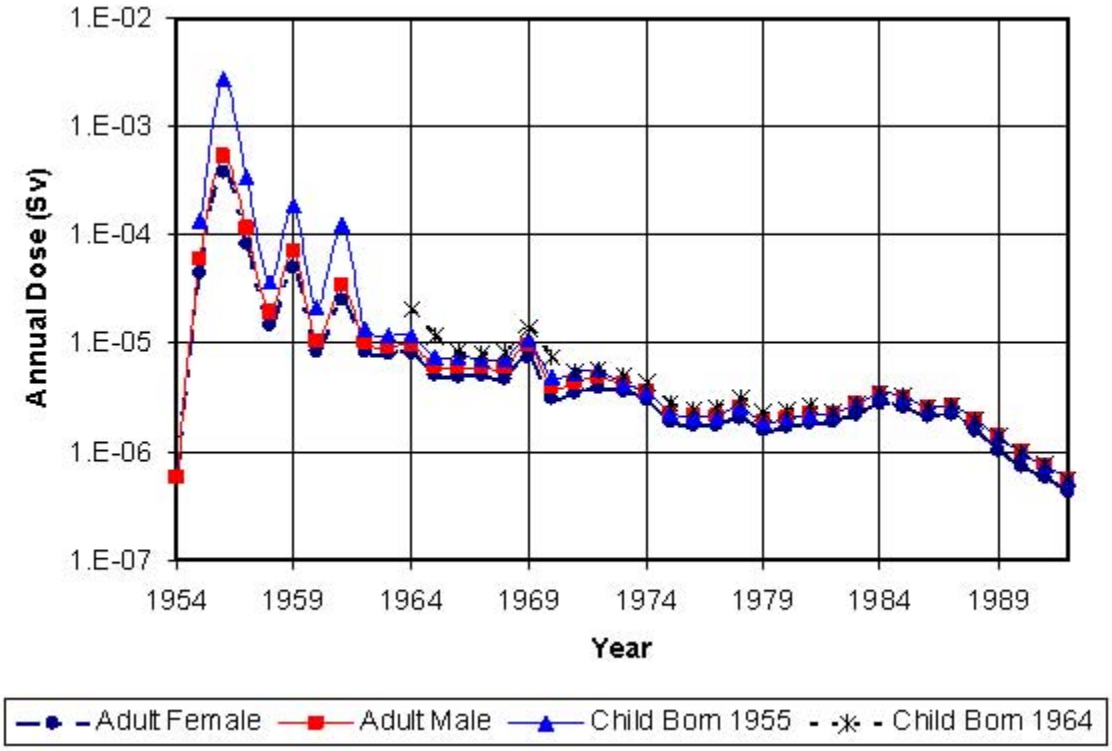

Figure 11-9 Annual Effective Dose (Sv) for Rural Family Two

Table 11-7 Annual Effective Dose (mSv) for Rural Family Two

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1954	$5.7x10^{-04}$	0.1	$5.8x10^{-04}$	0.1				
1955	0.045	6.5	0.061	6.3	0.14	3.6		
1956	0.37	53.6	0.54	55.5	2.8	73.7		
1957	0.081	11.6	0.12	11.9	0.33	8.9		
1958	0.015	2.1	0.019	2.0	0.037	1.0		
1959	0.049	7.1	0.070	7.1	0.19	5.1		
1960	0.0084	1.2	0.010	1.1	0.022	0.6		
1961	0.025	3.6	0.035	3.6	0.13	3.4		
1962	0.0084	1.2	0.010	1.0	0.014	0.4		
1963	0.0079	1.1	0.0094	1.0	0.012	0.3		
1964	0.0080	1.1	0.0096	1.0	0.012	0.3	0.025	14.9
1965	0.0051	0.7	0.0061	0.6	0.0074	0.2	0.014	8.2
1966	0.0049	0.7	0.0059	0.6	0.0073	0.2	0.0094	5.7
1967	0.0051	0.7	0.0060	0.6	0.0071	0.2	0.0095	5.8
1968	0.0048	0.7	0.0058	0.6	0.0071	0.2	0.0094	5.7
1969	0.0075	1.1	0.0097	1.0	0.011	0.3	0.015	9.0
1970	0.0031	0.4	0.0038	0.4	0.0049	0.1	0.0083	5.0
1971	0.0035	0.5	0.0043	0.4	0.0053	0.1	0.0065	4.0
1972	0.0039	0.6	0.0048	0.5	0.0057	0.2	0.0068	4.1
1973	0.0036	0.5	0.0043	0.4	0.0043	0.1	0.0064	3.9
1974	0.0029	0.4	0.0036	0.4	0.0036	0.1	0.0055	3.4
1975	0.0018	0.3	0.0023	0.2	0.0023	0.1	0.0036	2.2
1976	0.0018	0.3	0.0021	0.2	0.0021	0.1	0.0031	1.9
1977	0.0017	0.3	0.0022	0.2	0.0022	0.1	0.0031	1.9
1978	0.0020	0.3	0.0026	0.3	0.0026	0.1	0.0036	2.2
1979	0.0015	0.2	0.0019	0.2	0.0019	0.1	0.0028	1.7
1980	0.0017	0.2	0.0020	0.2	0.0020	0.1	0.0029	1.8
1981	0.0018	0.3	0.0022	0.2	0.0022	0.1	0.0031	1.9
1982	0.0019	0.3	0.0023	0.2	0.0023	0.1	0.0028	1.7
1983	0.0022	0.3	0.0027	0.3	0.0027	0.1	0.0032	2.0
1984	0.0027	0.4	0.0035	0.4	0.0035	0.1	0.0041	2.5
1985	0.0025	0.4	0.0032	0.3	0.0032	0.1	0.0038	2.3
1986	0.0021	0.3	0.0026	0.3	0.0026	0.1	0.0035	2.1
1987	0.0022	0.3	0.0027	0.3	0.0027	0.1	0.0034	2.1
1988	0.0016	0.2	0.0020	0.2	0.0020	0.1	0.0025	1.5
1989	0.0010	0.1	0.0014	0.1	0.0014	<0.1	0.0019	1.1
1990	$7.4x10^{-04}$	0.1	$9.8x10^{-04}$	0.1	$9.8x10^{-04}$	<0.1	0.0010	0.6
1991	$5.7x10^{-04}$	0.1	$7.6x10^{-04}$	0.1	$7.6x10^{-04}$	<0.1	$8.3x10^{-04}$	0.5
1992	$4.2x10^{-04}$	0.1	$5.6x10^{-04}$	0.1	$5.6x10^{-04}$	<0.1	$5.6x10^{-04}$	0.3
Total	0.70	100	0.97	100	3.8	100	0.16	100

11.2.2.3 Dominant Radionuclides, Exposure Routes, and Pathways

Figure 11-10 shows the radionuclides that caused the largest doses over 39 years for each family member.

Generally similar radionuclides dominated dose to each family member as those for Rural Family One (see Figure 11-4). Yet there were small differences: For example, the two adults received larger doses from ^{238}Pu than from ^{14}C (unlike Rural Family One), and the distribution of dose from the principal radionuclides was slightly different (e.g., ^{131}I caused 74% of the dose to the Adult Male in Rural Family One and 79% of the dose to the Adult Male in Rural Family Two).

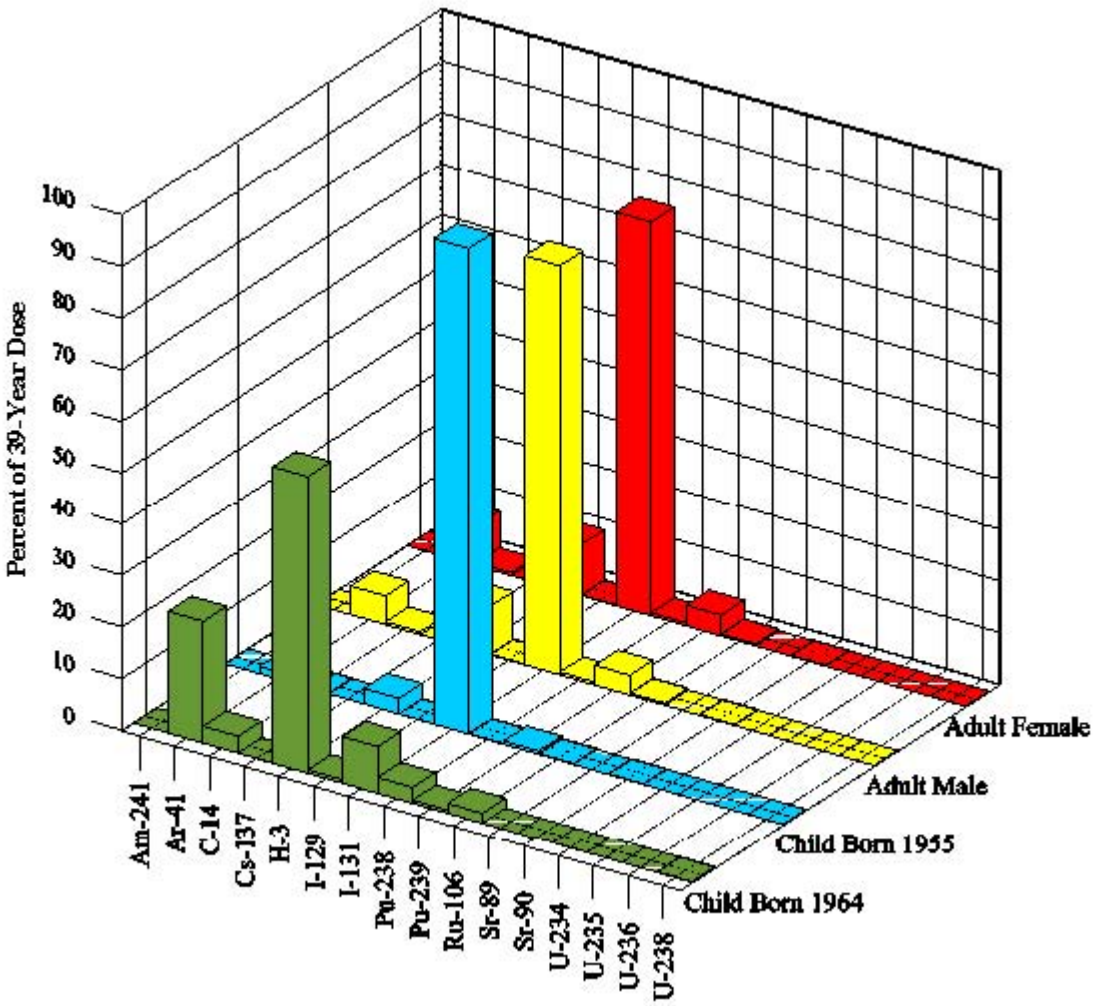

Figure 11-10 Percent of 39-Year Effective Dose by Dominant Isotopes for Rural Family Two

These differences occurred because Rural Families One and Two were located at different directions and distances from the points were radionuclides were released from SRS into the air. The distributions of average wind speeds and stability classes were different, resulting in different patterns of radionuclide dispersion in air. The average concentrations of radionuclides in air were different, over the 39 years considered in the study, at Waynesboro than they were at Girard.

Most of the radiation dose received by this family came from eating foods containing radionuclides (Figure 11-11). All family members received from 68 to 94 of their entire dose over 39 years from

ingestion. From 2 to 19 percent of their entire dose came from exposure to external radiation, and from 5 to 14 percent of their entire dose came from inhalation of radionuclides. This pattern of dose is similar to that seen for Rural Family One (Figure 11-5).

Table 11-8 lists the effective dose over 39 years, by pathway, for each family member. Figure 11-12 illustrates the percent of the effective dose received through each pathway over 39 years. Although the doses listed in Table 11-8 are larger for each pathway than those for Rural Family One (Table 11-5), the percent of dose caused by each pathway was similar.

For all family members, and especially the Child Born in 1955, most of their dose came from eating beef and milk (i.e., from 50 to 88 percent of their entire dose). For all family members, from 5 to 14 percent of their entire dose came from eating fruit and vegetables. A smaller dose was received from eating grain, poultry, and eggs. Eating these three foods contributed from 0.4 to 4 percent of each family member's entire dose. Relatively tiny doses came from inadvertently eating soil containing radionuclides – i.e., no more than 0.0005% of any family member's entire dose.

Most of the dose from external exposure to radiation came from immersion in a plume of air contaminated with radionuclides, rather than from radionuclides after they had been deposited on the ground. Similarly, most inhalation doses came from inhalation of radionuclides from this contaminated plume, as opposed to inhalation of radionuclides that had been resuspended from soil. This pattern is comparable to that seen for Rural Family One.

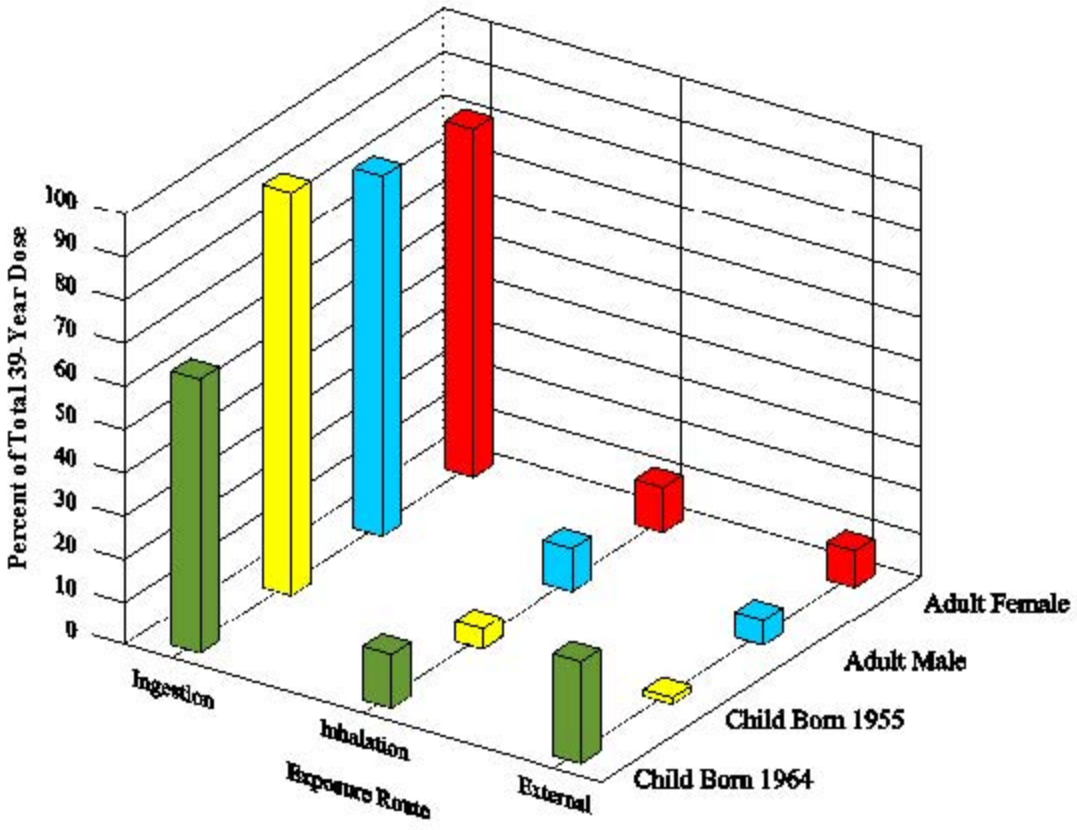

Figure 11-11 Percent of 39-Year Effective Dose by Exposure Route for Rural Family Two

Table 11-8 39-Year Effective Dose (mSv) by Exposure Pathway for Rural Family Two

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.054	7.8	0.054	5.6	0.054	1.4	0.039	23.5
	Ground Contamination	0.0056	0.8	0.0060	0.6	0.0057	0.2	$2.2x10^{-4}$	0.1
Ingestion	Beef	0.36	52.4	0.57	58.8	1.64	43.7	0.024	14.6
	Eggs	0.0027	0.4	0.0044	0.5	0.0040	0.1	0.0029	1.8
	Fruit	0.023	3.3	0.023	2.3	0.10	2.7	0.011	6.8
	Grain	0.0023	0.3	0.0028	0.3	0.0082	0.2	0.0013	0.8
	Leafy Vegetables	0.042	6.0	0.042	4.3	0.071	1.9	0.0021	1.3
	Milk	0.11	16.1	0.15	15.3	1.66	44.2	0.053	32.4
	Poultry	0.0019	0.3	0.0024	0.2	0.0024	0.1	0.0017	1.0
	Root Vegetables	0.015	2.1	0.021	2.1	0.029	0.8	0.0086	5.2
	Soil*	$1.2x10^{-6}$	<0.1	$1.2x10^{-6}$	<0.1	$1.8x10^{-5}$	<0.1	$1.9x10^{-7}$	<0.1
Inhalation	Air Inhalation	0.063	9.0	0.084	8.7	0.17	4.6	0.019	11.4
	Resuspended Soil	0.0099	1.4	0.013	1.4	0.0093	0.2	0.0019	1.2
	Total:	0.70	100	0.97	100	3.8	100	0.16	100

*Doses from the soil ingestion pathway were no more than 0.0005% of any family member's entire 39-year dose.

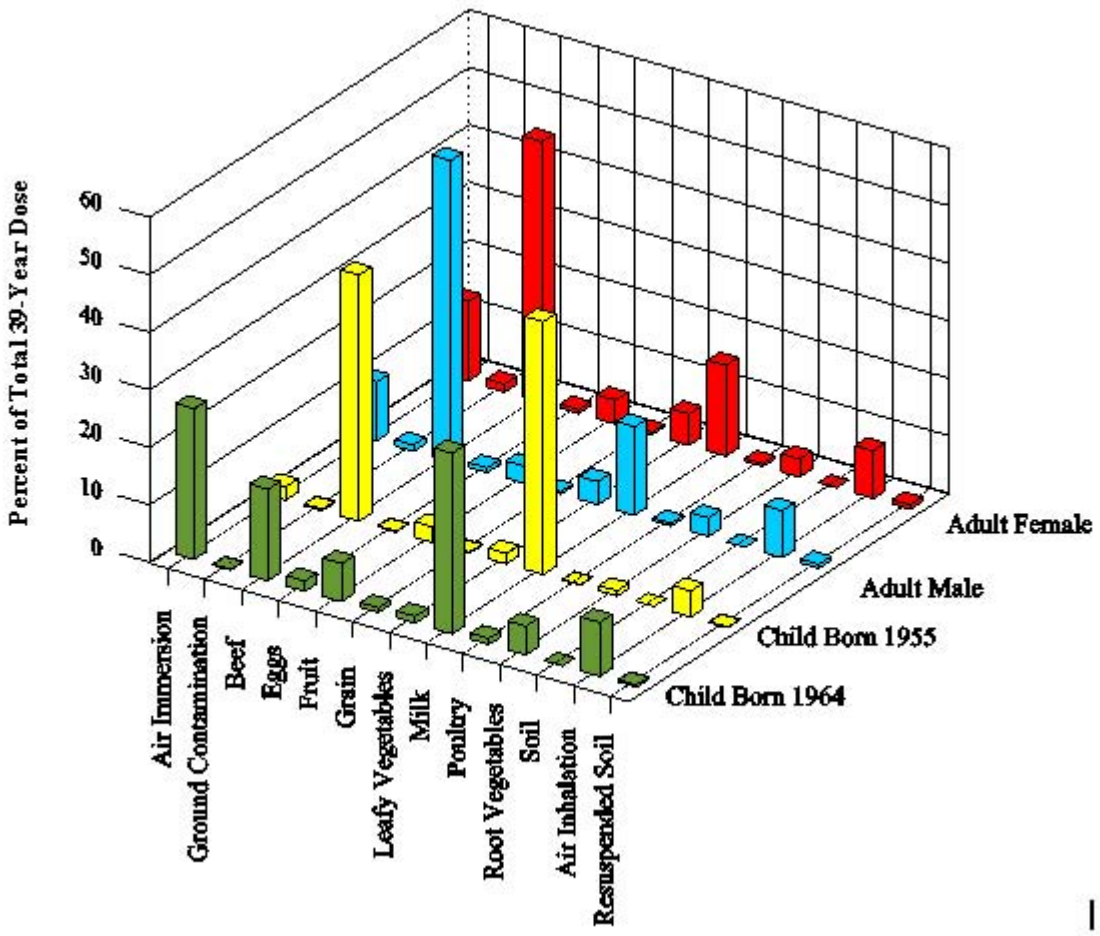

Figure 11-12 Percent of 39-Year Effective Dose (mSv) by Exposure Pathway for Rural Family Two

11.2.3 Urban/Suburban Family

This hypothetical family lived in Augusta, GA, and, except for employment for the Adult Male and for the children when they each reached age 18, all family members stayed in Augusta for all activities, including school and church (Figure 11-13). The Adult Male worked onsite at SRS for all 39 years. When the children grew up, they lived in Augusta and worked onsite at SRS (beginning in 1973 for the Child Born in 1955 and in 1982 for the Child Born in 1964). All family members swam, boated, and fished in the Savannah River flowing through Augusta upstream of SRS.

Half the family's milk came from cows located in the Augusta area, and half came from cows located in the New Ellenton area. All eggs came from hens located in the Augusta area. Half of the beef, poultry, leafy vegetables, root vegetables, and fruit was grown or produced in the Augusta area, and half came from unaffected non-local sources. All of the corn eaten by the family was grown locally. Fish came from surface water sources assumed by be unaffected by releases from SRS (e.g., from the Savannah River upstream of SRS).

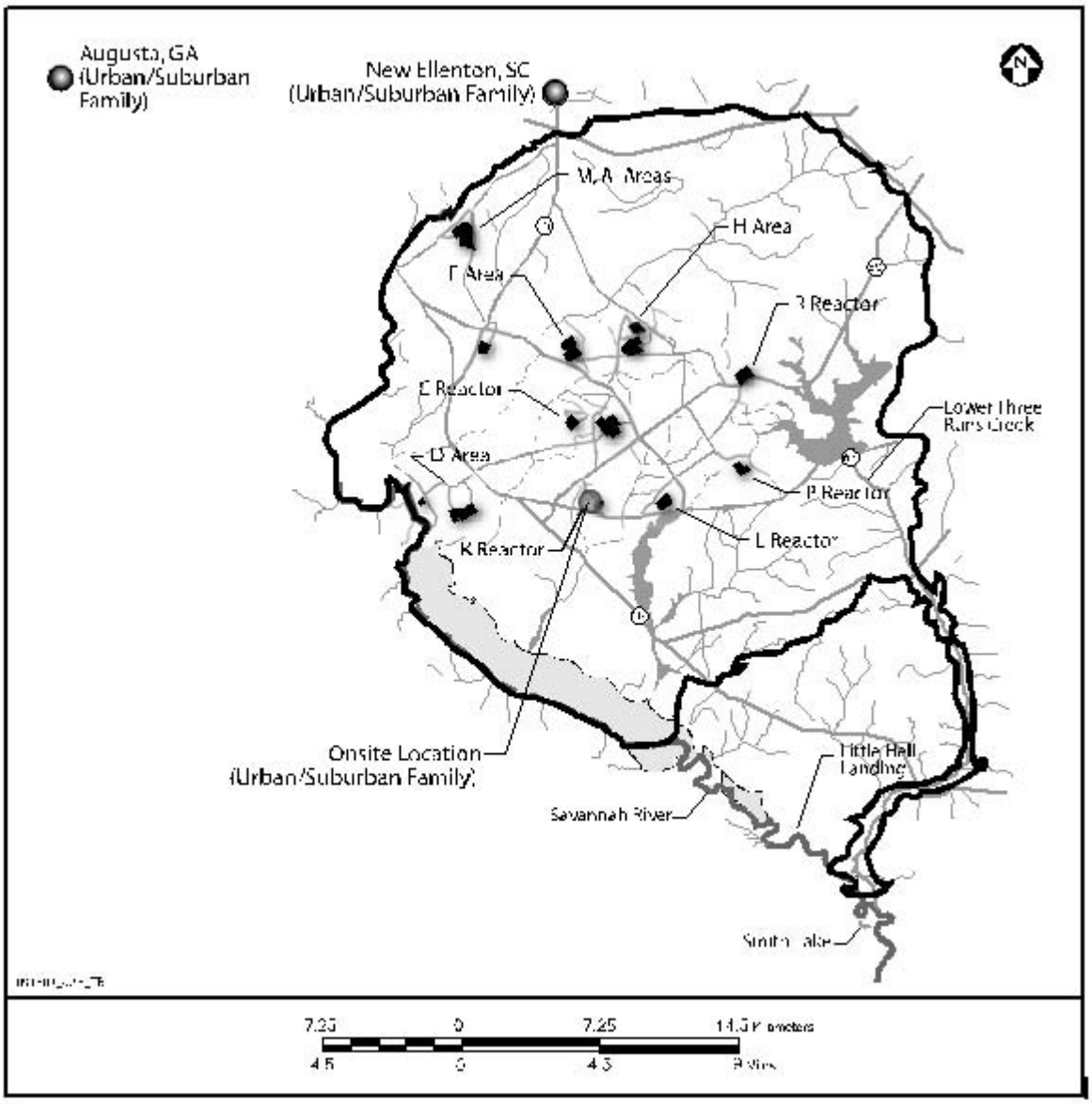

Figure 11-13 Exposure Locations for Urban/Suburban Family

11.2.3.1 Doses and Total Risks

Table 11-9 lists the effective dose and cancer risks determined for each member of the Urban/Suburban Family over 39 years of SRS operation. All doses and risks came from exposure to radionuclides that had been released into the air.

The Child Born in 1955 received the largest radiation dose and cancer risks in the scenario. He received an effective dose of 2.7 mSv (270 mrem), a cancer incidence risk of 0.027%, and a cancer fatality risk of 0.0041%. The Child Born in 1964 received the smallest dose and risks which is 4% of that for the Child Born in 1955.

The Adult Male received more than twice the dose than did the Adult Female. This difference in dose between the two adults is more significant than was the case for Rural Family One (Table 11-3) and Rural Family Two (Table 11-6). The reason is as follows: For the Urban/Suburban Scenario the Adult Female

spent her entire time in the Augusta area, while the Adult Male spent 2000 hours each year on the SRS site. But for the two rural family scenarios, the Adult Male and Adult Female both spent their entire time "at home" in Girard and Williston.

Table 11-9 39-Year Effective Dose and Cancer Risks for Urban/Suburban Family

Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)	0.33	0.73	2.7	0.11
Cancer Incidence Risk (%)	0.00090	0.0025	0.027	0.0016
Cancer Fatality Risk (%)	0.00032	0.0013	0.0041	0.00098

11.2.3.2 Effective Dose by Year

Figure 11-14 shows the percent of the entire 39-year effective dose received each year by each family member, while Figure 11-15 shows the annual effective dose (in units of s) received by each family member. Table 11-10 lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose. Again, most of the dose was received during the early days of site operation.

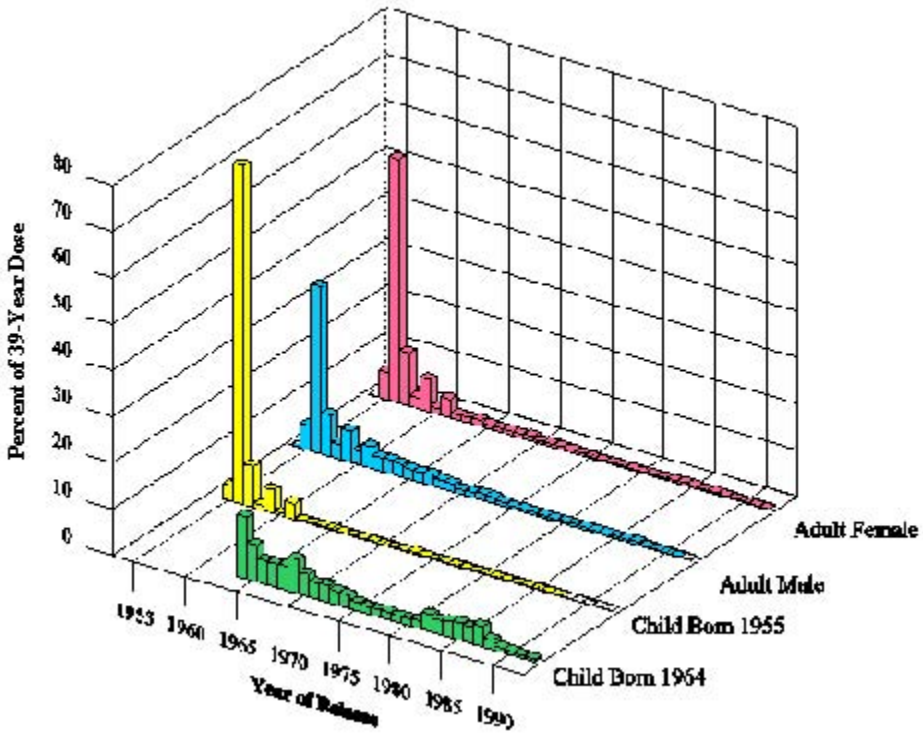

Figure 11-14 Percent of 39-Year Effective Dose by Year for Urban/Suburban Family

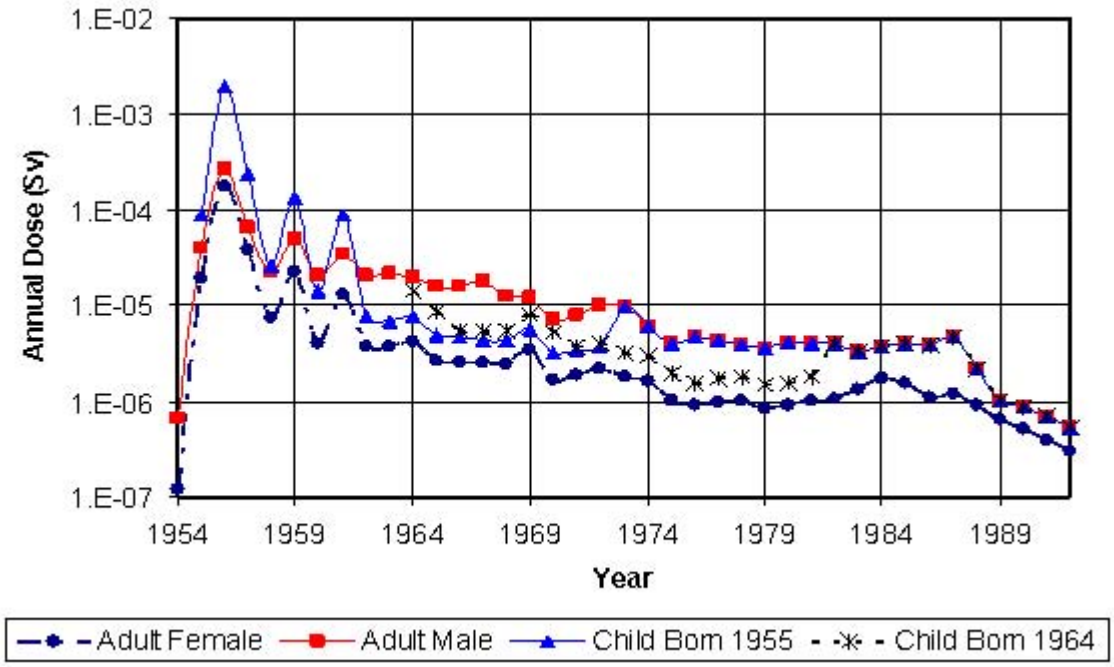

Figure 11-15 Annual Effective Dose (Sv) for Urban/Suburban Family

Table 11-10 Annual Effective Dose (mSv) for Urban/Suburban Family

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1954	$1.2x10^{-04}$	0.0	$6.7x10^{-04}$	0.1				
1955	0.021	7.9	0.046	7.0	0.046	2.7		
1956	0.13	49.7	0.21	32.1	1.2	71.5		
1957	0.030	10.9	0.055	8.3	0.15	8.7		
1958	0.0062	2.3	0.021	3.2	0.018	1.0		
1959	0.018	6.7	0.043	6.5	0.084	5.0		
1960	0.0036	1.3	0.020	3.0	0.010	0.6		
1961	0.010	3.9	0.030	4.6	0.059	3.5		
1962	0.0034	1.3	0.020	3.1	0.0059	0.4		
1963	0.0033	1.2	0.022	3.3	0.0054	0.3		
1964	0.0037	1.4	0.019	2.9	0.0060	0.4	0.0081	9.5
1965	0.0024	0.9	0.016	2.4	0.0039	0.2	0.0064	7.5
1966	0.0023	0.8	0.016	2.4	0.0037	0.2	0.0041	4.8
1967	0.0023	0.8	0.018	2.7	0.0035	0.2	0.0041	4.8
1968	0.0022	0.8	0.013	1.9	0.0035	0.2	0.0042	4.9
1969	0.0039	1.4	0.013	2.0	0.0057	0.3	0.0072	8.4
1970	0.0015	0.5	0.0068	1.0	0.0025	0.1	0.0038	4.5
1971	0.0016	0.6	0.0077	1.2	0.0027	0.2	0.0028	3.3

1972	0.0019	0.7	0.0096	1.5	0.0030	0.2	0.0031	3.6
1973	0.0016	0.6	0.0096	1.5	0.0096	0.6	0.0025	3.0
1974	0.0014	0.5	0.0059	0.9	0.0059	0.3	0.0023	2.7
1975	0.0010	0.3	0.0040	0.6	0.0040	0.2	0.0015	1.7
1976	$9.1x10^{-04}$	0.3	0.0047	0.7	0.0047	0.3	0.0012	1.4
1977	$9.9x10^{-04}$	0.3	0.0042	0.6	0.0042	0.3	0.0014	1.6
1978	0.0010	0.4	0.0037	0.6	0.0037	0.2	0.0015	1.8
1979	$8.6x10^{-04}$	0.3	0.0035	0.5	0.0035	0.2	0.0012	1.4
1980	$9.0x10^{-04}$	0.3	0.0042	0.6	0.0042	0.2	0.0012	1.4
1981	0.0009	0.3	0.0039	0.6	0.0039	0.2	0.0014	1.7
1982	0.0009	0.3	0.0038	0.6	0.0038	0.2	0.0038	4.5
1983	0.0011	0.4	0.0031	0.5	0.0031	0.2	0.0031	3.6
1984	0.0015	0.5	0.0034	0.5	0.0034	0.2	0.0034	4.0
1985	0.0013	0.5	0.0038	0.6	0.0038	0.2	0.0038	4.5
1986	0.0010	0.4	0.0037	0.6	0.0037	0.2	0.0037	4.3
1987	0.0010	0.4	0.0045	0.7	0.0045	0.3	0.0045	5.3
1988	$9.3x10^{-04}$	0.3	0.0021	0.3	0.0021	0.1	0.0021	2.4
1989	$6.4x10^{-04}$	0.2	0.0010	0.1	0.0010	0.1	0.0010	1.1
1990	$5.1x10^{-04}$	0.2	$8.7x10^{-04}$	0.1	$8.7x10^{-04}$	<0.1	$8.7x10^{-04}$	0.9
1991	$3.9x10^{-04}$	0.1	$7.0x10^{-04}$	0.1	$7.0x10^{-04}$	<0.1	$7.0x10^{-04}$	0.7
1992	$3.0x10^{-04}$	0.1	$5.4x10^{-04}$	0.1	$5.4x10^{-04}$	<0.1	$5.4x10^{-04}$	0.6
Total	0.2702	100	0.6588	100	1.6789	100	0.0856	100

In 1956, the Child Born in 1955 received 2.0 mSv (200 mrem), or 73% of his entire dose. During this year, the Adult Female received 0.17 mSv (17 mrem), or 53% of her entire dose, and the Adult Male received 0.26 mSv (26 mrem), or 36% of his entire dose.[11] In 1964, the Child Born in 1964 received 0.014 mSv (1.4 mrem), or 13% of his entire dose. This dose was 1% of the largest annual dose received by the Child Born in 1955.

The pattern shown in Figure 11-15 differs notably from that shown for Rural Family One (Figure 11-3) and Rural Family Two (Figure 11-9). For the two rural families, the annual doses for all family members were similar after the mid 1960s. But for the Urban/Suburban Family, annual doses for some members differed after the mid 1960s, for the following reasons: Although the Adult Male always worked on the SRS site, the children spent their early years entirely in Augusta. But when the children began work in 1973 and 1982, respectively, their annual doses equaled those for the Adult Male. The Adult Female always stayed in Augusta.

11.2.3.3 Exposure Routes and Pathways

Figure 11-16 shows the radionuclides that were the largest contributors of dose over 39 years for each family member.

The major contributors to dose were essentially the same as those identified for Rural Family One (Figure 11-4) and Rural Family Two (Figure 11-10). Of interest is the larger importance of ^{41}Ar, compared to tritium, for the Adult Male.

[11] This information was obtained from the tables of effective dose by year presented in Appendix I for each scenario and receptor.

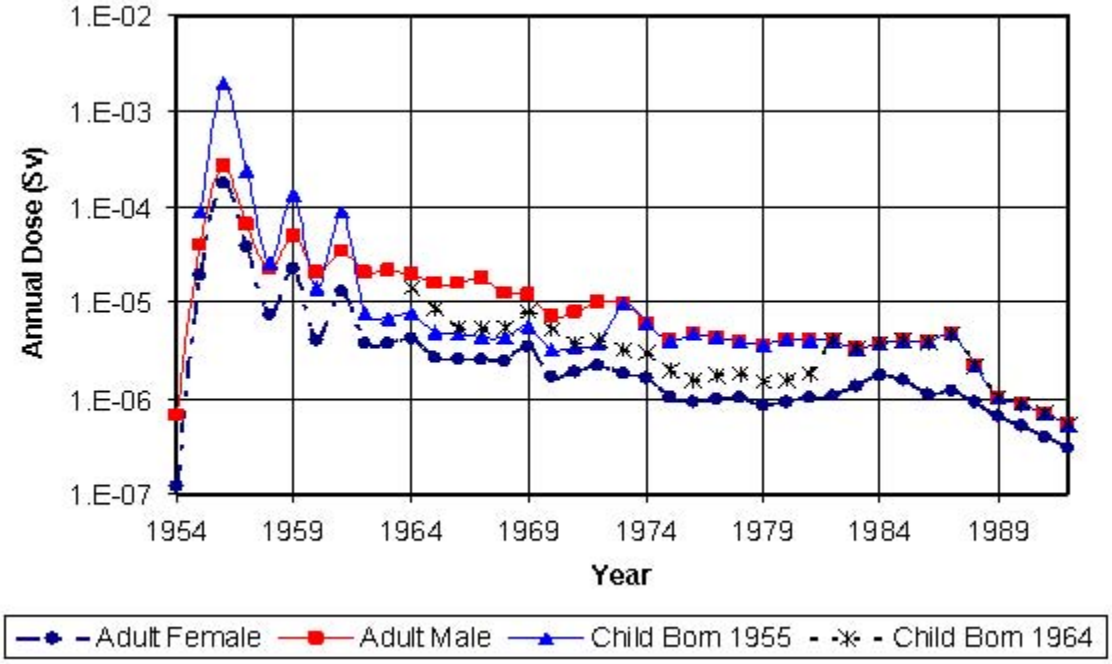

Figure 11-16 Percent of 39-Year Effective Dose by Dominant Isotopes for Urban/Suburban Family

The larger dose from ^{41}Ar is partially illustrated by Figure 11-17. External exposure to radiation caused 36% of the entire dose for the Adult Male, a larger percent than that for any other member of the family.[12] Otherwise, doses from ingestion were again important. For all family members, from 52 to 93 percent of their entire 39-year dose came from eating foods containing radionuclides. Except for the Adult Male, the contribution to dose by ingestion was comparable to that seen for Rural Family One (Figure 11-5) and Rural Family Two (Figure 11-11).

Table 11-11 and Figure 11-18 show the dose, and percent of dose, over 39 years by pathway for each member of the family. The foods that contributed most to radiation dose were beef and milk. For all family members, from 48 to 91 percent of their entire dose came from eating beef and milk. The next largest doses generally came from eating fruit and vegetables (from 2 to 9 percent of their entire dose). Eating grain, poultry, and eggs contributed from 0.2 to 3 percent of their entire dose. Inadvertently eating soil containing radionuclides contributed no more than 0.0003% of any family member's entire dose.

[12] ^{41}Ar contributed 98% of the external exposure received by the Adult Male (see Appendix K).

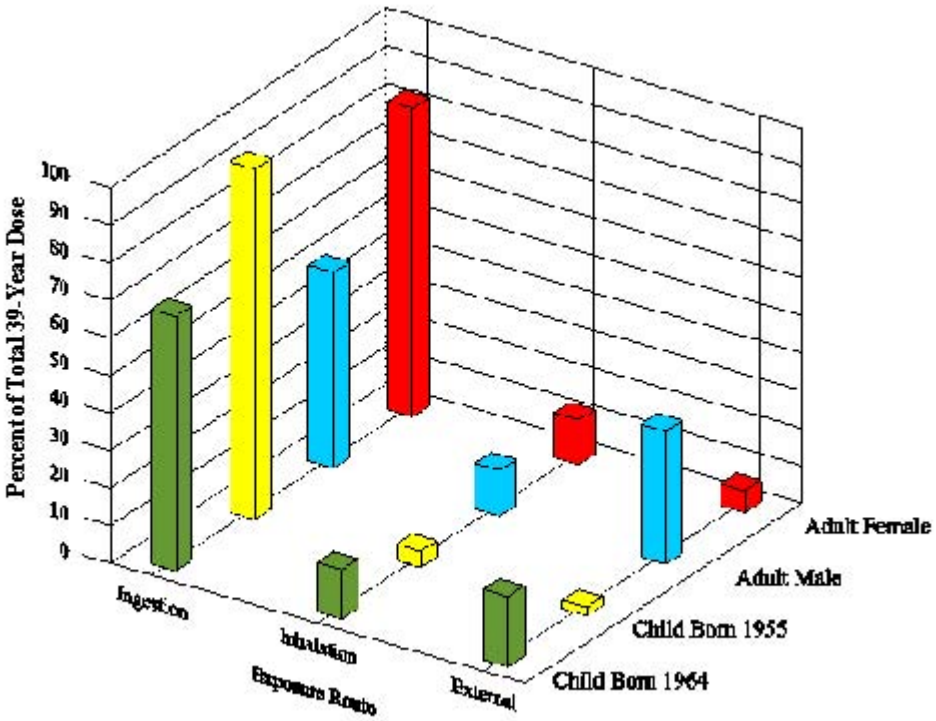

Figure 11-17 Percent of 39-Year Effective Dose by Exposure Route for Urban/Suburban Family

Table 11-11 39-Year Effective Dose (mSv) by Exposure Pathway for Urban/Suburban Family

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.017	6.2	0.257	38.6	0.0577	3.4	0.0207	23.6
	Ground Contamination	0.0026	1.0	0.0052	0.8	0.0026	0.2	1.0×10^{-4}	0.1
Ingestion	Beef	0.12	42.6	0.18	27.4	0.51	30.4	0.0099	11.6
	Eggs	0.0017	0.6	0.0028	0.4	0.0026	0.2	0.0017	1.9
	Fruit	0.0075	2.8	0.0073	1.1	0.023	1.3	0.0050	5.9
	Grain	0.0011	0.4	0.0013	0.2	0.0029	0.2	7.3×10^{-4}	0.8
	Leafy Vegetables	0.0089	3.3	0.0089	1.3	0.014	0.8	8.5×10^{-4}	1.0
	Milk	0.065	24.1	0.087	13.1	0.93	55.7	0.027	31.7
	Poultry	0.0010	0.4	0.0012	0.2	0.0012	0.1	7.6×10^{-4}	0.9
	Root Vegetables	0.0065	2.4	0.0090	1.4	0.012	0.7	0.0041	4.8
	Soil*	5.5×10^{-7}	<0.1	1.1×10^{-6}	<0.1	8.3×10^{-6}	<0.1	9.0×10^{-8}	<0.1
Inhala-tion	Air Inhalation	0.039	14.5	0.090	13.6	0.12	6.9	0.014	16.6
	Resuspended Soil	0.0046	1.7	0.012	1.8	0.0044	0.3	9.2×10^{-6}	1.1
Total		0.27	100	0.66	100	1.7	100	0.086	100

* Doses from the soil ingestion pathway were no more than 0.0003% of any family member's entire 39-year dose.

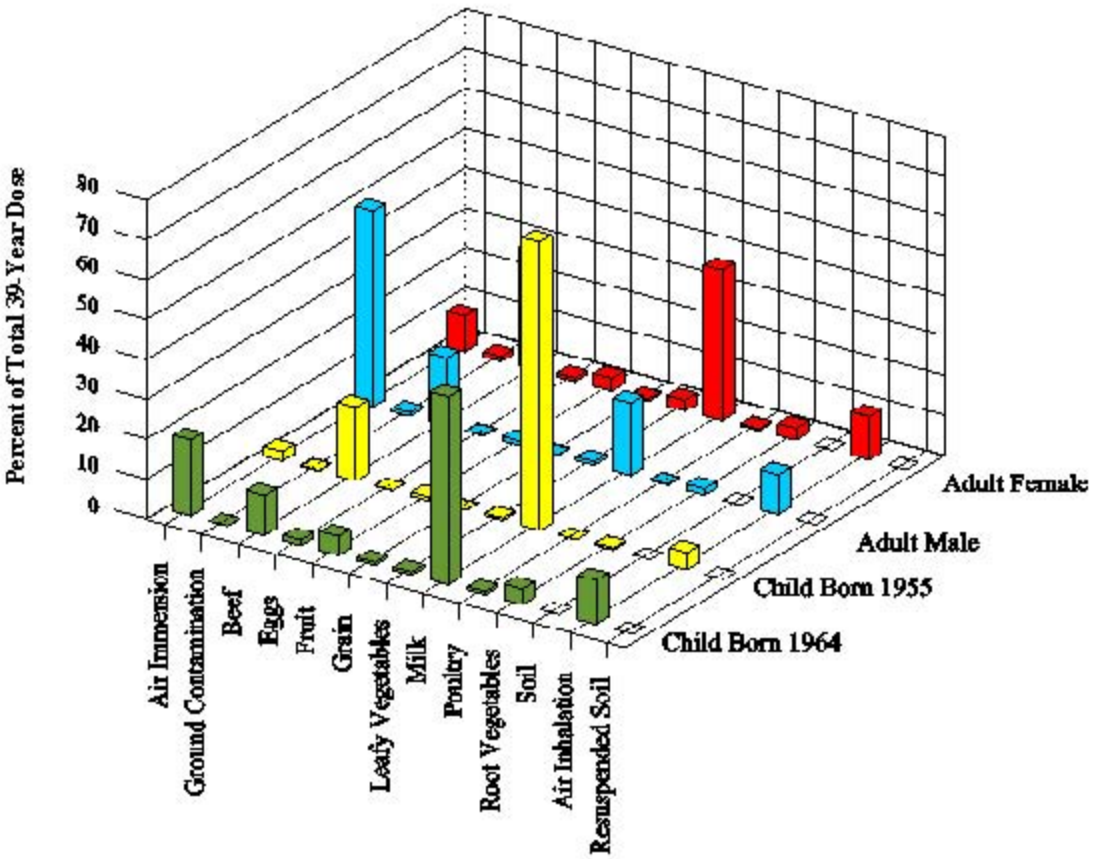

Figure 11-18 Percent of 39-Year Effective Dose for Exposure Pathway for Urban/Suburban Family

The large external radiation dose received by the Adult Male came from the 2000 hours he spent each year at work. It was assumed that all hours were spent near K-Reactor. The great bulk of his external exposures resulted from immersion in a plume of radionuclides in air, rather than from exposure to radionuclides that had been deposited on the ground.

For all family members, doses from inhalation mainly came from breathing radionuclides from the contaminated air plume, rather than breathing radionuclides that had been resuspended from soil after being deposited on the ground.

11.2.4 Migrant Worker Family

As a hypothetical rural family, all family members spent much of their work, home activities, and recreation time outdoors. Because the Adult Male and Adult Female worked as migrant farm workers, the family lived in New Ellenton for half of each year (Figure 11-19). The family did no boating but did enjoy other water sports such as fishing and swimming in local pools, ponds and creeks. The children attended schools in New Ellenton. When grown, the children became migrant farmers spending half of each year in New Ellenton.

During the six months of each year that the family lived in New Ellenton, all of their milk and eggs came from cows and hens located in New Ellenton. Half of the family's beef, poultry, leafy vegetables, root vegetables, and fruit was grown or produced in New Ellenton and half came from sources away from SRS. All of their corn was grown in New Ellenton. Because ponds and creeks in the vicinity of New

Ellenton are not located hydrologically downstream from SRS, none of the fish eaten by the family was affected by SRS releases. Drinking water and water used to irrigate foods eaten by the family came from sources unaffected by SRS releases.

Figure 11-19 Exposure Location for Migrant Worker Family

11.2.4.1 Doses and Total Risks

Table 11-12 lists the effective dose and cancer risks assessed for each member of the Migrant Worker Family over 39 years of SRS operation. All doses and risks came from exposure to radionuclides that had been released into the air.

The Child Born in 1955 received the largest dose and risks – i.e., an effective dose of 2.2 mSv (220 mrem), a cancer incidence risk of 0.022%, and a cancer fatality risk of 0.0034%. The Child Born in 1964 received the smallest dose and risks. The dose for the Child Born in 1964 was 4% of that for the Child Born in 1955.

Table 11-12 39-Year Effective Dose and Cancer Risks for Migrant Worker Family

Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)	0.45	0.62	2.2	0.083
Cancer Incidence Risk (%)	0.0012	0.0016	0.022	0.0013
Cancer Fatality Risk (%)	0.00042	0.00052	0.0034	0.00078

Of interest is the relatively large doses received by these family members, compared to those received by members of the previous scenarios, even though the Migrant Worker Family was assumed to be in the vicinity of SRS only half of any year. The main reason is that the members of the Migrant Worker Family resided in New Ellenton, SC, which is immediately north of SRS, while members of other scenarios lived farther away from SRS, and in different directions. New Ellenton was the source of all of their milk and eggs, and half of their other foods.

11.2.4.2 Effective Dose by Year

Figure 11-20 shows the percent of the 39-year effective dose received each year by each family member, while Figure 11-21 shows the annual effective dose (in units of s) received by each family member. Table 11-13 lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose.

In 1956 the Child Born in 1955 received 1.6 mSv (160 mrem)), or 73% of his entire dose. During this year, the Adult Female received 0.23 mSv (23 mrem), or 52% of her entire dose, and the Adult Male received 0.34 mSv (34 mrem), or 54% of his entire dose.[13] In 1964, the Child Born in 1964 received 0.011 mSv (1.1 mrem), or 13% of his entire dose.

This 1964 dose was less than 1% of the largest annual dose for the Child Born in 1955. The pattern of annual dose is comparable to that seen for Rural Family One (Figure 11-3) and Rural Family Two (Figure 11-9).

[13] This information was obtained from the tables of annual effective dose that are presented in Appendix I for each scenario.

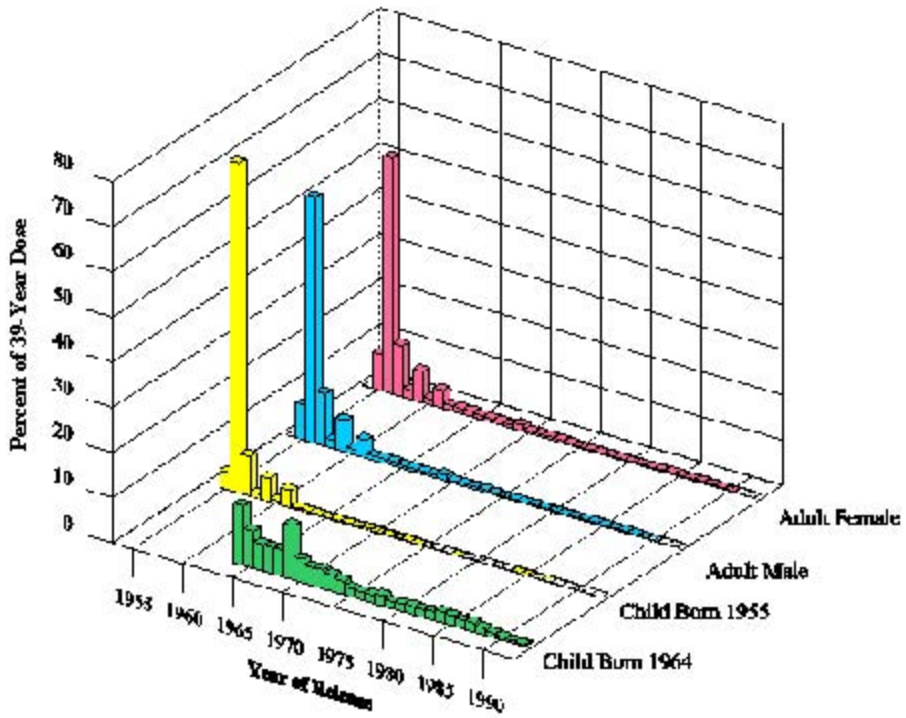

Figure 11-20 Percent of 39-Year Effective Dose by Year for Migrant Worker Family

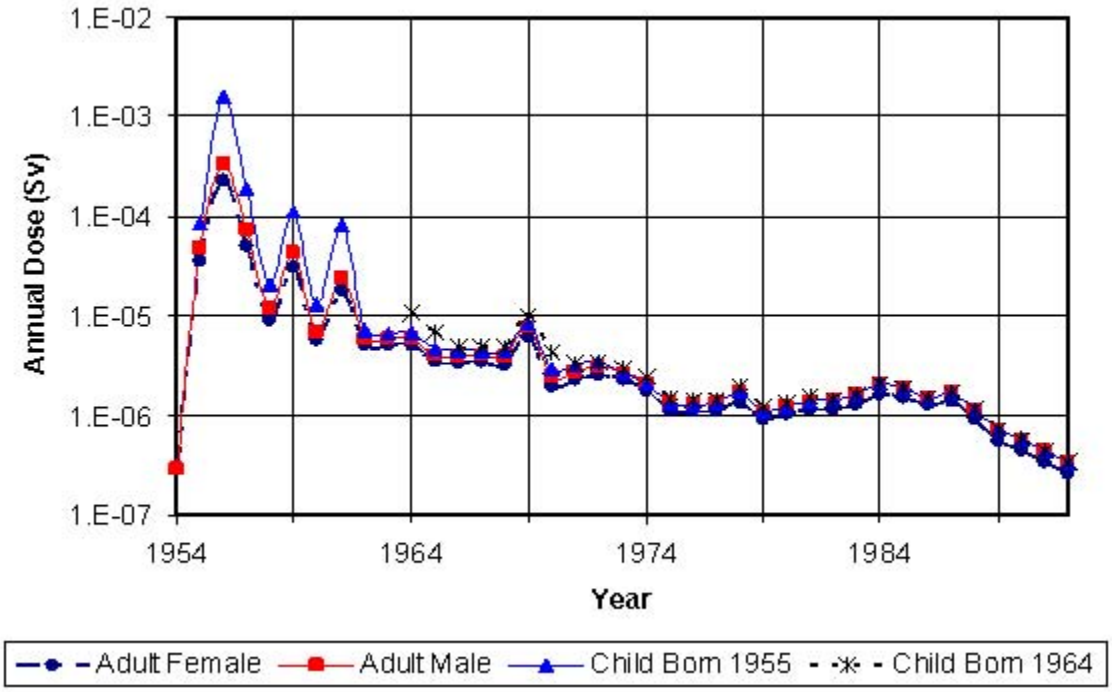

Figure 11-21 Annual Effective Dose (Sv) for Migrant Worker Family

Table 11-13 Annual Effective Dose (mSv) for Migrant Worker Family

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1954	$2.9x10^{-04}$	0.1	$2.9x10^{-04}$	0.0				
1955	0.036	8.0	0.049	7.8	0.084	3.8		
1956	0.236	52.2	0.34	54.3	1. 6	73.1		
1957	0.050	11.3	0.072	11.6	0.19	8.8		
1958	0.0090	2.0	0.012	1.9	0.021	1.0		
1959	0.031	6.9	0.043	6.9	0.11	5.1		
1960	0.0056	1.3	0.0068	1.1	0.013	0.6		
1961	0.018	4.0	0.024	3.9	0.083	3.8		
1962	0.0051	1.1	0.0060	1.0	0.0072	0.3		
1963	0.0050	1.1	0.0058	0.9	0.0067	0.3		
1964	0.0051	1.1	0.0060	1.0	0.0069	0.3	0.011	13.2
1965	0.0035	0.8	0.0041	0.7	0.0046	0.2	0.0068	8.2
1966	0.0034	0.8	0.0039	0.6	0.0046	0.2	0.0050	6.0
1967	0.0035	0.8	0.0040	0.6	0.0045	0.2	0.0049	5.9
1968	0.0032	0.7	0.0038	0.6	0.0044	0.2	0.0049	5.9
1969	0.0060	1.3	0.0078	1.3	0.0084	0.4	0.010	12.1
1970	0.0020	0.4	0.0025	0.4	0.0030	0.1	0.0044	5.2
1971	0.0023	0.5	0.0028	0.4	0.0032	0.1	0.0033	4.0
1972	0.0026	0.6	0.0031	0.5	0.0034	0.2	0.0035	4.2
1973	0.0023	0.5	0.0027	0.4	0.0027	0.1	0.0030	3.6
1974	0.0018	0.4	0.0021	0.3	0.0021	0.1	0.0024	2.9
1975	0.0011	0.2	0.0014	0.2	0.0014	0.1	0.0015	1.8
1976	0.0011	0.2	0.0013	0.2	0.0013	0.1	0.0014	1.7
1977	0.0011	0.2	0.0013	0.2	0.0013	0.1	0.0015	1.7
1978	0.0014	0.3	0.0017	0.3	0.0017	0.1	0.0019	2.3
1979	$9.3x10^{-04}$	0.2	0.0011	0.2	0.0011	0.1	0.0012	1.5
1980	0.0010	0.2	0.0012	0.2	0.0012	0.1	0.0014	1.6
1981	0.0011	0.3	0.0014	0.2	0.0014	0.1	0.0015	1.8
1982	0.0012	0.3	0.0014	0.2	0.0014	0.1	0.0014	1.7
1983	0.0013	0.3	0.0016	0.3	0.0016	0.1	0.0016	2.0
1984	0.0016	0.4	0.0021	0.3	0.0021	0.1	0.0021	2.5
1985	0.0015	0.3	0.0019	0.3	0.0019	0.1	0.0019	2.3
1986	0.0013	0.3	0.0015	0.2	0.0015	0.1	0.0015	1.8
1987	0.0014	0.3	0.0017	0.3	0.0017	0.1	0.0017	2.0
1988	$9.2x10^{-04}$	0.2	0.0012	0.2	0.0012	0.1	0.0012	1.4
1989	$5.5x10^{-04}$	0.1	$7.2x10^{-04}$	0.1	$7.2x10^{-04}$	<0.1	$7.2x10^{-04}$	0.9
1990	$4.5x10^{-04}$	0.1	$5.9x10^{-04}$	0.1	$5.9x10^{-04}$	<0.1	$5.9x10^{-04}$	0.7
1991	$3.3x10^{-04}$	0.1	$4.4x10^{-04}$	0.1	$4.4x10^{-04}$	<0.1	$4.4x10^{-04}$	0.5
1992	$2.6x10^{-04}$	0.1	$3.4x10^{-04}$	0.1	$3.4x10^{-04}$	<0.1	$3.4x10^{-04}$	0.4
Total	0.45	100	0.62	100	2.2	100	0.083	100

11.2.4.3 Dominant Radionuclides, Exposure Routes, and Pathways

Figure 11-22 shows the radionuclides that were the largest contributors of dose over 39 years for each member of the Migrant Worker Family. The dominant radionuclides were generally the same as those for Rural Family One (Figure 11-4) and Rural Family Two (Figure 11-10). But there were small differences. For example, ^{238}Pu was somewhat more important for the Child Born in 1955 for the Migrant Worker Family than for Rural Family Two; and Ru-106 was somewhat more important for the Child Born in 1964 for the Migrant Worker Family than for Rural Family Two.

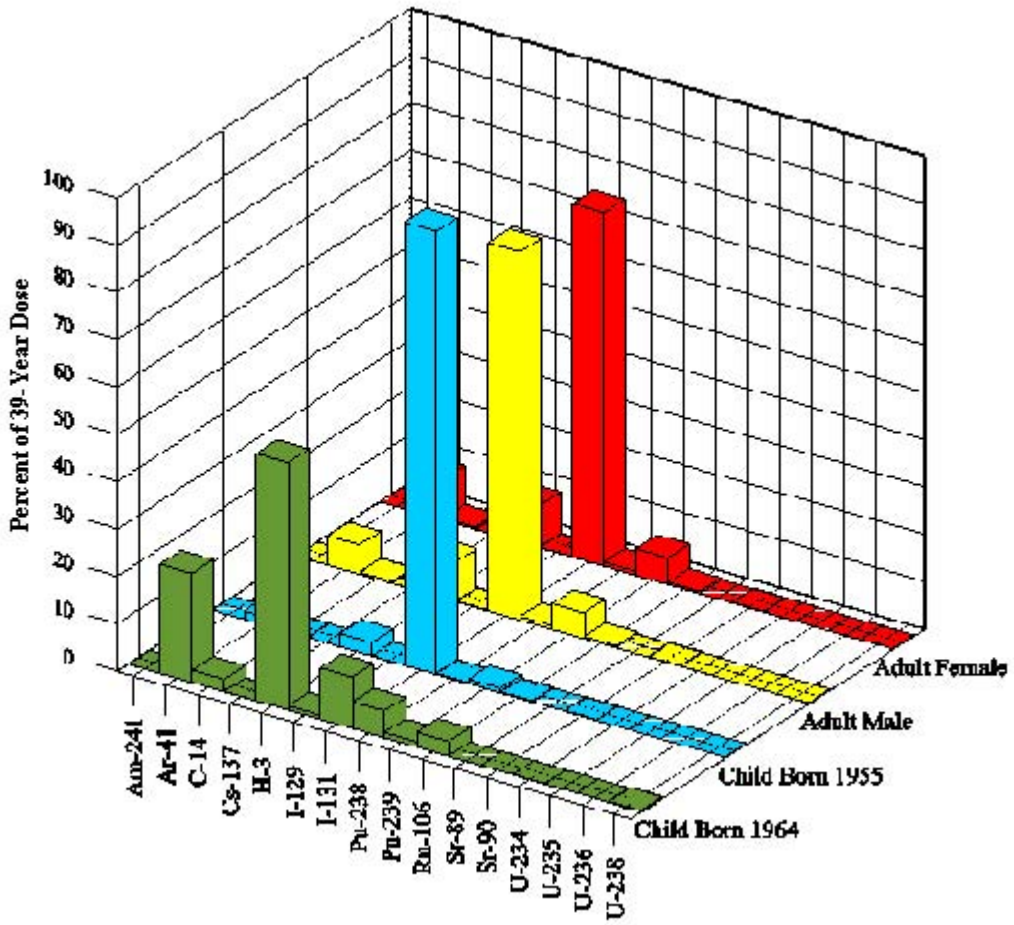

Figure 11-22 Percent of 39-Year Effective Dose by Dominant Isotopes for Migrant Worker Family

Most of the radiation dose received by this family came from eating food containing radionuclides (Figure 11-23). All family members received from 58 to 91 percent of their entire dose from ingestion. From 2 to 23 percent of their entire dose came from exposure to external radiation, and from 7 to 18 percent of their entire dose came from inhalation. This pattern of dose is similar to that seen for Rural Family One (Figure 11-5) and Rural Family Two (Figure 11-11).

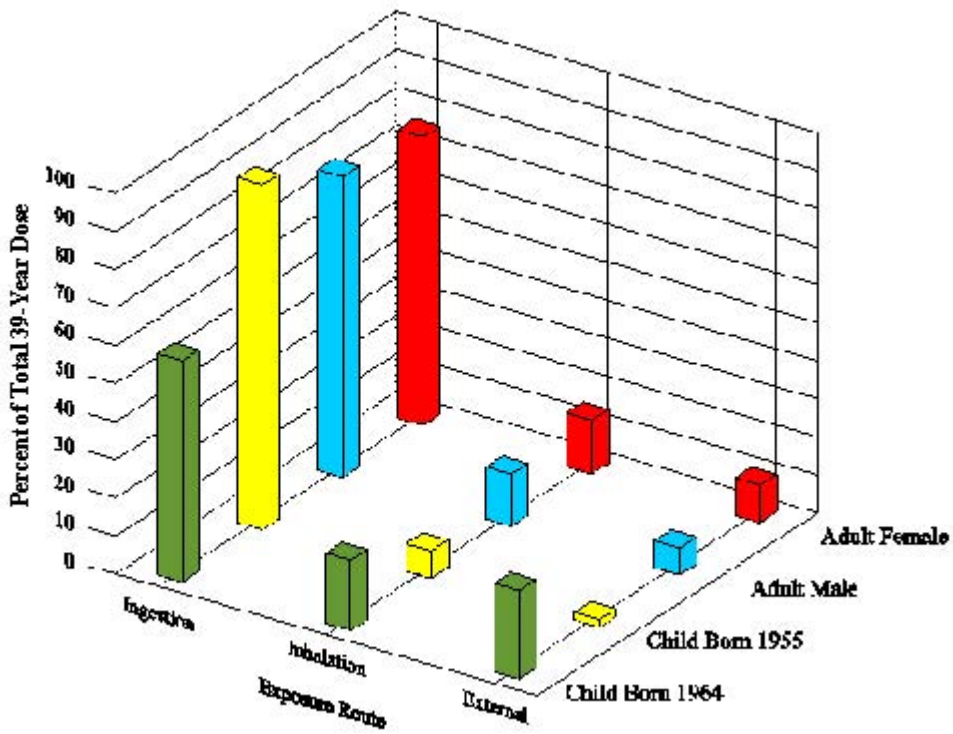

Figure 11-23 Percent of 39-Year Effective Dose by Exposure Route for Migrant Worker Family

Table 11-14 and Figure 11-24 show the effective dose, and percent of dose, by pathway and family member over 39 years. In general, the same pathways dominated radiation doses as those seen for Rural Family One (Table 11-5) and Rural Family Two (Table 11-8). Eating beef and drinking milk caused from 40 to 84 percent of their entire dose. Eating fruit and vegetables caused from 6 to 15 percent of their entire dose, and eating poultry, eggs, and grain caused from 1 to 3 percent of their entire dose. Inadvertently eating soil contributed no more than 0.0008% of any family member's entire dose.

Most external radiation doses came from immersion in a plume of contaminated air, rather than from radionuclides that had been deposited on the ground. Most inhalation doses came from breathing radionuclides directly from the plume of contaminated air, rather than breathing radionuclides that had been resuspended from soil.

Table 11-14 39-Year Effective Dose (mSv) by Exposure Pathway for Migrant Worker Family

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.039	8.7	0.039	6.2	0.039	1.8	0.019	23.1
	Ground Contamination	0.0054	1.2	0.0058	0.9	0.0054	0.2	2.2×10^{-4}	0.3
Ingestion	Beef	0.23	52.1	0.37	58.7	1.0	48.2	0.015	17.8
	Eggs	0.0010	0.2	0.0017	0.3	0.0016	0.1	0.0010	1.2
	Fruit	0.015	3.2	0.014	2.3	0.064	2.9	0.0061	7.4

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
	Grain	0.0020	0.4	0.0024	0.4	0.0075	0.3	9.7×10^{-4}	1.1
	Leafy Vegetables	0.027	6.0	0.027	4.3	0.045	2.1	0.0012	1.5
	Milk	0.052	11.6	0.069	11.0	0.79	36.2	0.019	22.4
	Poultry	0.0011	0.3	0.0014	0.2	0.0015	0.1	9.0×10^{-4}	1.1
	Root Vegetables	0.0091	2.0	0.013	2.0	0.019	0.9	0.0049	5.9
	Soil*	1.1×10^{-6}	<0.1	1.1×10^{-6}	<0.1	1.7×10^{-5}	<0.1	1.8×10^{-7}	<0.1
Inhala-tion	Air Inhalation	0.054	12.1	0.073	11.6	0.15	6.9	0.013	16.2
	Resuspend-ed Soil	0.0098	2.2	0.013	2.1	0.0091	0.4	0.0019	2.3
Total		0.45	100	0.62	100	2.29	100	0.083	100

* Doses from the soil ingestion pathway were no more than 0.0008% of any family member's entire 39-year dose.

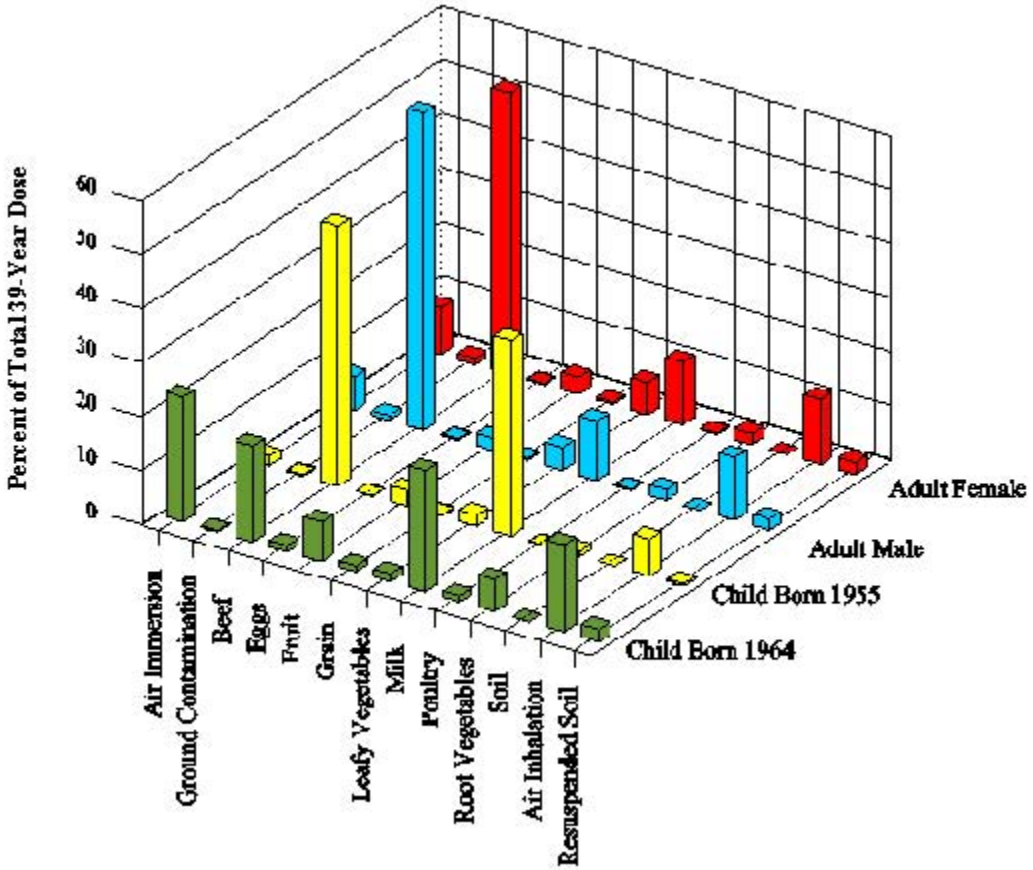

Figure 11-24 Percent of 39-Year Effective Dose by Exposure Pathway for Migrant Worker Family

11.2.5 Delivery Person Family

This hypothetical family lived in Barnwell, SC, where the children attended grade and high school. Because the Adult Male worked as a delivery driver for a bottling plant in Allendale, SC, he spent portions of his time in Allendale and onsite at SRS, where he made periodic deliveries. (When the children reached 18 they lived in Barnwell and became delivery drivers like the Adult Male.) The Adult Female worked at home. All family members attended religious services in Martin, SC, for a few hours per week. All family members swam, fished, and spent time along the shoreline at Lower Three Runs Creek near Martin. The Adult Male hunted deer and fowl in the Martin vicinity. The family boated in the Savannah River, catching fish in Smith Lake and spending time along its shoreline (Figure 11-25).

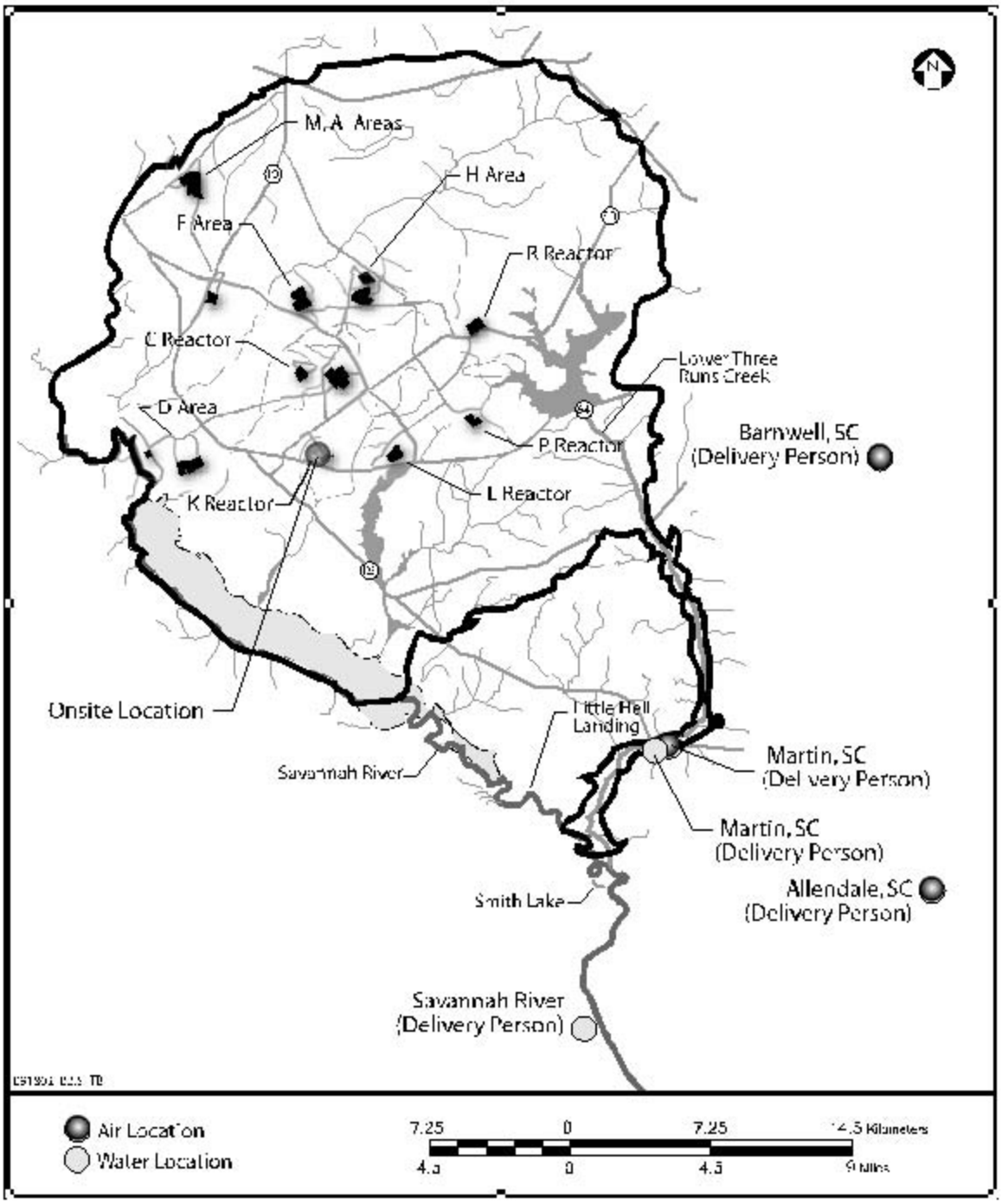

Figure 11-25 Exposure Locations for Delivery Person Family

Half the family's milk and eggs came from cows and hens located in Barnwell, and half from cows and hens located in Martin. In addition, half the family's beef and poultry came from Barnwell and half from Martin. Half of the beef and poultry from Barnwell was actually produced in the Barnwell area (and therefore possibly contained radionuclides from SRS), and half was acquired (e.g., by stores) from sources away from the SRS area.

Of the beef and poultry from Martin, 25% consisted of meat from hunting deer and wild fowl. [14] That is, 25% of the beef from Martin consisted of locally-hunted venison while 25% of the poultry from Martin consisted of locally-hunted wild fowl. Of the remaining 75% of the beef and poultry from Martin, half was produced in the Martin area, and half was acquired (e.g., by stores) from sources well away from SRS.[15]

Half the leafy vegetables, root vegetables, and fruit came from Barnwell and half from Martin. Half of this produce from Barnwell was locally-grown, as was half of this produce from Martin.[16] Half of the corn eaten by the family was grown in Barnwell and half was grown in Martin. Half of the fish was caught in Lower Three Runs Creek at Martin, and half was caught in Smith Lake.

11.2.5.1 Effective Dose and Total Risk

Table 11-15 lists the effective dose and cancer risks for each member of the Delivery Person Family over 39 years of SRS operation. The doses and risks included those from radionuclides released into surface water as well as radionuclides released into the air.

The Adult Male received an effective dose of 6.3 mSv (630 mrem), the Adult Female received an effective dose of 6.1 mSv (610 mrem), and the Child Born in 1955 received an effective dose of 5.2mSv (520 mrem). The dose for the Child Born in 1964 was about one-half to one-third of the dose for the other family members. The Child Born in 1955 had the largest cancer risks in this scenario; the Child Born in 1964 had the smallest.

Although the doses received from only the air pathways were comparable for most Delivery Family members to those received by Rural Family One members, the addition of the water pathways raised the overall doses received by the Delivery Family members to levels much larger than those received by Rural Family One members. The distribution of dose between all air pathways and all surface water pathways is shown in Figure 11-26. Except for the Child Born in 1955, surface water pathways caused at least 91% of the entire dose over 39 years. For that child, however, air pathways contributed 41% of his entire dose while water pathways contributed 59%.

In the previous four scenarios based on air pathways only, the Child Born in 1955 always received the largest dose. But here, when doses through all water pathways are added to those through all air pathways, the Adult Male received the largest dose. This dose resulted mainly from eating fish containing radionuclides (see below).

[14] Recall from Chapter 8 and Appendix D that consumption of game animals was modeled as consumption of additional beef and poultry.

[15] Combining the venison and wild fowl obtained from hunting with other beef and poultry obtained in Martin, it was assumed that 62.5% of all beef (including venison) obtained from Martin potentially contained radionuclides from SRS, as did 62.5% of all poultry (including wild fowl) eaten by the family.

[16] In other words, 50% of the vegetables and fruit obtained from Barnwell potentially contained radionuclides released by SRS, as did 50% of the vegetables and fruit obtained from Martin.

Table 11-15 39-Year Effective Dose and Risks for Delivery Person Family

Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)				
Air Pathways	0.40	0.57	2.1	0.12
Water Pathways	5.7	5.7	3.1	2.0
All Pathways	6.1	6.3	5.2	2.1
Cancer Incidence Risk (%)				
Air Pathways	0.0012	0.0017	0.022	0.0018
Water Pathways	0.027	0.027	0.048	0.031
All Pathways	0.028	0.029	0.070	0.033
Cancer Fatality Risk (%)				
Air Pathways	0.00050	0.00074	0.0038	0.0011
Water Pathways	0.020	0.020	0.032	0.021
All Pathways	0.020	0.021	0.036	0.022

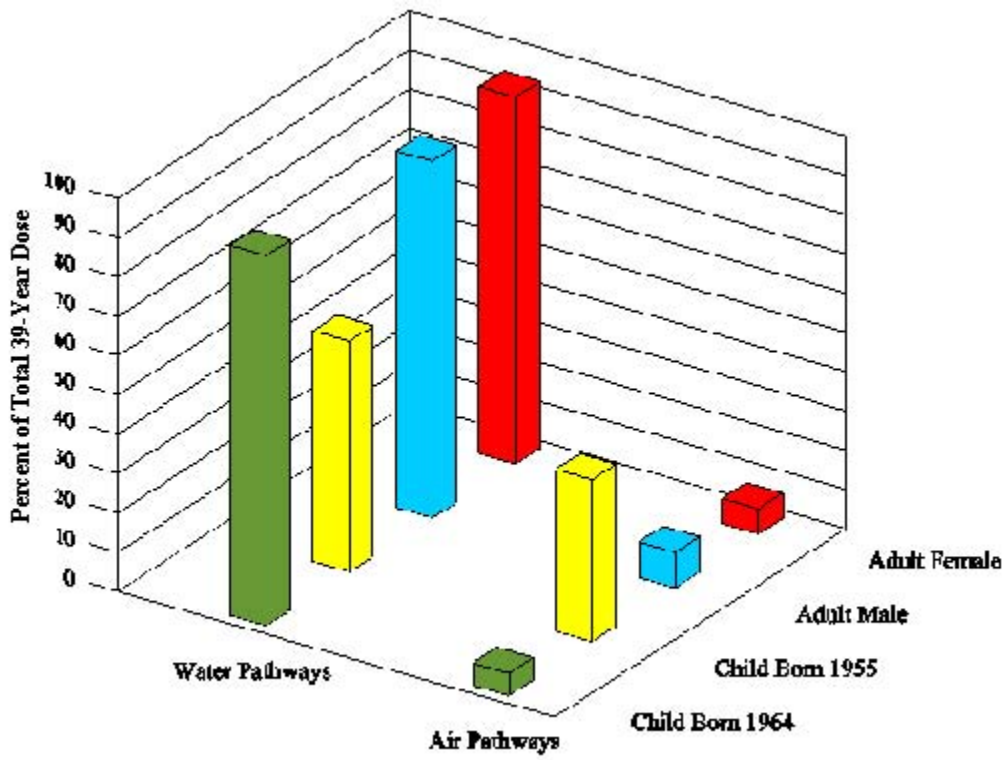

Figure 11-26 Distribution of 39-Year Effective Dose (%) Between Air and Water Pathways for Delivery Person Family

11.2.5.2 Effective Dose by Year

The percent of the entire dose contributed each year for each family member is shown in Figure 11-27, while Figure 11-28 shows the annual dose for each member of the Delivery Person Family. Table 11-16 lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose. These two figures and table include doses from all air and all water pathways.

The Child Born in 1955 received the largest annual dose of any family member: In 1956, he received 1.6 mSv (160 mrem), or 30% of his entire dose. In 1958, the Adult Female and Adult Male each received their largest annual dose: the Adult Female received 1.0 mSv (100 mrem), or 17% of her entire dose, while the Adult Male also received 1.0 mSv (100 mrem), or 16% of his entire dose. The largest annual dose for the Child Born in 1964 occurred in 1964 when he received 0.55 mSv (55 mrem), or 15% of his entire dose.

Figure 11-29 shows the annual effective dose received by each family member from all air pathways. Annual doses from the air pathways followed a similar pattern as those for previous scenarios. Most doses were received during the early days of operation. During 1956, the Adult Female received 0.18 mSv (18 mrem), or 46% of her dose from all air pathways, the Adult Male received 0.26 mSv (26 mrem), or 46% of his dose from all air pathways, and the Child Born in 1955 received 1.5 mSv (150 mrem), or 71% of his dose from all air pathways. In 1964, the Child Born in 1964 received 0.017 mSv (1.7 mrem), or 15% of his dose from all air pathways.

Figure 11-29 shows that the annual doses received by the two children eventually merged with doses received by the Adult Male, when the children began work in Allendale and at SRS when each child reached age 18. The dose curves for the Adult Male and two children tended to "separate" from that for the Adult Female in later years, although the separation is not as pronounced as that seen Figure 11-15 for the Urban/Suburban Family. This occurred because the Adult Male and grown children of the Delivery Family spent much less time on the SRS site than did the Adult Male and grown children of the Urban/Suburban Family.[17]

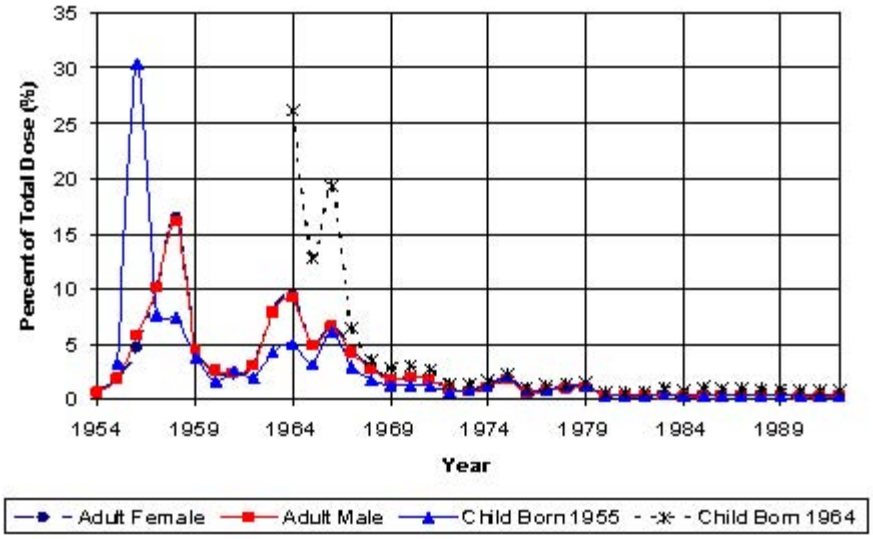

Figure 11-27 Percent of 39-Year Effective Dose by Year for Delivery Person Family – Air + Water Pathways

[17] For the Urban/Suburban scenario, the Adult Male (and two children when they each reached age 18) spent 2,000 hours per year on the SRS site. But for the Delivery Family Scenario, the Adult Male (and two children when they each reached age 18) spent only 400 hours per year on the SRS site.

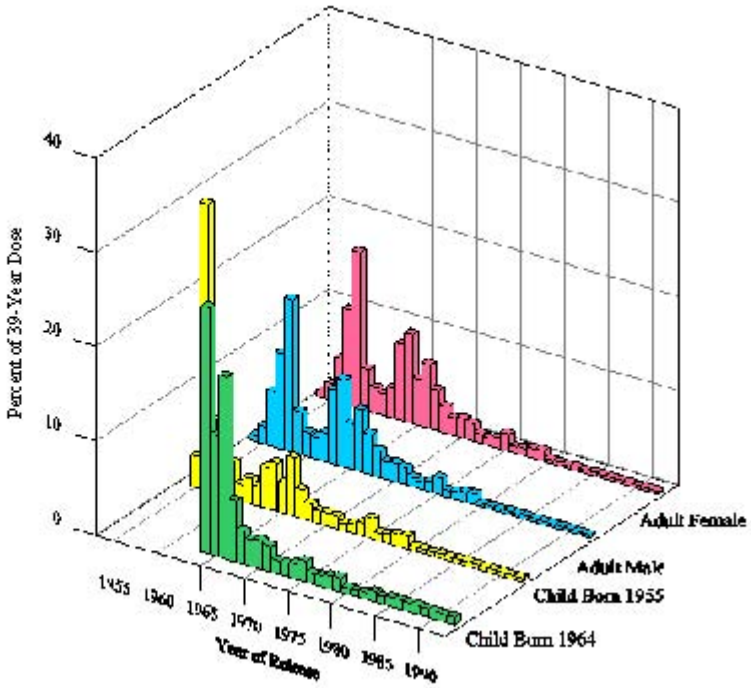

Figure 11-28 Annual Effective Dose (Sv) for Delivery Person Family – Air + Water Pathways

Table 11-16 Annual Effective Dose (mSv) for Delivery Person Family

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1954	0.040	0.6	0.040	0.6				
1955	0.11	1.7	0.12	1.8	0.17	3.3		
1956	0.29	4.7	0.37	5.8	1.58	30.4		
1957	0.62	10.2	0.64	10.2	0.40	7.7		
1958	1.0	16.5	1.0	16.1	0.39	7.5		
1959	0.27	4.4	0.28	4.5	0.20	3.8		
1960	0.16	2.6	0.16	2.6	0.088	1.7		
1961	0.14	2.3	0.15	2.3	0.13	2.6		
1962	0.19	3.1	0.19	3.1	0.10	2.0		
1963	0.49	8.0	0.50	7.9	0.22	4.3		
1964	0.57	9.4	0.58	9.2	0.26	5.0	0.55	26.2
1965	0.30	4.9	0.30	4.8	0.17	3.2	0.271	12.9
1966	0.41	6.7	0.41	6.6	0.32	6.1	0.40	19.3
1967	0.26	4.3	0.27	4.3	0.16	3.0	0.14	6.5
1968	0.17	2.8	0.17	2.8	0.092	1.8	0.073	3.5
1969	0.11	1.8	0.11	1.8	0.065	1.2	0.060	2.8
1970	0.12	2.0	0.12	2.0	0.069	1.3	0.064	3.0
1971	0.11	1.8	0.11	1.8	0.063	1.2	0.057	2.7
1972	0.059	1.0	0.060	1.0	0.034	0.6	0.030	1.5
1973	0.046	0.8	0.048	0.8	0.048	0.9	0.029	1.4

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1974	0.066	1.1	0.067	1.1	0.067	1.3	0.034	1.6
1975	0.11	1.8	0.11	1.7	0.11	2.1	0.046	2.2
1976	0.040	0.7	0.041	0.6	0.041	0.8	0.023	1.1
1977	0.049	0.8	0.050	0.8	0.050	1.0	0.024	1.2
1978	0.062	1.0	0.063	1.0	0.063	1.2	0.030	1.4
1979	0.067	1.1	0.067	1.1	0.067	1.3	0.032	1.5
1980	0.020	0.3	0.021	0.3	0.021	0.4	0.013	0.6
1981	0.020	0.3	0.021	0.3	0.021	0.4	0.013	0.6
1982	0.015	0.2	0.015	0.2	0.015	0.3	0.015	0.7
1983	0.022	0.4	0.023	0.4	0.023	0.4	0.023	1.1
1984	0.016	0.3	0.016	0.3	0.016	0.3	0.016	0.8
1985	0.020	0.3	0.021	0.3	0.021	0.4	0.021	1.0
1986	0.020	0.3	0.020	0.3	0.020	0.4	0.020	1.0
1987	0.019	0.3	0.020	0.3	0.020	0.4	0.020	0.9
1988	0.019	0.3	0.020	0.3	0.020	0.4	0.020	0.9
1989	0.019	0.3	0.019	0.3	0.019	0.4	0.019	0.9
1990	0.018	0.3	0.018	0.3	0.018	0.3	0.018	0.9
1991	0.017	0.3	0.017	0.3	0.017	0.3	0.017	0.8
1992	0.017	0.3	0.017	0.3	0.017	0.3	0.017	0.8
Total	6.1	100	6.3	100	5.2	100	2.1	100

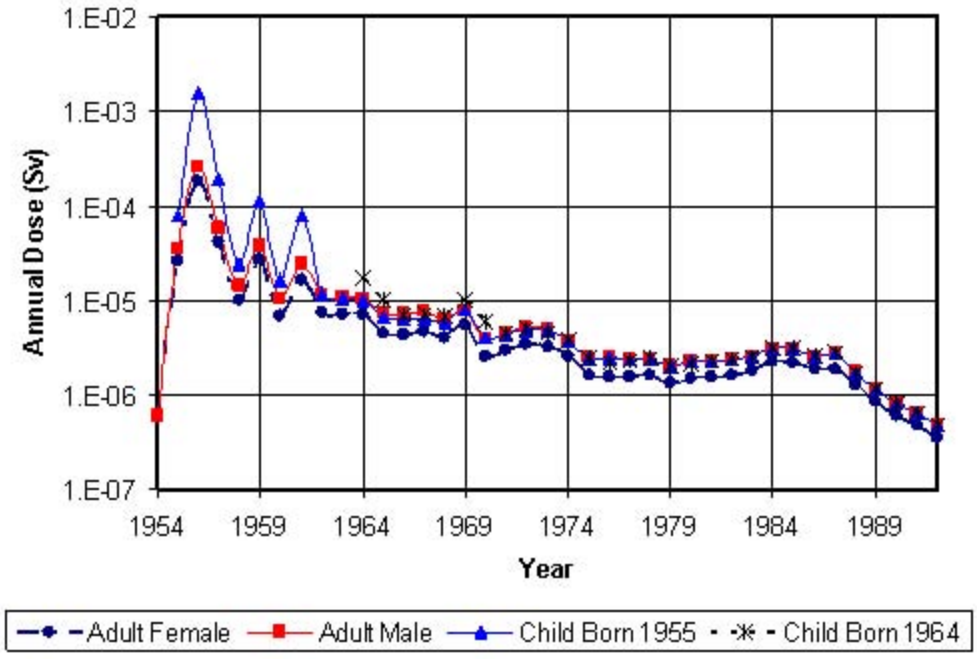

Figure 11-29 Annual Effective Dose (Sv) for Delivery Person Family – Air Pathways Only

Figure 11-30 shows the annual dose from all water pathways. The Adult Female, Adult Male, and Child Born in 1955 each received their largest annual doses from the water pathways in 1958, although doses received in 1964 and 1966 were also relatively large. Doses for these family members were, in 1958:

- Adult Female: 1.0 mSv (100 mrem) – 18% of her dose from all water pathways.
- Adult Male: 1.0 mSv (100 mrem) – 18% of his dose from all water pathways.

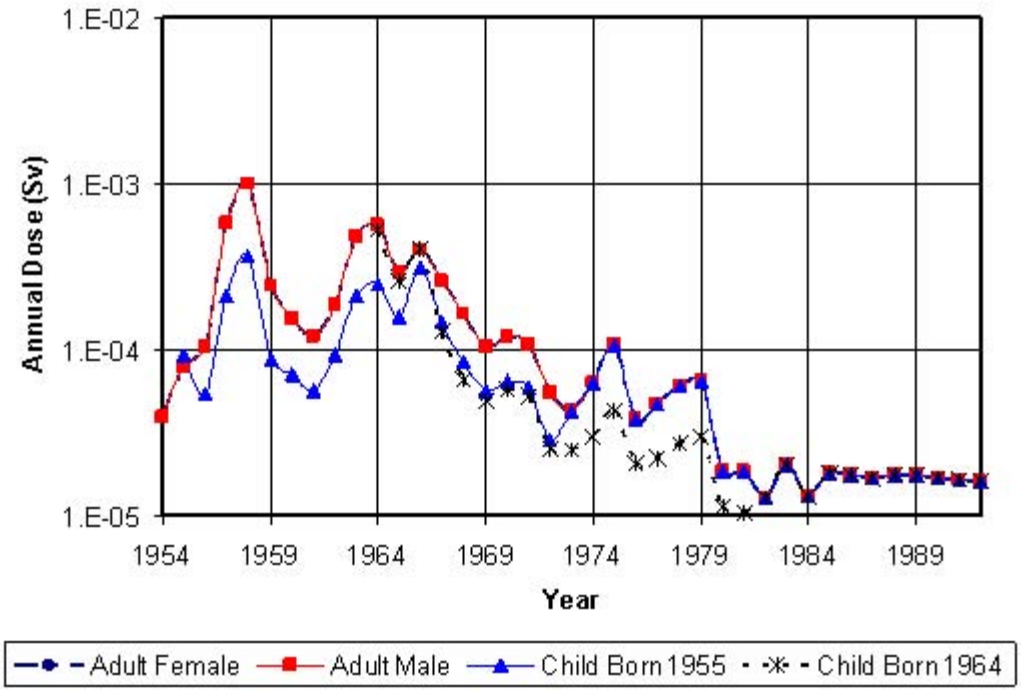

Figure 11-30 Annual Effective Dose (Sv) for Delivery Person Family – Water Pathways Only

Child Born in 1955: 0.36 mSv (36 mrem) – 12% of his dose from all water pathways. The Child Born in 1964 received his largest annual dose – 0.53 mSv (53 mrem) -- from the water pathways in 1964. This dose was 27% of his dose from all water pathways. Another year of relatively large dose for this child was 1966.[18]

The annual doses from the water pathways for the Adult Male and Adult Female were nearly equivalent, mainly because the Adult Male and Adult Female each ate the same annual quantities of fish containing radionuclides.[19] When the children reached age 18, they each ate the same annual quantities of fish as did the two adults. Hence, the curve for the Child Born in 1955 merges with those for the two adults in 1973, and the curve for the Child Born in 1964 merges with those for the two adults in 1982.

The pattern for annual dose from all water pathways (Figure 11-30) is clearly different than the pattern from all air pathways (Figure 11-29). Whereas the annual dose received from the air pathways peaked during the 1950s and early 1960s, and thereafter declined significantly, the annual dose from the water pathways varies over a smaller range. Except for the earliest years, the annual dose from the water pathways was also larger than those from the air pathways. This point is illustrated in Figure 11-31 which shows the annual dose from all air pathways and all water pathways for the Child Born in 1955. Except

[18] Annual doses received by each family member through all water pathways are listed in Appendix I.
[19] The Adult Female curve on Figure 11.2.5.6 is not seen because the curve for the Adult Male is superimposed over that for the Adult Female.

for the years 1955, 1959, and 1961, annual doses from the water pathways were larger than those for the air pathways. Doses from the air pathways also dropped over the years more abruptly than did doses from the water pathways.

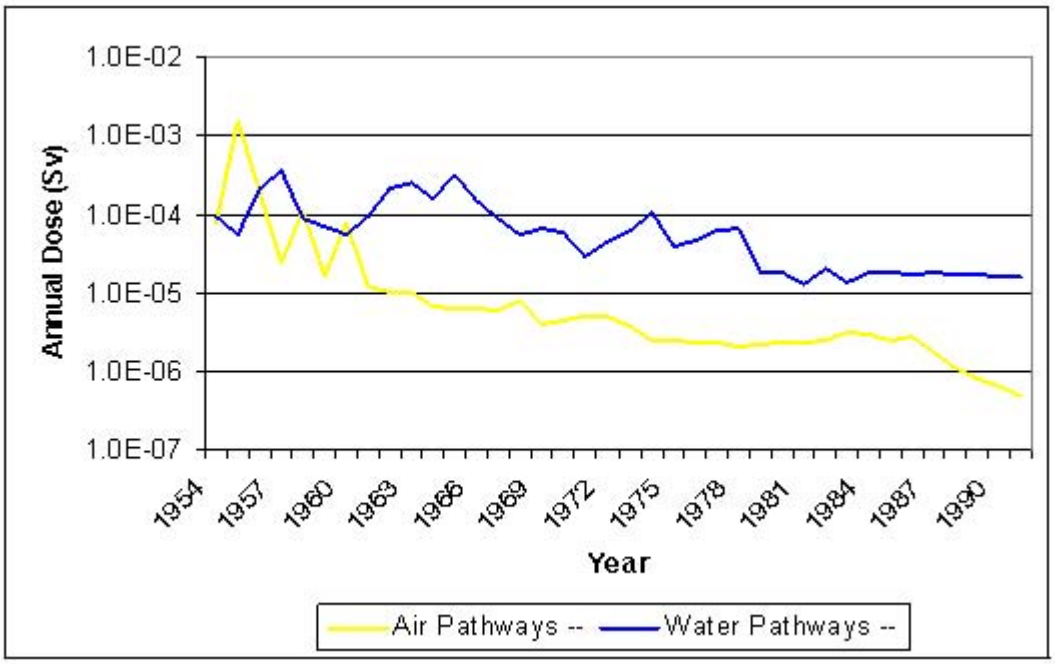

Figure 11-31 Annual Effective Dose (Sv) for Child Born in 1955, Delivery Person Family – Air vs. Water Pathways

11.2.5.3 Dominant Radionuclides, Exposure Routes, and Pathways

Figure 11-32 lists the radionuclides that caused the largest doses for each member of the Delivery Person Family. These radionuclides were different from those dominating dose for the previous scenarios.

For example, although ^{131}I caused most of the dose for the two adults and the Child Born in 1955 of the Urban/Suburban Family (Figure 11-16), ^{137}Cs caused most of the dose for these members of the Delivery Person Family. Although tritium (followed by ^{41}Ar) caused most of the dose for the Child Born in 1955 of the Urban/Suburban Family, ^{137}Cs caused most of the dose for this member of the Delivery Person Family. For all Delivery Person Family members the doses from ^{137}Cs, ^{90}Sr, and ^{32}P came mainly from eating fish containing these radionuclides.

As shown in Figure 11-33, at least 95% of the entire dose for any member of the Delivery Person Family came from ingestion. External exposure accounted for 2 to 3 percent of the entire dose; inhalation accounted for 1 to 3 percent of the entire dose.

The dose from ingestion mainly came from eating fish, followed by beef and milk (Table 11-17 and Figure 11-34). At least 90% of the entire dose received by the two adults and the Child Born in 1964 came from eating fish, and from 3 to 6 percent of their dose came from eating beef and milk. Nearly 58% of the entire dose received by the Child Born in 1955 came from eating fish, while 13% of his dose came from eating beef and 22% of his dose came from drinking milk. For all family members, doses from eating vegetables, fruit, grain, eggs, and poultry were comparatively small. Combined doses from eating fruit and vegetables represented no more than 1.5% of any family member's entire dose, and combined doses from eating grain, eggs, and poultry represented no more than 0.2% of any family member's entire

dose. Still smaller doses came from inadvertently drinking water while swimming: for all family members they represented less than 0.1% of the entire dose. Doses from inadvertently eating soil were again very small – contributing no more than 0.0003% of the entire dose of any family member over 39 years.

The dose from external radiation exposure primarily came from being immersed in a plume of air containing radionuclides. External doses from air immersion caused from 1 to 1.5 percent of the entire dose received by each family member. Also of interest were the doses caused by activities performed along a contaminated shoreline.[20] Shoreline external doses contributed roughly one percent of the entire dose received by each family member.

Inhalation doses from breathing a cloud of air containing radionuclides were again much larger than the inhalation doses received from breathing radionuclides that had been resuspended from soil.

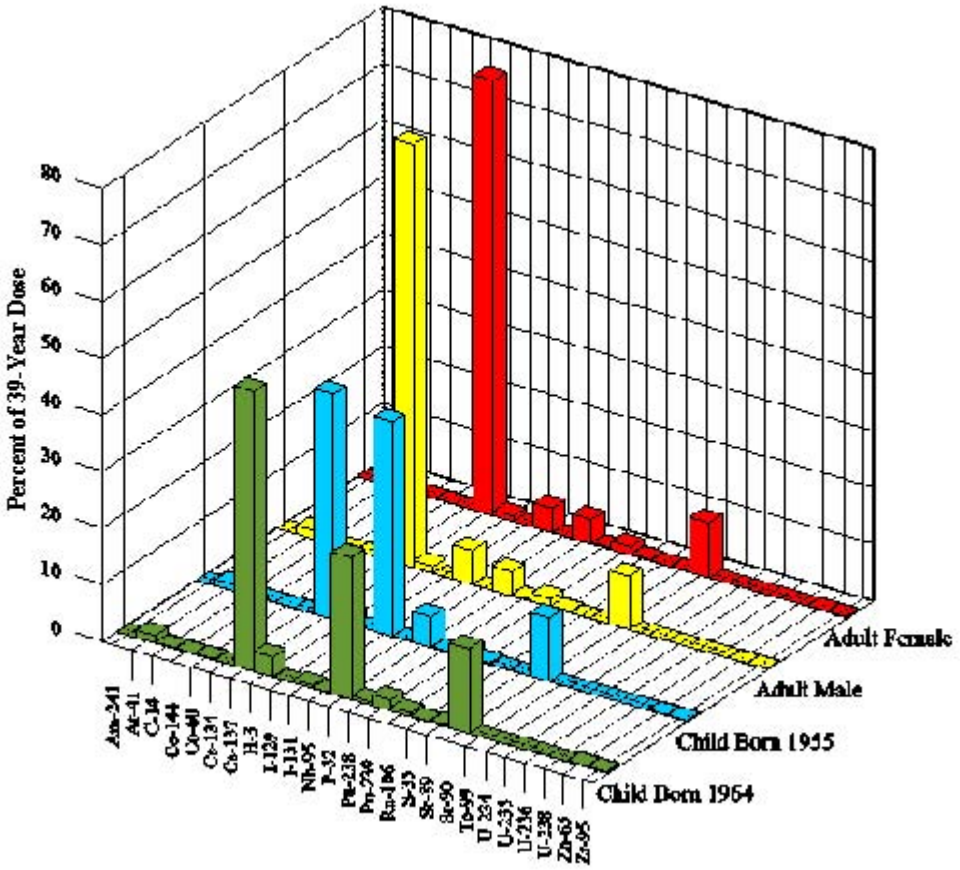

Figure 11-32 Percent of 39-Year Effective Dose by Dominant Isotopes for Delivery Person Family

[20] Recall that this scenario is modeled in GENII as external exposure to radionuclides deposited from river or water onto shoreline sediments. The model used in GENII uses a transport rate constant of 35,400 L/m^2/y for all radionuclides, a value that was chosen for use in GENII based on river and sediment samples mostly obtained from the Columbia River. The model also took into account that exposures would occur from radionuclides deposited on a finite plane surface (the narrow width of the shoreline) as opposed to an large, semi-infinite plane surface.

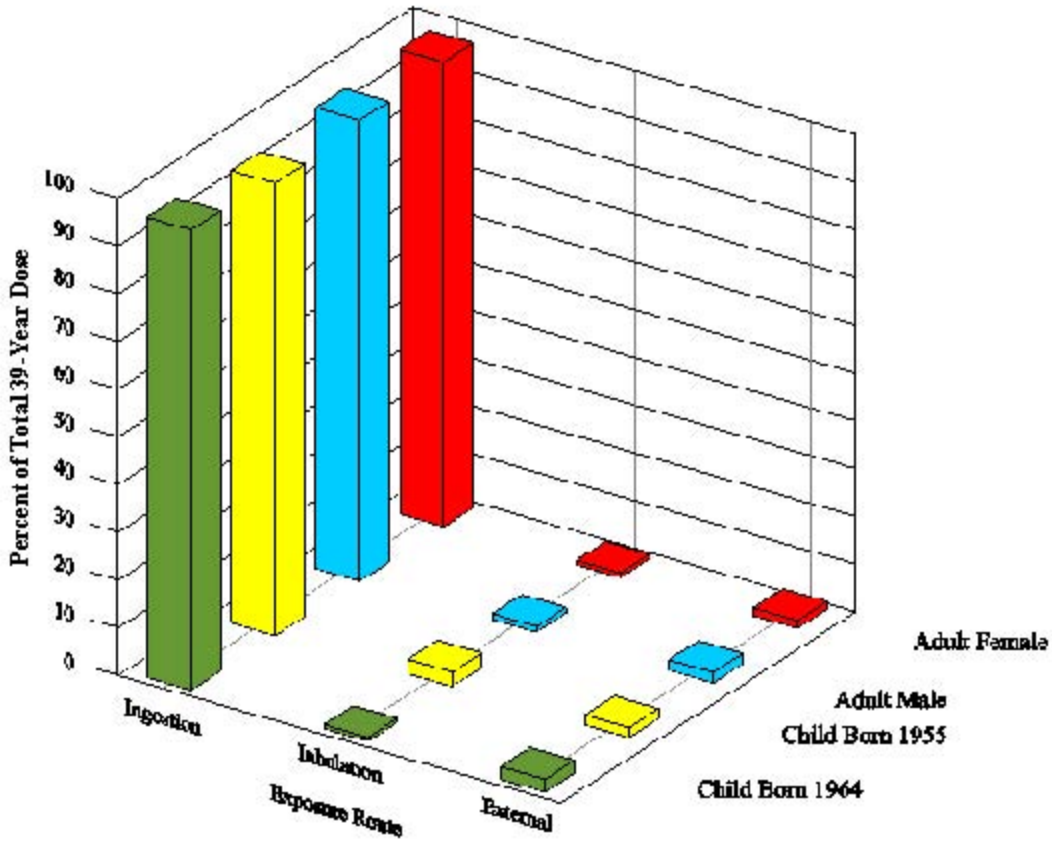

Figure 11-33 Percent of 39-Year Effective Dose by Exposure Route for Delivery Person Family

Table 11-17 39-Year Effective Dose (mSv) by Exposure Pathway for Delivery Person Family

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.055	0.9	0.093	1.5	0.060	1.2	0.028	1.3
	Boating	8.2×10^{-5}	<0.1	8.2×10^{-5}	<0.1	8.2×10^{-5}	<0.1	5.2×10^{-5}	<0.1
	Ground Contamination	0.0047	0.1	0.0046	0.1	0.0047	0.1	1.8×10^{-4}	<0.1
	Shoreline	0.044	0.7	0.044	0.7	0.044	0.8	0.029	1.4
	Swimming	5.9×10^{-5}	<0.1	5.9×10^{-5}	<0.1	5.8×10^{-5}	<0.1	2.6×10^{-5}	<0.1
Ingestion	Beef	0.16	2.6	0.25	3.9	0.69	13.3	0.015	0.7
	Eggs	0.0023	<0.1	0.0038	0.1	0.0034	0.1	0.0023	0.1
	Fish	5.7	92.8	5.7	90.2	3.0	57.9	1.9	92.9
	Fruit	0.011	0.2	0.011	0.2	0.038	0.7	0.0069	0.3
	Grain	0.0016	<0.1	0.0019	<0.1	0.0031	0.1	8.8×10^{-4}	<0.1

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
	Inadvertent swimming ingestion	$7.7x10^{-4}$	<0.1	$7.7x10^{-4}$	<0.1	0.0011	<0.1	$8.0x10^{-4}$	<0.1
	Leafy Vegetables	0.016	0.3	0.016	0.2	0.025	0.5	0.0012	0.1
	Milk	0.080	1.3	0.11	1.7	1.14	21.9	0.041	2.0
	Poultry	0.0014	<0.1	0.0017	<0.1	0.0018	<0.1	0.0011	0.1
	Root Vegetables	0.0089	0.1	0.012	0.2	0.016	0.3	0.0056	0.3
	Soil*	$9.8x10^{-7}$	<0.1	$9.5x10^{-7}$	<0.1	$1.5x10^{-5}$	<0.1	$1.6x10^{-7}$	<0.1
Inhalation	Air Inhalation	0.059	1.0	0.077	1.2	0.16	3.1	0.017	0.8
	Resuspended Soil	$8.2x10^{-5}$	<0.1	$1.0x10^{-4}$	<0.1	$7.7x10^{-5}$	<0.1	$1.6x10^{-5}$	<0.1
Total		6.1	100	6.3	100	5.2	100	2.1	100

* Doses from the soil ingestion pathway were on the order of 10^{-7} to 10^{-5} mSv for each family member. These doses were no more than 0.0003% of any family member's entire 39-year dose.

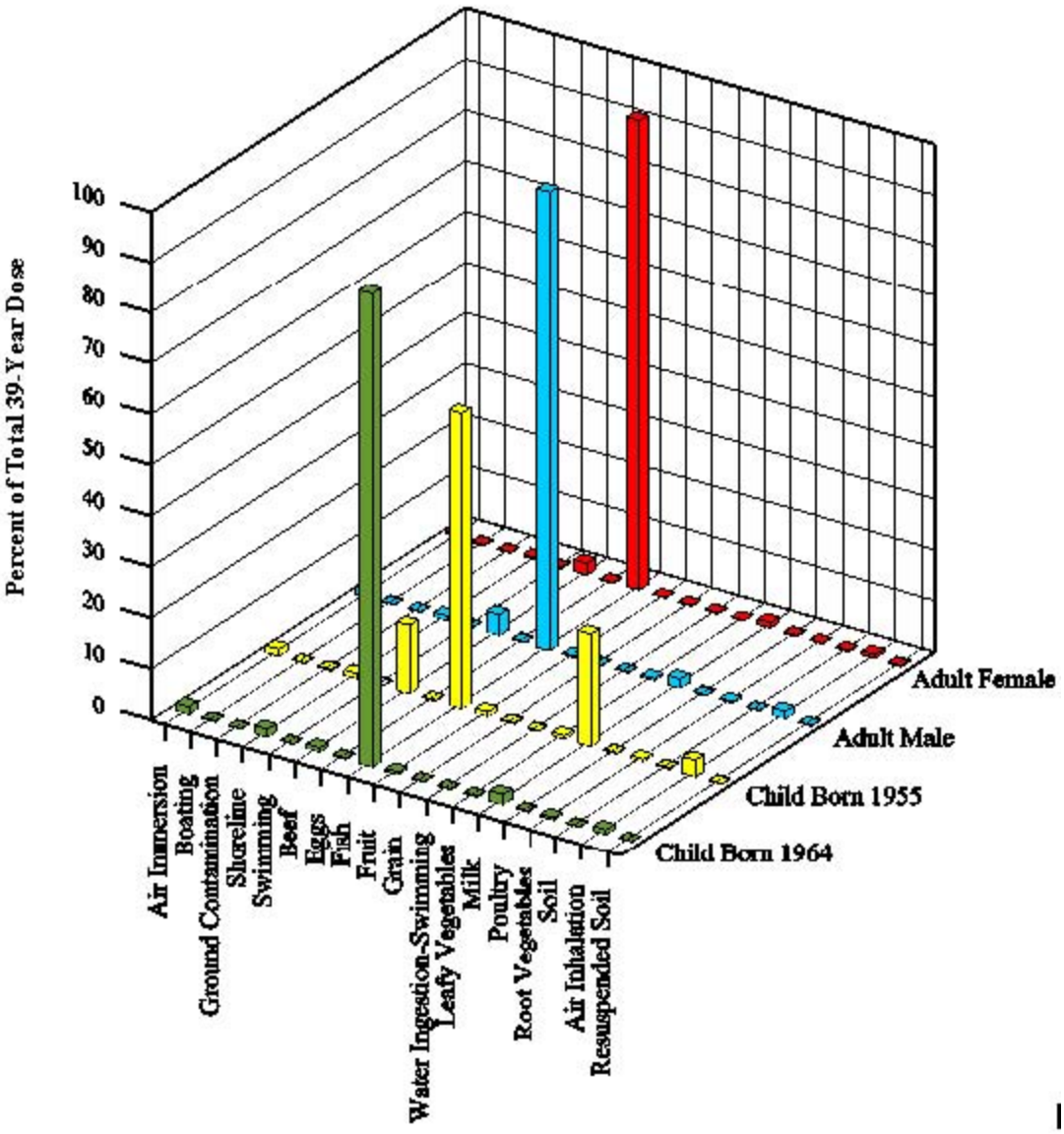

Figure 11-34 Percent of 39-Year Effective Dose by Exposure Pathway for Delivery Person Family

11.2.6 Outdoors Person Family

This hypothetical family lived in Jackson, SC, and all family members stayed there for most activities, including school and religious services. When the children grew up, they also lived in Jackson. The Adult Male worked onsite at SRS as a hunter, for 2000 hours out of each year, as did the children when they reached age 18. His job required him to spend 260 hours each year boating on the Savannah River. The Adult Male took game animals in the form of deer and birds, and caught fish from the Savannah River.[21] The children performed similar activities after they started work (Figure 11-35).

[21] It was assumed that he would be exposed to radionuclides discharged into the Savannah River from all surface water sources from SRS, including Lower Three Runs Creek. To determine exposures from air pathways, it was assumed a single onsite exposure location to represent all the locations that he might have occupied while working.

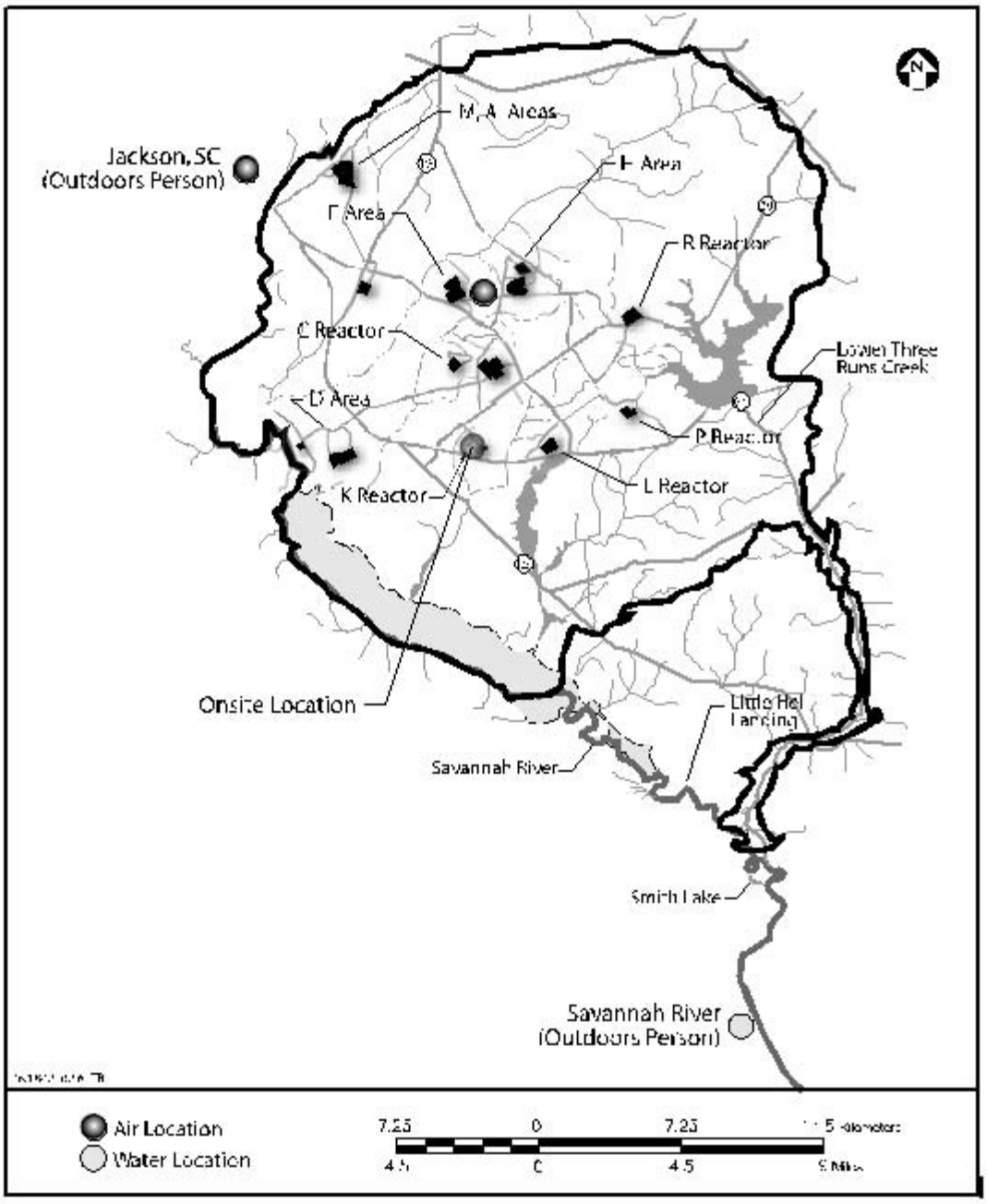

Figure 11-35 Exposure Locations for Outdoors Person Family

All family members (including the adult male) swam, camped, and fished on the Savannah River near the Jackson, SC, boat ramp (upstream of the site). They boated, however, in the Savannah River downstream of the discharge from SRS.

All milk and eggs came from cows and hens located in Jackson. Hence, it was assumed that all milk and eggs contained radionuclides released by SRS into the air. Half the leafy and root vegetables and fruit were grown in Jackson, and half came from sources away from the SRS area. All of the family corn was grown in Jackson.

Three-quarters of the family's beef and poultry consisted of venison and wild fowl that was hunted by the Adult Male on the SRS site. All of this meat contained radionuclides from SRS operations. Their remaining beef and poultry came from other sources such as stores. Of this remaining 25%, half was produced in Jackson (and therefore contained radionuclides from SRS operations and half came from sources away from the SRS area. All fish taken from the Savannah River contained radionuclides from SRS operations.[22]

11.2.6.1 Effective Dose and Total Risks

Table 11-18 lists effective dose and cancer risks for the Outdoors Person Family over 39 years of SRS operation. These doses and risks included those from exposure to radionuclides released into the air as well as to radionuclides released into surface water. The Child Born in 1955 received the largest dose (9.4 mSv, or 940 mrem) and risks while the Child Born in 1964 received the smallest dose (1.8 mSv, or 180 mrem) and risks.

Table 11-18 39-Year Effective Dose and Cancer Risks for Outdoors Person Family

Total Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)				
Air Pathways	1.6	2.5	8.3	0.36
Water Pathways	1.5	1.7	1.2	1.5
All Pathways	3.0	4.2	9.4	1.8
Cancer Incidence Risk (%)				
Air Pathways	0.0042	0.0071	0.082	0.0053
Water Pathways	0.0063	0.0072	0.018	0.030
All Pathways	0.011	0.014	0.10	0.035
Cancer Fatality Risk (%)				
Air Pathways	0.0013	0.0025	0.012	0.0030
Water Pathways	0.0048	0.0055	0.011	0.020
All Pathways	0.0061	0.0080	0.024	0.023

Doses and risks from the air pathways were larger than those for the family members in any other scenario. The Child Born in 1955 received the largest doses from the air pathways: 8.3 mSv (830 mrem) over 39 years. The next largest doses were received by the Adult Male who received 2.5 mSv (250 mrem), and the Adult Female who received 1.6 mSv (160 mrem); the Child Born in 1964 received the smallest dose through the air pathways: 0.36 mSv (36 mrem).

One reason that the doses received by these family members through all air pathways were larger than those for comparable members of other scenarios was because it was assumed that three-quarters of the meat eaten by these family members was venison obtained from the SRS site. The exposure location assumed for deer hunting was much closer to the assumed SRS airborne release points than any other

[22] To determine exposures from consumption of fish, it was assumed that the fish would be taken from areas below the confluence of the Savannah River with Lower Three Runs Creek, so that the fish would be affected by radionuclides discharged into the Savannah River from all SRS surface sources, including Lower Three Runs Creek.

exposure location assumed in this study. From about half to three-quarters of the entire 39-year dose from all air pathways received by any family member came from eating beef (see below). In addition, much of the remaining food eaten by the family came from Jackson, which is located close to (and west-north-west) of the assumed SRS airborne release points.

All family members received comparable doses from the water pathways. The Adult Male received the largest dose; his incremental increase was because he spent much more time than the other family members along the Savannah River shoreline and boating in the Savannah River. His dose from all water pathways was 1.7 mSv (170 mrem) over 39 years. The Adult Female and Child Born in 1964 each received 1.5 mSv (150 mrem), while the Child Born in 1955 received 1.2 mSv (120 mrem). These doses were smaller than those received from the water pathways by members of the Delivery Person Family (Table 11-15).

The percent distribution of dose between air and surface water pathways is shown in Figure 11-36 for the Outdoors Person Family. The water pathways caused a smaller percent of overall dose for members of the Outdoors Person Family than for members of the Delivery Person Family (Figure 11-26). The main difference is Lower Three Runs Creek.

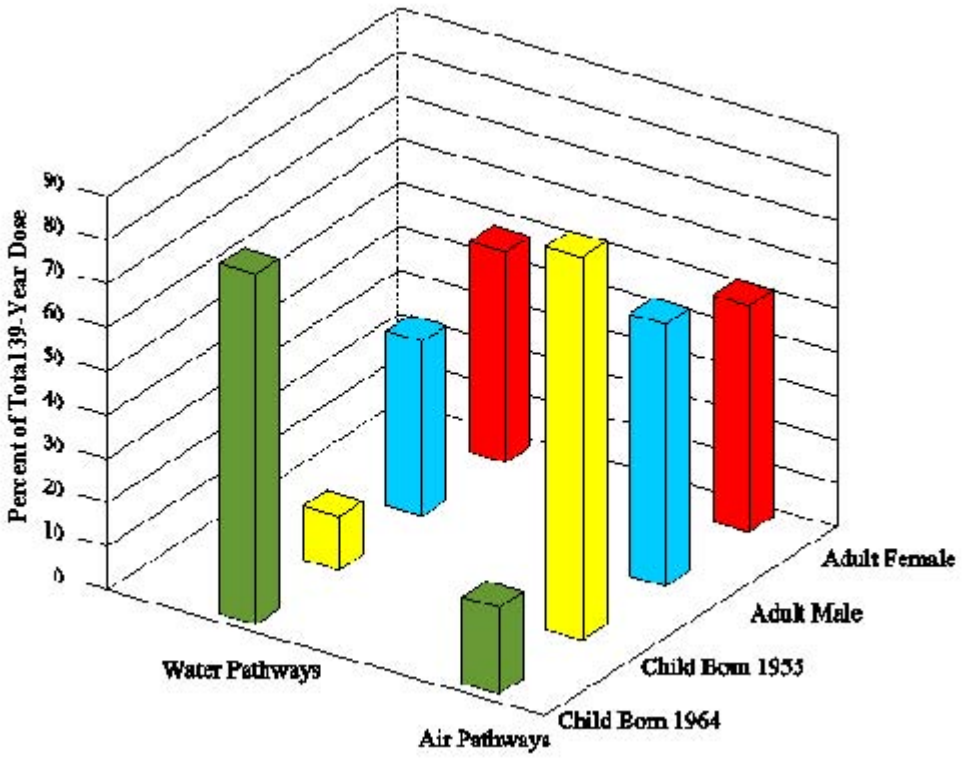

Figure 11-36 Percent Distribution of 39-Year Effective Dose (%) Between Air and Water Pathways for Outdoors Person Family

Members of the Delivery Person family swam in, spent time along the shoreline of, and ate fish taken from Lower Three Runs Creek and the Savannah River. But members of the Outdoors Person Family were not affected by radionuclides in Lower Three Runs Creek. They swam in the Savannah River upstream of SRS's discharge. The Adult Male received shoreline exposures (along the Savannah River) as part of work, as did the two children when they each reached age 18. (The Adult Female spent her entire time along the Savannah River shoreline upstream of SRS's discharge.) All family members

received exposures from boating in the Savannah River as well as exposures from eating fish taken from the Savannah River.

11.2.6.2 Effective Dose by Year

Figure 11-37 shows the percent of the entire dose received by each family member from all (air + water) pathways, while Figure 11-38 shows the percent annual effective dose received by each family member through all pathways. Table 11-19 lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose.

Two large peaks in dose are seen for the years 1956 and 1966, while two smaller peaks are seen for the years 1959 and 1961 (Figure 11-38). The Child Born in 1955 received his largest dose in 1956, when he received 5.9 mSv (590 mrem), or 63% of his entire dose over 39 years. The Adult Female and Adult Male also received their largest doses during this year. The Adult Female received 0.86 mSv (86 mrem), or 28% of her entire dose, while the Adult Male received 1.3 mSv (130 mrem), or 30% of his entire dose. The Child Born in 1964 received his largest dose in 1966, when he received 0.70 mSv (70 mrem), or 38% of his entire dose.

The patterns of annual dose and percent of dose are different from those seen for the Delivery Person Scenario (see Figure 11-27 and Figure 11-28).

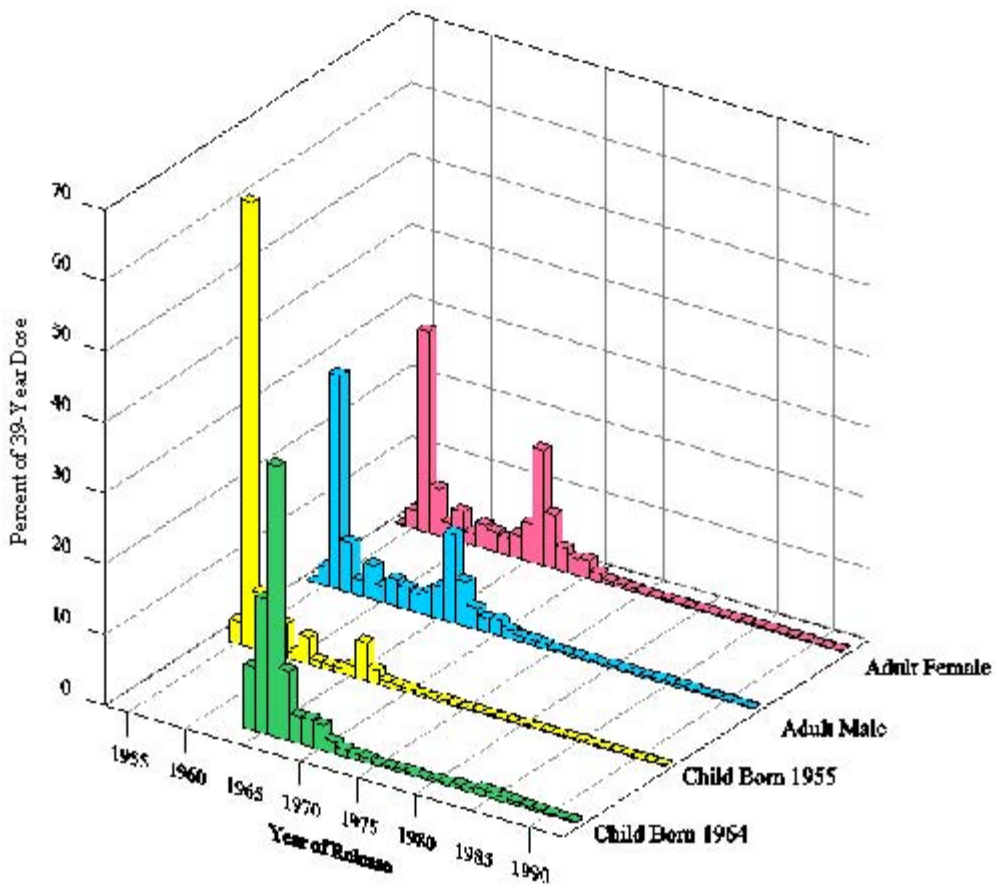

Figure 11-37 Percent of 39-Year Effective Dose by Year for Outdoors Person Family – Air + Water Pathways

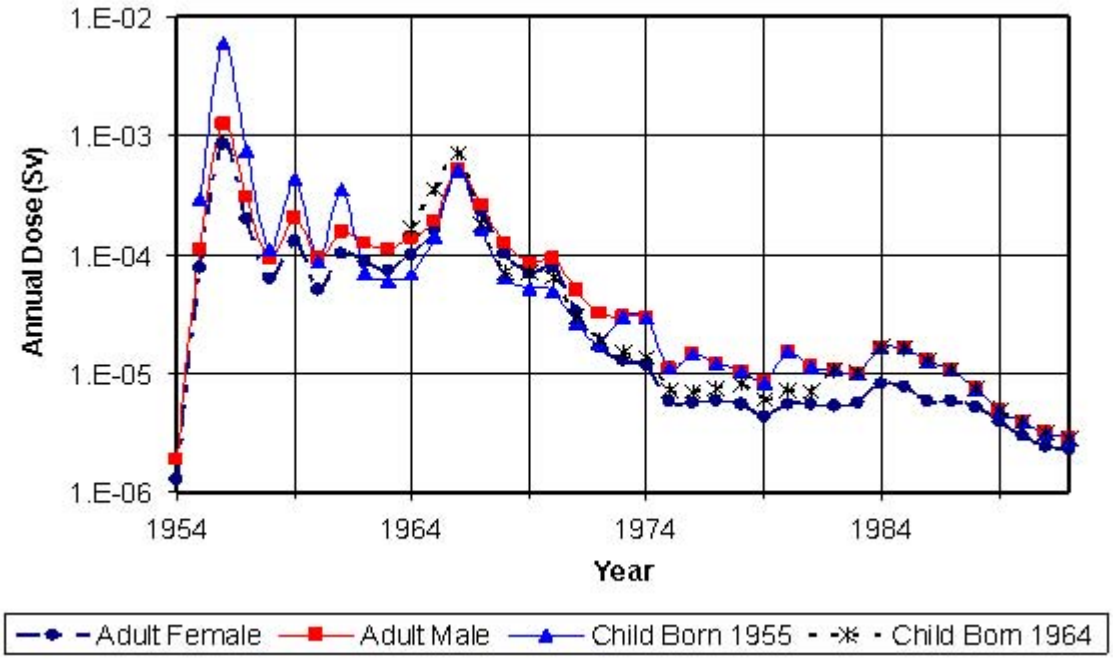

Figure 11-38 Annual Effective Dose (Sv) for the Outdoors Person Family – Air + Water Pathways

Annual doses from all air pathways for the Outdoors Person Family are shown in Figure 11-39. The pattern is familiar. During 1956, the Child Born in 1955 received 5.9 mSv (592 mrem), or 72% of his dose from all air pathways, the Adult Female received 0.84 mSv (84 mrem), or 53% of her dose from all air pathways, and the Adult Male received 1.3 mSv (130 mrem), or 50% of his dose from all air pathways. In 1964, the Child Born in 1964 received 0.045 mSv (4.5 mrem), or 12% of his dose from all air pathways.

Figure 11-40 shows annual effective doses received by each member of the Outdoors Person Family through the water pathways. Annual doses rose to a peak in 1966, and then dropped. After the mid 1970s annual doses fluctuated for all family members between about 0.001 and 0.01 mSv per year. Annual doses through all water pathways were, during 1966:

- Adult Female: 0.48 mSv (48 mrem) -- 33% of her dose from all water pathways.
- Adult Male: 0.50 mSv (50 mrem) -- 30% of his dose from all water pathways.
- Child Born in 1955: 0.48 mSv (48 mrem) -- 42% of his dose from all water pathways.
- Child Born in 1966: 0.68 mSv (68 mrem) -- 47% of his dose from all water pathways.

The annual pattern of dose shown in Figure 11-40 for the water pathways is different than that for the Delivery Person Scenario (Figure 11-30). Whereas for the Delivery Person Scenario the annual doses fluctuated over a range of about 0.01 to 1 mSv, the doses from the water pathways for the Outdoors Person Scenario built to a peak and varied over a larger range. Except for a few years on either side of 1966, annual doses from the water pathways tended to be smaller than those from the air pathways. This second point is illustrated in Figure 11-41, which shows the annual dose from all air pathways and all water pathways for the Child Born in 1955 of the Outdoors Person Family. This pattern is clearly different from that seen for the Child Born in 1955 of the Delivery Person Family (Figure 11-31).

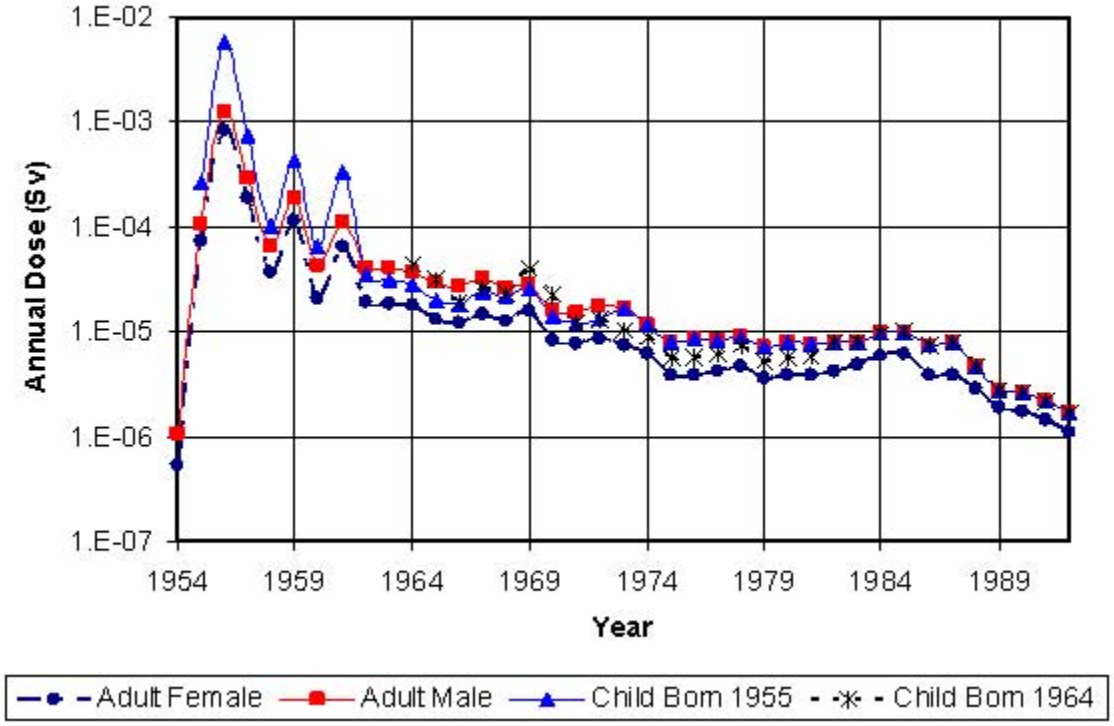

Figure 11-39 Annual Effective Dose (Sv) for the Outdoors Person Family – Air Pathways Only

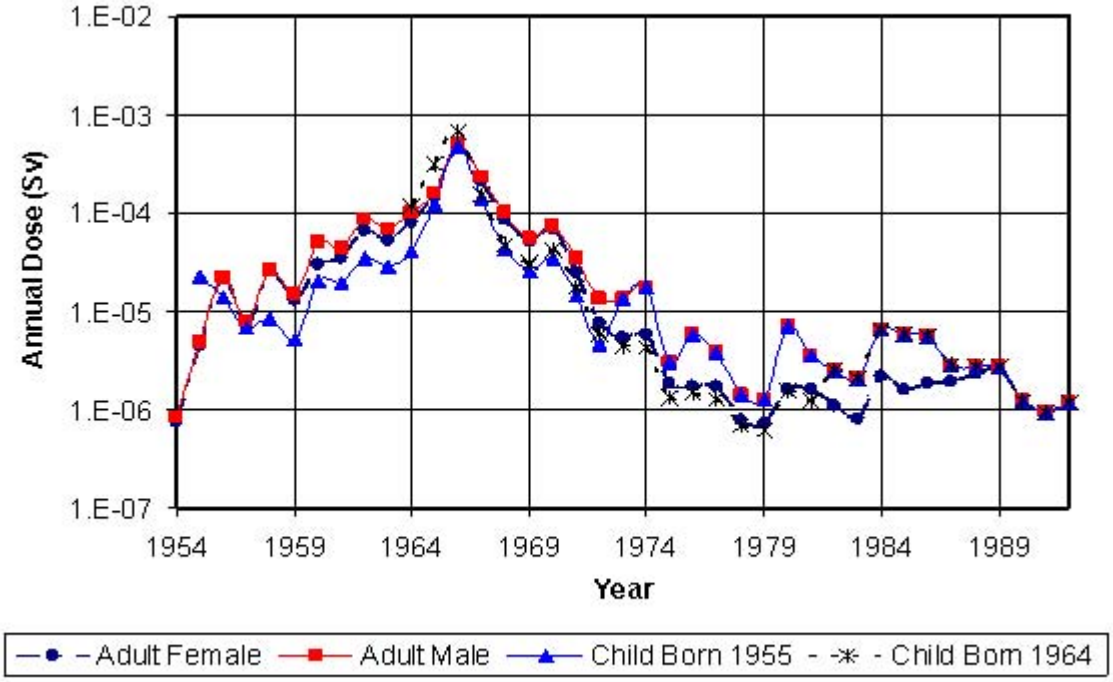

Figure 11-40 Annual Effective Dose (Sv) for Outdoors Person Family – Water Pathways Only

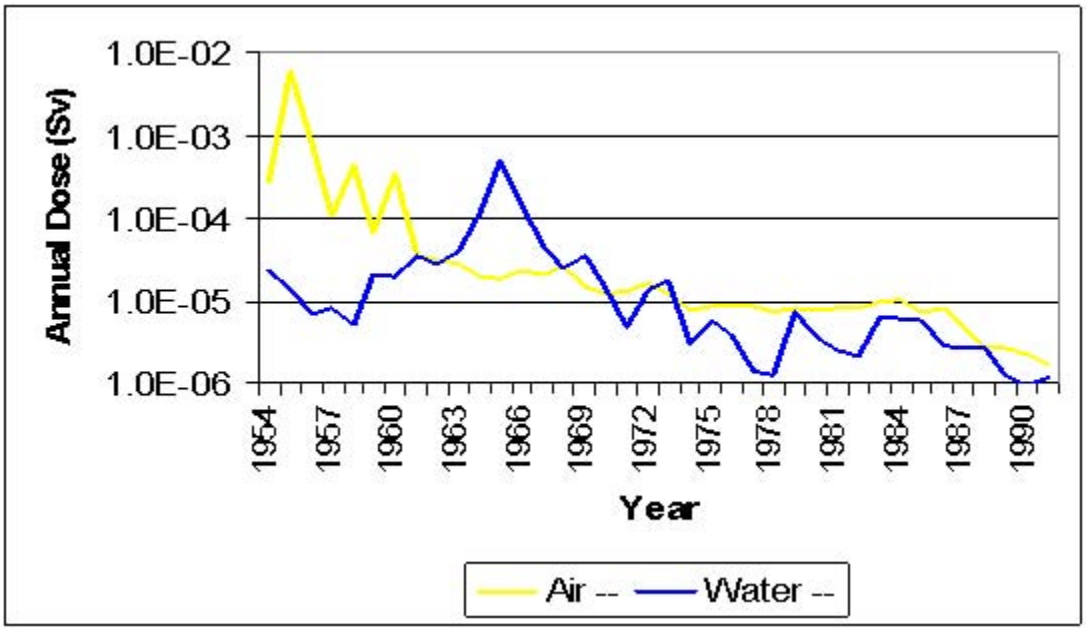

Figure 11-41 Annual Effective Dose (Sv) for Child Born in 1955, Outdoors Person Family – Air vs. Water Pathways

Table 11-19 Annual Effective Dose (mSv) for Outdoors Person Family

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	Dose	%	Dose	%	Dose	%	Dose	%
1954	0.0013	0.0	0.0019	0.0				
1955	0.077	2.5	0.11	2.7	0.29	3.1		
1956	0.86	28.3	1.3	30.3	5.9	62.9		
1957	0.20	6.5	0.30	7.2	0.76	8.0		
1958	0.062	2.1	0.09	2.2	0.11	1.2		
1959	0.13	4.3	0.20	4.8	0.44	4.7		
1960	0.050	1.7	0.093	2.2	0.087	0.9		
1961	0.10	3.3	0.15	3.6	0.35	3.7		
1962	0.087	2.8	0.13	3.0	0.070	0.7		
1963	0.072	2.4	0.11	2.6	0.060	0.6		
1964	0.098	3.2	0.14	3.3	0.068	0.7	0.16	9.0
1965	0.16	5.3	0.19	4.5	0.14	1.5	0.35	19.1
1966	0.49	16.3	0.53	12.5	0.50	5.3	0.70	38.4
1967	0.23	7.5	0.26	6.3	0.17	1.8	0.18	9.8
1968	0.10	3.3	0.13	3.0	0.065	0.7	0.070	3.8
1969	0.067	2.2	0.084	2.0	0.052	0.5	0.071	3.9
1970	0.077	2.5	0.092	2.2	0.049	0.5	0.064	3.5
1971	0.033	1.1	0.050	1.2	0.027	0.3	0.030	1.7
1972	0.016	0.5	0.032	0.8	0.018	0.2	0.019	1.0
1973	0.013	0.4	0.030	0.7	0.030	0.3	0.015	0.8

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	Dose	%	Dose	%	Dose	%	Dose	%
1974	0.012	0.4	0.029	0.7	0.029	0.3	0.014	0.7
1975	0.0058	0.2	0.011	0.3	0.011	0.1	0.0071	0.4
1976	0.0056	0.2	0.014	0.3	0.014	0.2	0.0071	0.4
1977	0.0059	0.2	0.012	0.3	0.012	0.1	0.0074	0.4
1978	0.0056	0.2	0.010	0.2	0.010	0.1	0.0081	0.4
1979	0.0043	0.1	0.0084	0.2	0.0084	0.1	0.0059	0.3
1980	0.0055	0.2	0.015	0.4	0.015	0.2	0.0072	0.4
1981	0.0055	0.2	0.011	0.3	0.011	0.1	0.0071	0.4
1982	0.0054	0.2	0.011	0.3	0.011	0.1	0.011	0.6
1983	0.0057	0.2	0.010	0.2	0.010	0.1	0.010	0.6
1984	0.0082	0.3	0.016	0.4	0.016	0.2	0.016	0.9
1985	0.0076	0.3	0.016	0.4	0.016	0.2	0.016	0.9
1986	0.0058	0.2	0.013	0.3	0.013	0.1	0.013	0.7
1987	0.0058	0.2	0.011	0.3	0.011	0.1	0.011	0.6
1988	0.0052	0.2	0.0074	0.2	0.0074	0.1	0.0074	0.4
1989	0.0045	0.1	0.0055	0.1	0.0055	0.1	0.0055	0.3
1990	0.0030	0.1	0.0039	0.1	0.0039	<0.1	0.0039	0.2
1991	0.0024	0.1	0.0032	0.1	0.0032	<0.1	0.0032	0.2
1992	0.0022	0.1	0.0029	0.1	0.0029	<0.1	0.0029	0.2
Total	3.0	100	4.2	100	9.4	100	1.83	100

11.2.6.3 Dominant Radionuclides, Exposure Routes, and Pathways

Figure 11-42 lists the radionuclides causing the largest doses over 39 years for each member of the Outdoors Person Family. For the two adults and the Child Born in 1955, the largest contributor to dose was ^{131}I. This radionuclide caused radiation dose principally from eating foods such as beef and milk. The next two important radionuclides were generally ^{137}Cs and ^{32}P, radionuclides that caused radiation dose principally from eating fish. For the Child Born in 1964, ^{32}P was the largest contributor to radiation dose. It again caused dose mostly from eating fish, as did ^{137}Cs and ^{32}P. Tritium caused dose to this family member mainly from inhaling air and eating foods containing this radionuclide.

Each family member received most of their dose from ingestion (Figure 11-43). From 83 to 95 percent of the dose received by each family member came from ingestion, from 2 to 13 percent came from external exposure to radiation, and from 2 to 4 percent came from inhalation.

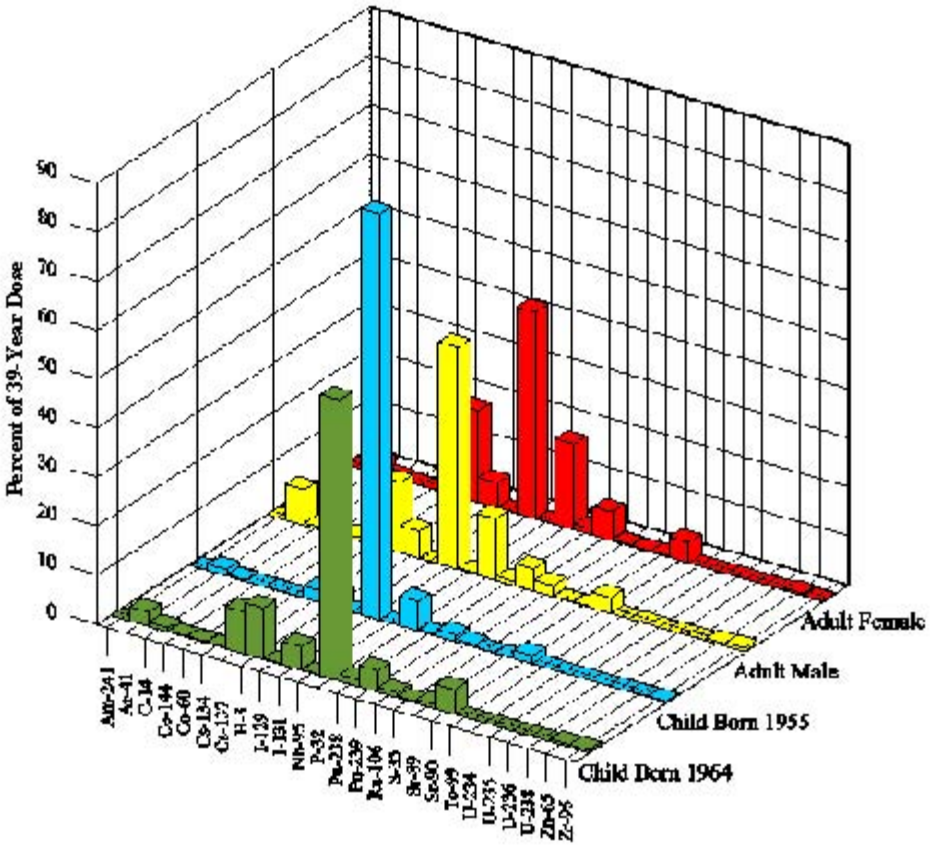

Figure 11-42 Percent of 39-Year Effective Dose by Dominant Isotopes for Outdoors Person Family

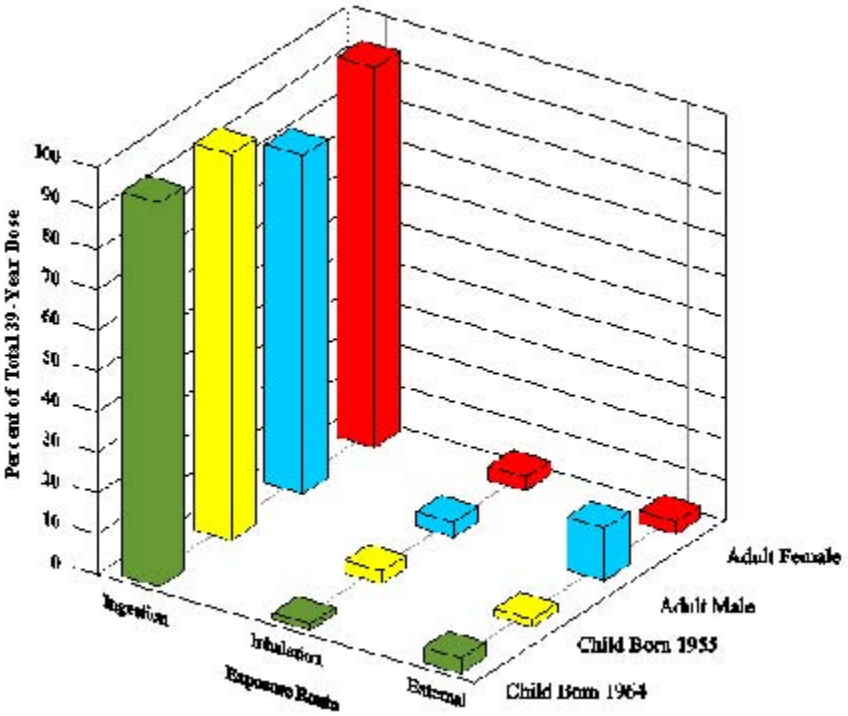

Figure 11-43 Percent of 39-Year Effective Dose by Exposure Route for Outdoors Person Family

As shown in Table 11-20 and Figure 11-44, eating fish was a significant contributor to dose for all family members – i.e., from 12 to 79 percent of any family member's entire dose. It was not, however, as significant as the dose received from eating fish by the members of the Delivery Person Family (Table 11-17). Doses to members of the Outdoors Person family from eating fish were smaller than doses to members of the Delivery Person Family by a factor of up to 3.9. Each member in the Outdoors Person Family ate the same amount of fish as the comparable member of the Delivery Person Family. The doses were different because members of the Delivery Person family ate fish from Lower Three Runs Creek and the Savannah River, while members of the Outdoors Person Family ate fish only from the Savannah River.

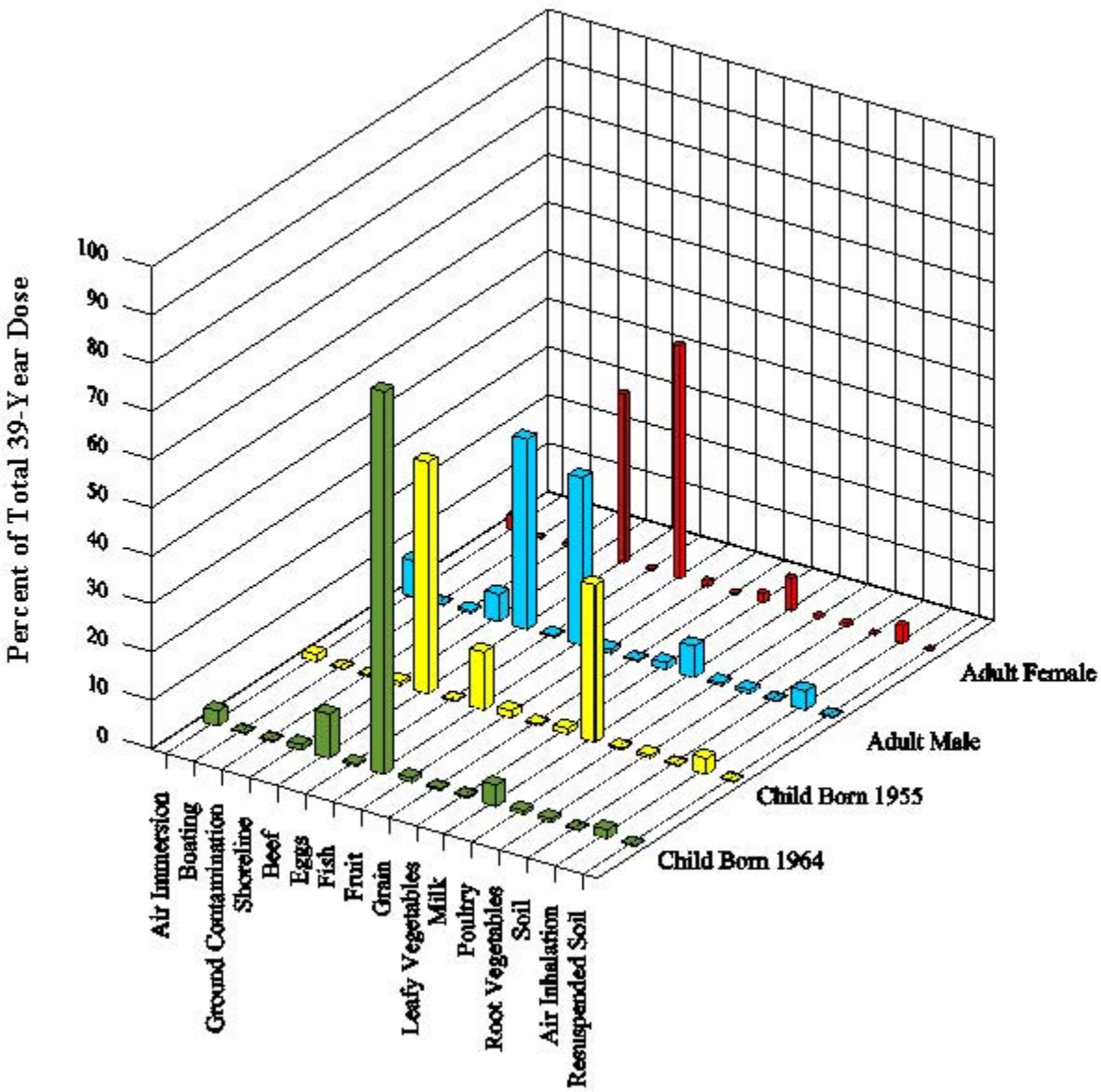

Figure 11-44 Percent of Effective Dose by Exposure Pathways for Outdoors Person Family

Eating beef and milk was a strong contributor to dose for members of the Outdoors Person Family, ranging from 13 to 80 percent of any member's entire dose. The beef and milk pathways were less important for the Child Born in 1964 than for the other family members because he missed the large radionuclide releases into the air during the 1950s and early 1960s. By comparison, doses from eating fruit and vegetables were small, ranging from 1 to 3 percent of any family member's entire dose. Doses from eating eggs, grain, and poultry contributed no more than 1% of any family member's entire dose. Doses from inadvertently eating soil contributed to no more than 0.0004% of any family member's entire dose.

Of interest is the external radiation dose received by the Adult Male (Table 11-20). He received a larger external dose from air immersion than did the Adult Male for the Urban/Suburban Family (Table 11-11). Although they both spent the same amount of time onsite at SRS, the Urban/Suburban Family home in Augusta was farther away from SRS than was the Outdoors Person home in Jackson. In addition, the Adult Male of the Outdoors Person Family received a relatively large dose from shoreline exposure (0.23 mSv, or 23 mrem), contributing about 5% of his entire dose over 39 years. This dose reflected the 260 hours per year he spent along the Savannah River shoreline while at work. By contrast, his doses from boating were relatively small despite the 356 hours per spent boating in the Savannah River.

Table 11-20 Effective Dose (mSv) by Exposure Pathway for Outdoors Person Family

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.084	2.8	0.31	7.3	0.12	1.3	0.053	2.9
	Boating	8.2×10^{-5}	<0.1	3.1×10^{-4}	<0.1	1.3×10^{-4}	<0.1	7.2×10^{-5}	<0.1
	Ground Contamin-ation	0.010	0.3	0.012	0.3	0.011	0.1	4.2×10^{-4}	<0.1
	Shoreline	--	--	0.23	5.4	0.053	0.6	0.017	0.9
Ingestion	Beef	1.1	34.8	1.7	39.3	4.5	47.8	0.16	8.9
	Eggs	0.0041	0.1	0.0068	0.2	0.0062	0.1	0.0039	0.2
	Fish	1.5	48.2	1.5	34.6	1.1	11.8	1.4	79.3
	Fruit	0.028	0.9	0.028	0.7	0.12	1.3	0.012	0.7
	Grain	0.0038	0.1	0.0046	0.1	0.015	0.2	0.0018	0.1
	Leafy Vegetables	0.052	1.7	0.052	1.2	0.088	0.9	0.0024	0.1
	Milk	0.20	6.6	0.27	6.3	3.1	32.4	0.075	4.1
	Poultry	0.011	0.4	0.014	0.3	0.014	0.1	0.010	0.6
	Root Vegetables	0.018	0.6	0.025	0.6	0.037	0.4	0.0099	0.5
	Soil*	2.2×10^{-6}	<0.1	2.4×10^{-6}	<0.1	3.4×10^{-5}	<0.1	3.8×10^{-7}	<0.1
Inhalation	Air Inhalation	0.10	3.4	0.16	3.7	0.29	3.1	0.030	1.6
	Resuspend-ed Soil	1.9×10^{-4}	<0.1	2.6×10^{-4}	<0.1	1.8×10^{-4}	<0.1	3.7×10^{-5}	<0.1
Total		3.0	100	4.2	100	9.4	100	1.8	100

* Doses from the soil ingestion pathway were on the order of 10^{-7} to 10^{-5} mSv for each family member. These doses were no more than 0.0004% of any family member's entire 39-year dose.

External radiation doses for the three other members of the Outdoors Person Family ranged from 2 to 4 percent of their entire dose. Most of their external radiation dose came from immersion in a plume of radionuclides in air. Boating in the Savannah River contributed less than 0.1% of their entire dose. Doses from external exposure to radionuclides on the ground were larger, as were doses from shoreline exposures.[23] Still, doses from these pathways were smaller than air immersion doses.

Inhalation doses from breathing a plume of air containing radionuclides were again much larger than the inhalation doses received from breathing radionuclides that had been resuspended from soil.

11.2.7 Near River Family

This hypothetical family lived in Martin, SC (Figure 11-45). All members spent much of their work, home activities, and recreation time outdoors. The family lived, worked, and went to school and church in Martin, and participated in outdoor activities such as hunting, fishing, and boating. This family spent twice as much time boating (in the Savannah River) as did other families. Each family member spent an average of an hour per day of each year on the Savannah River shoreline, and an average of an hour a day swimming during the summer in the Savannah River.[24] When the children grew up, they continued to live in Martin. The family's milk and eggs all came from cows and hens located in Martin. Half of the family's beef, poultry, leafy vegetables, root vegetables, and fruit was grown or produced in Martin and half came from sources outside the SRS vicinity. All of the corn eaten by the family was grown in Martin. All of the fish eaten by the family was caught in the Savannah River below its confluence with Lower Three Runs Creek. Drinking water and any irrigation used to produce the food eaten by the family came from sources unaffected by SRS releases.

[23] Except for the Adult Female, who did not experience any shoreline exposures to radionuclides.
[24] All boating, swimming, and shoreline activities took place below the confluence of the Savannah River with Lower Three Runs Creek.

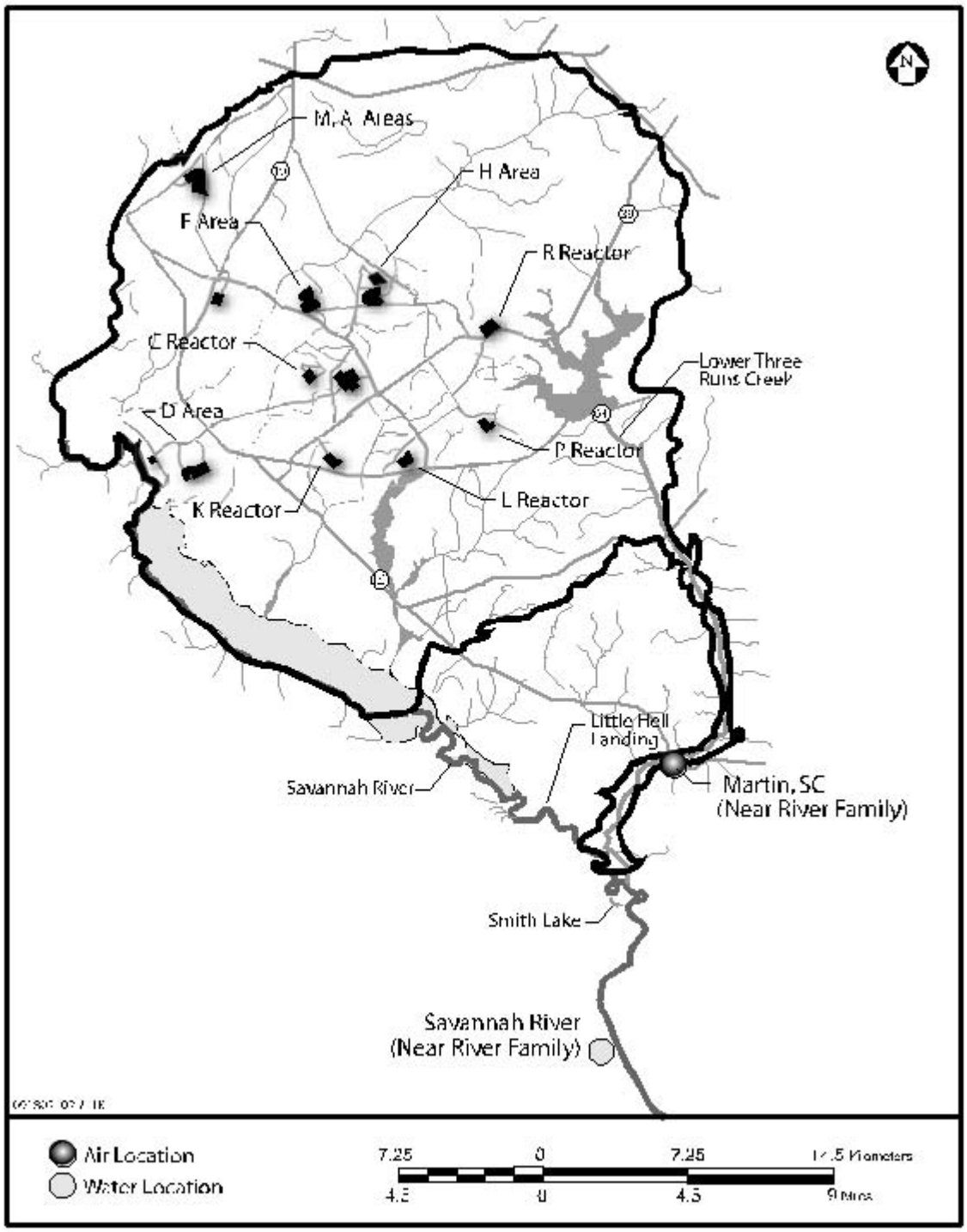

Figure 11-45 Exposure Location for Near Water Family

11.2.7.1 Effective Doses and Total Risks

Table 11-21 lists effective dose and cancer risks for the Near River Family over 39 years of SRS operation. Doses and risks included those from exposure to radionuclides released into the air as well as to radionuclides released into surface water. The Child Born in 1955 received the largest doses and risks; the Child Born in 1964 received the smallest doses and risks.

Doses from all air pathways are similar to those received by members of Rural Family One (Table 11-3). Doses from all water pathways are only a little larger than those received by members of the Outdoors Person Family but much smaller than those received by members of the Delivery Person Family. The members of the Near River Family spent more time in contact with the Savannah River than did the Outdoors Person family, but did not spend time in nor eat fish taken from Lower Three Runs Creek.

Nonetheless, for the two adults and the Child Born in 1964, most radiation doses resulted from the water pathways as illustrated in Figure 11-46. For these family members the water pathways contributed from 81 to 95 percent of their entire dose over 39 years. For the Child Born in 1955, however, the water pathways contributed only 45% of his entire dose over 39 years.

Table 11-21 39-Year Effective Dose and Cancer Risks for Near River Family

Total Dose or Risk	Adult Female	Adult Male	Child Born in 1955	Child Born in 1964
Effective Dose (mSv)				
Air Pathways	0.31	0.42	1.7	0.088
Water Pathways	1.8	1.8	1.4	1.7
All Pathways	2.1	2.2	3.1	1.8
Cancer Incidence Risk (%)				
Air Pathways	0.00089	0.0012	0.017	0.0013
Water Pathways	0.0076	0.0076	0.021	0.033
All Pathways	0.0085	0.0088	0.038	0.034
Cancer Fatality Risk (%)				
Air Pathways	0.00036	0.00044	0.0028	0.00084
Water Pathways	0.0057	0.0057	0.014	0.021
All Pathways	0.0061	0.0062	0.017	0.022

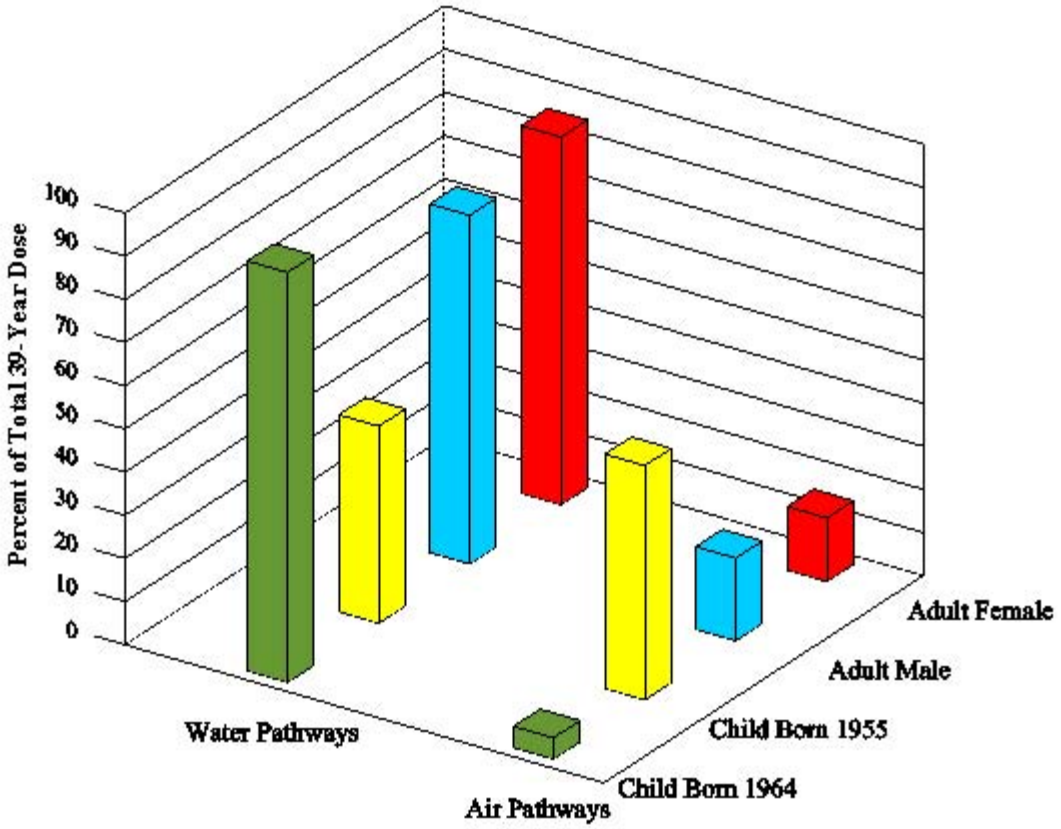

Figure 11-46 Distribution of 39-Year Effective Dose (%) Between Air and Water Pathways for Near River Family

11.2.7.2 Effective Dose by Year

Figure 11-47 shows the percent of the entire dose received by each family member, while Figure 11-48 shows the annual effective dose received by each family member. Table 11-22 lists the percent of the entire 39-year effective dose received each year by each family member, as well as their annual dose. Both the two figures and the table include combined doses from all (air + water) pathways.

Two large peaks in dose are seen for the years 1956 and 1966 (Figure 11-47 and Figure 11-48). These two figures appear similar to corresponding figures for annual dose and percent of entire dose for the Outdoors Person Family (Figure 11-37 and Figure 11-38). Largest dose for the Child Born in 1955 occurred in 1956, while the largest dose for the two adults and the Child Born in 1964 occurred in 1966. In 1956, the Child Born in 1955 received 1.2 mSv (120 mrem), or 40% of his entire dose. In 1966, the Adult Female received 24% (0.51 mSv, or 51 mrem) of her entire dose, the Adult Male received 23% (0.51 mSv, or 51 mrem) of his entire dose, and the Child Born in 1964 received 40% (0.71 mSv, or 71 mrem) of his entire dose.

Figure 11-49 shows the effective dose received by each receptor from only the air pathways. In 1956, the Adult Female received a dose of 0.15 mSv (15 mrem) from the air pathways, the Adult Male received a dose of 0.21 mSv (21 mrem), and the Child Born in 1955 received a dose of 1.2 mSv (120 mrem). After the 1950s, annual doses through all air pathways for these family members typically ranged from about 0.001 to 0.005 mSv per year. The Child Born in 1964 received his largest annual dose (0.013 mSv, or 1.3 mrem) in 1964. Annual doses thereafter fell -- by about a factor of ten by 1988.

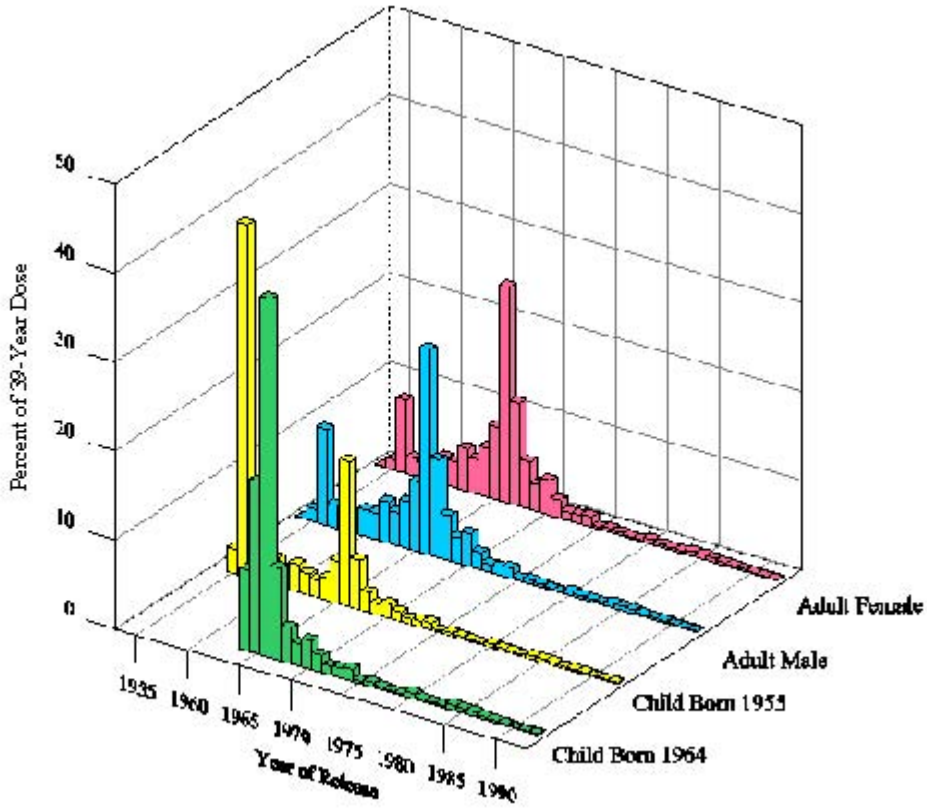

Figure 11-47 Percent of 39-Year Effective Dose for Near River Family – Air + Water Pathways

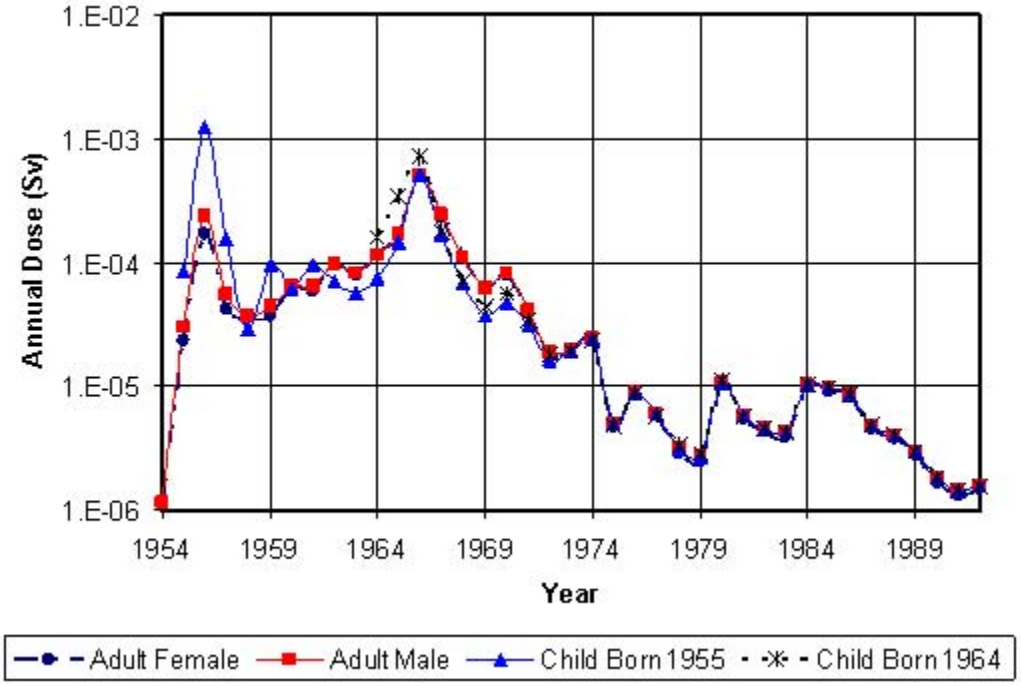

Figure 11-48 Annual Effective Dose (Sv) for Near River Family – Air + Water Pathways

Table 11-22 Annual Effective Dose (mSv) for Near River Family

	Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Year	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
1954	0.0011	0.1	0.0011	0.1				
1955	0.024	1.1	0.031	1.4	0.084	2.7		
1956	0.17	8.2	0.24	10.7	1.24	39.6		
1957	0.041	2.0	0.055	2.5	0.16	5.0		
1958	0.035	1.7	0.037	1.7	0.030	0.9		
1959	0.037	1.8	0.045	2.0	0.095	3.0		
1960	0.064	3.1	0.065	3.0	0.063	2.0		
1961	0.060	2.8	0.064	2.9	0.095	3.0		
1962	0.099	4.7	0.10	4.5	0.071	2.3		
1963	0.080	3.8	0.081	3.7	0.058	1.8		
1964	0.11	5.4	0.11	5.2	0.076	2.4	0.16	9.1
1965	0.17	8.1	0.17	7.7	0.15	4.6	0.34	19.5
1966	0.51	24.3	0.51	23.0	0.51	16.3	0.71	40.4
1967	0.24	11.5	0.24	11.0	0.17	5.5	0.18	10.4
1968	0.11	5.2	0.11	5.0	0.067	2.1	0.071	4.0
1969	0.062	2.9	0.063	2.8	0.037	1.2	0.044	2.5
1970	0.080	3.8	0.081	3.7	0.048	1.5	0.057	3.2
1971	0.040	1.9	0.041	1.8	0.031	1.0	0.034	1.9
1972	0.018	0.9	0.019	0.9	0.017	0.5	0.018	1.0
1973	0.019	0.9	0.019	0.9	0.019	0.6	0.019	1.1
1974	0.024	1.1	0.024	1.1	0.024	0.8	0.024	1.3
1975	0.0047	0.2	0.0049	0.2	0.0049	0.2	0.0048	0.3
1976	0.0087	0.4	0.0089	0.4	0.0089	0.3	0.0089	0.5
1977	0.0058	0.3	0.0060	0.3	0.0060	0.2	0.0059	0.3
1978	0.0029	0.1	0.0032	0.1	0.0032	0.1	0.0034	0.2
1979	0.0025	0.1	0.0027	0.1	0.0027	0.1	0.0029	0.2
1980	0.0105	0.5	0.011	0.5	0.0107	0.3	0.011	0.6
1981	0.0055	0.3	0.0058	0.3	0.0058	0.2	0.0057	0.3
1982	0.0043	0.2	0.0046	0.2	0.0046	0.1	0.0046	0.3
1983	0.0039	0.2	0.0043	0.2	0.0043	0.1	0.0043	0.2
1984	0.010	0.5	0.0105	0.5	0.011	0.3	0.011	0.6
1985	0.0093	0.4	0.0097	0.4	0.0097	0.3	0.0097	0.6
1986	0.0084	0.4	0.0087	0.4	0.0087	0.3	0.0087	0.5
1987	0.0045	0.2	0.0048	0.2	0.0048	0.2	0.0048	0.3
1988	0.0038	0.2	0.0040	0.2	0.0040	0.1	0.0040	0.2
1989	0.0034	0.2	0.0036	0.2	0.0036	0.1	0.0036	0.2
1990	0.0017	0.1	0.0018	0.1	0.0018	0.1	0.0018	0.1
1991	0.0013	0.1	0.0014	0.1	0.0014	<0.1	0.0014	0.1
1992	0.0015	0.1	0.0016	0.1	0.0016	<0.1	0.0016	0.1
Total	2.1	100	2.2	100	3.1	100	1.7586	100

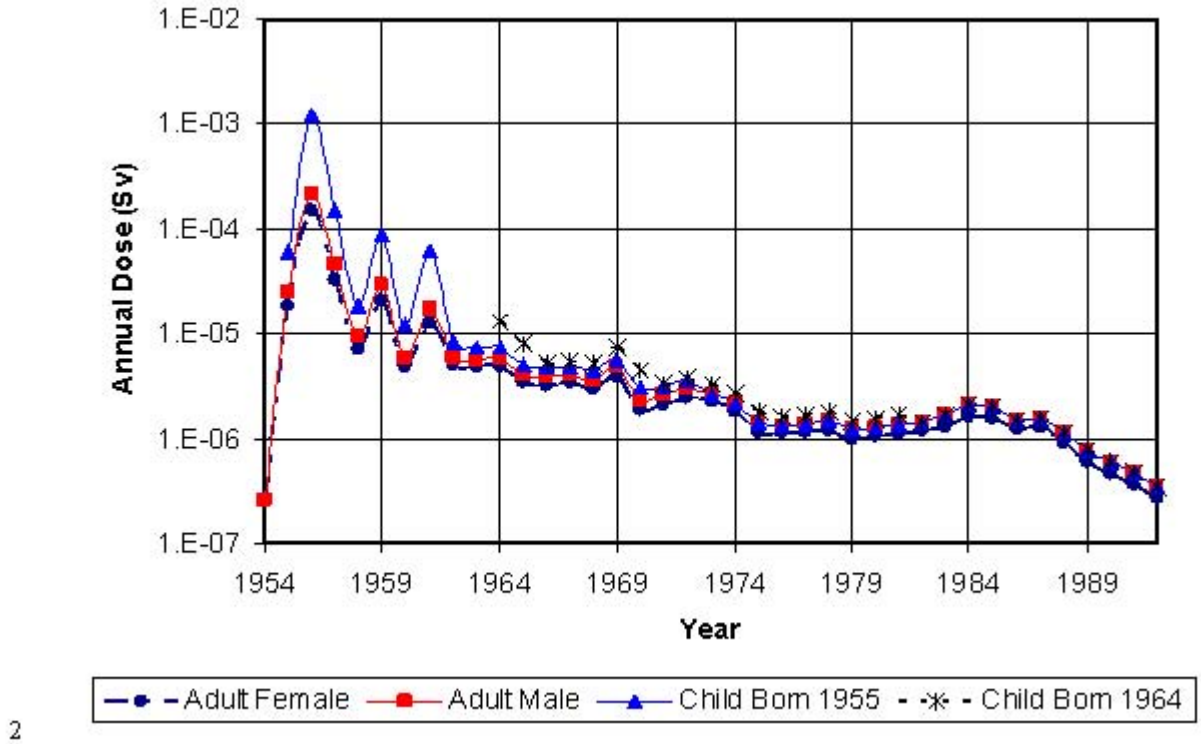

Figure 11-49 Annual Effective Dose (Sv) for Near River Family – Air Pathways Only

As shown in Figure 11-50, annual doses from the water pathways followed a similar pattern to those shown in Figure 11-40 for the Outdoors Person Family. Annual doses from all water pathways built to a maximum in 1966 for all family members:

- Adult Female: 0.50 mSv (50 mrem) – 28% of her dose from all water pathways.
- Adult Male: 0.50 mSv (50 mrem) – 28% of her dose from all water pathways.
- Child Born in 1955: 0.51 mSv (51 mrem) – 35% of his dose from all water pathways.
- Child Born in 1964: 0.70 mSv (70 mrem) – 42% of his dose from all water pathways.

Unlike the situation for the Outdoors Person Family (Figure 11-40), however, after the early 1970s, each member of the Near River Family received essentially equivalent annual doses (Figure 11-50). This pattern of dose occurred because all members of the

Near River Family spent all their time in the Martin area, and all spent the same amount of time swimming and boating in the Savannah River, and spending time along its shoreline.[25]

The result of the combined doses from the air and water pathways was two large peak doses that occurred in 1956 for the air pathways and 1966 for the water pathways. After the early to mid 1960s, most of the doses for each family member were caused by the water pathways as illustrated in Figure 11-51 for the Child Born in 1955.

[25] By contrast, the children of the Outdoors Person Family, after they each reached age 18, worked on the SRS site. The Adult Female of the Outdoors Person Family always stayed at home.

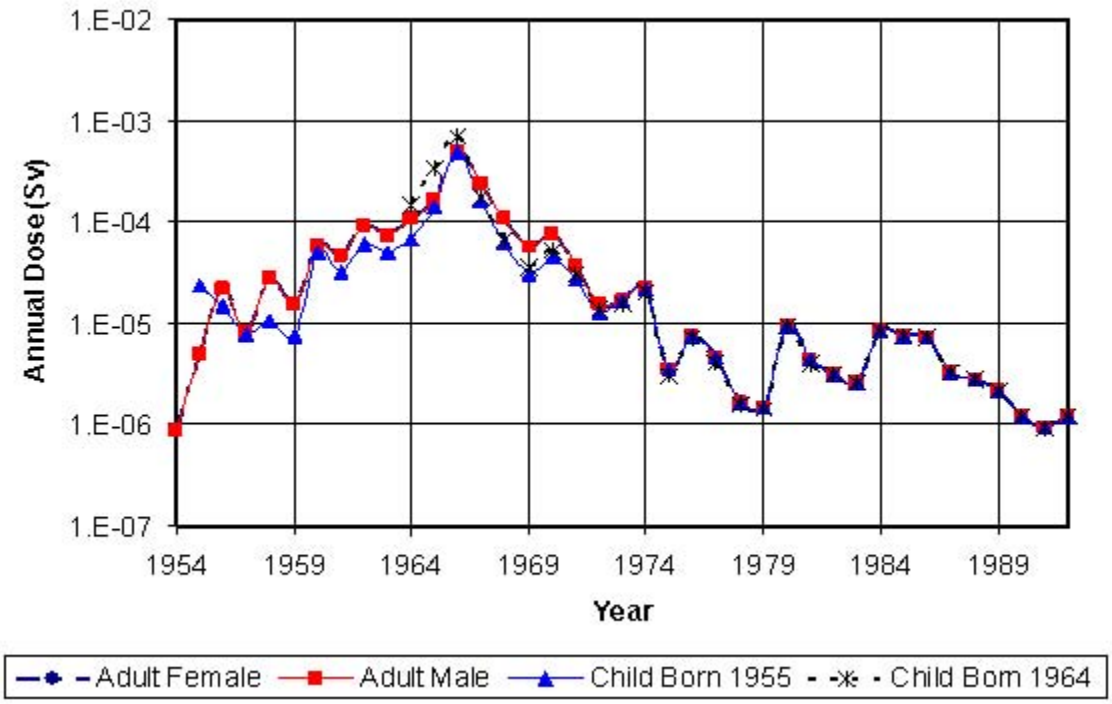

Figure 11-50 Annual Effective Dose (Sv) for Near River Family – Water Pathways Only

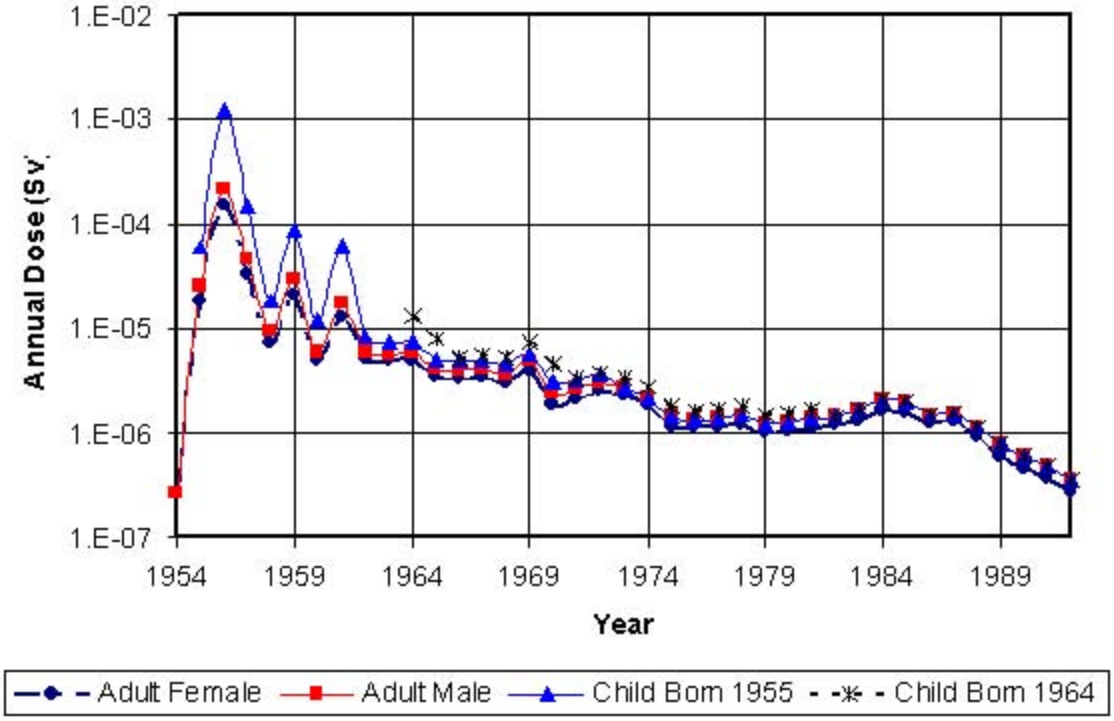

Figure 11-51 Annual Effective Dose (Sv) for Child Born in 1955, Near River Family – Air vs. Water Pathways

11.2.7.3 Dominant Radionuclides, Exposure Routes, and Pathways

Figure 11-52 shows the radionuclides that were the largest contributors of dose over 39 years for each family member. For the two adults, the dominant radionuclides were ^{137}Cs and ^{32}P. The importance of these two radionuclides reflects the importance of the water pathways for the Near River Family. Doses from these two radionuclides mainly resulted from eating fish. For the Child Born in 1955, ^{131}I again caused most of his radiation dose. This dose was caused mainly by eating foods containing ^{131}I, and occurred mostly during the 1950s and early 1960s. The Child Born in 1964 missed the large releases of iodine that occurred during the 1950s. Most of his dose was caused by eating fish containing ^{32}P, ^{137}Cs, and ^{90}Sr.

Similar to previous scenarios, each family member received most of their dose from ingestion (Figure 11-53). From 81 to 86 percent of the dose received by each family member came from ingestion, from 12 to 17 percent came from external exposure to radiation, and from 1 to 3 percent came from inhalation.

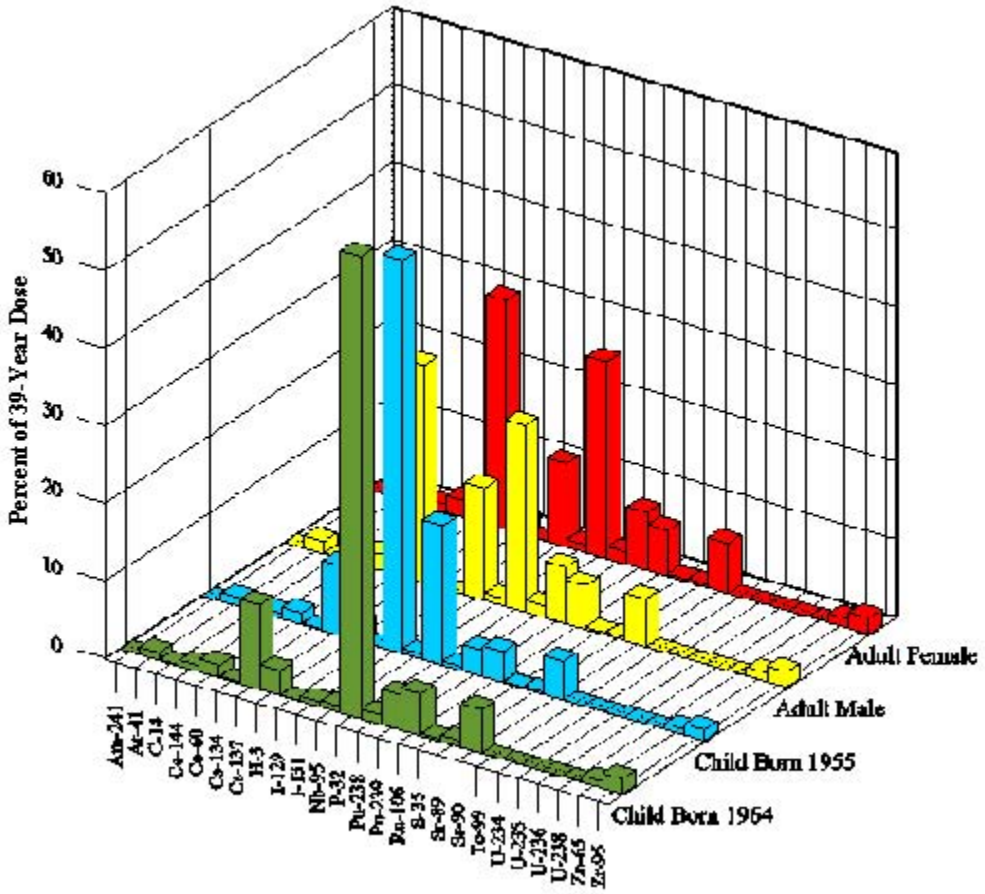

Figure 11-52 Percent of 39-Year Effective Dose by Dominant Isotopes for Near River Family

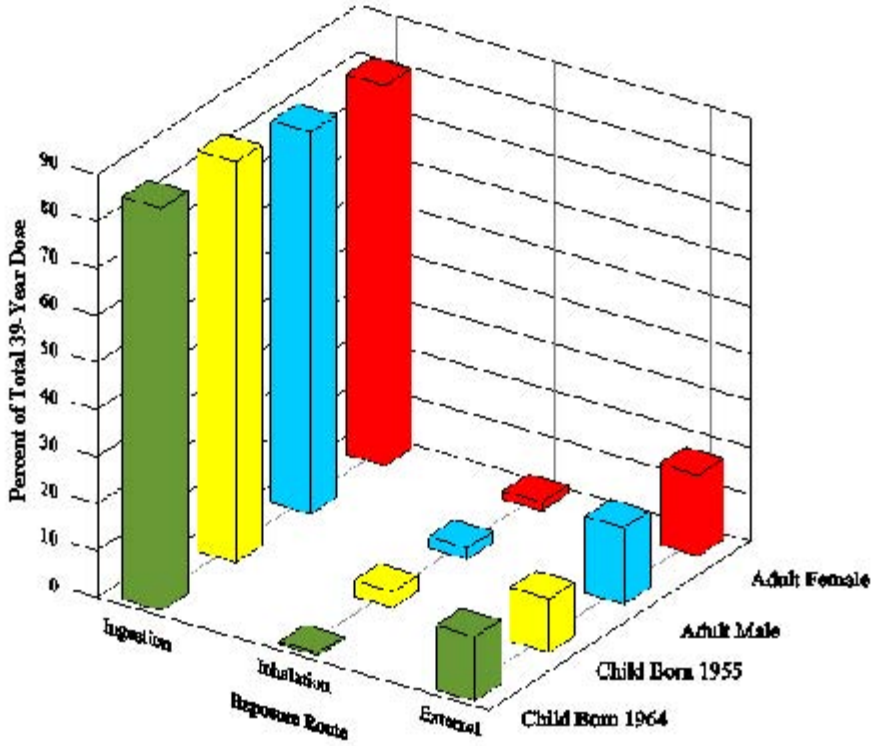

Figure 11-53 Percent of 39-Year Effective Dose by Exposure Route for Near River Family

All family members received most of their dose from eating fish, beef, and milk (Table 11-23 and Figure 11-54). Eating fish accounted for 35 to 82 percent of their entire dose over 39 years, eating beef accounted for 0.6 to 19 percent of their entire dose, and drinking milk accounted for about 2 to 28 percent of their entire dose. These three combined pathways caused from 79 to 85 percent of the entire dose received by any family member. Doses from eating vegetables and fruit were smaller: these combined pathways contributed from 0.7 to 2.4 percent of any family member's entire dose. Doses from eating poultry, eggs, and grain were smaller still, no more than 0.2% of any family member's entire dose. Doses from inadvertently consuming water while swimming in the Savannah River were about as large as those from eating poultry -- i.e., 0.1% of the entire dose. Doses from inadvertently eating soil contributed no more than 0.0003% of any family member's entire dose.

For all family members, most of the external dose came from exposure to radioactive material that had been deposited on the shoreline of the Savannah River. Each family member spent 365 hours per year along the shoreline, a larger time than members of other scenarios. Doses from shoreline exposure contributed from 10 to 16 percent of any family member's entire dose. In contrast, doses from other external radiation exposure pathways associated with boating and swimming accounted for less than 0.1% of any family member's entire dose. Doses from these two water pathways were, for the two adults and the Child Born in 1955, more than 10 times smaller than the doses received by these family members from external exposure to radionuclides that had been deposited from the air onto the ground. These latter doses still contributed no more than 0.1% of any family member's entire dose. Otherwise, external radiation doses from immersion in a plume of air containing radionuclides accounted for no more than about 2% of any family member's entire dose.

Doses from inhaling radionuclides showed a familiar pattern. For all family members, doses from breathing radionuclides from a contaminated plume were much larger than doses from breathing radionuclides after they had been resuspended after being deposited onto soil.

Table 11-23 39-Year Effective Dose (mSv) by Exposure Pathway for Near River Family

		Adult Female		Adult Male		Child Born in 1955		Child Born in 1964	
Route	**Pathway**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**	**Dose**	**%**
External	Air Immersion	0.036	<0.1	0.036	1.6	0.036	1.1	0.018	1.0
	Boating	$1.6x10^{-4}$	<0.1	$1.6x10^{-4}$	<0.1	$1.6x10^{-4}$	<0.1	$1.0x10^{-4}$	<0.1
	Ground Contamina-tion	0.0029	0.1	0.0029	0.1	0.0029	0.1	$1.2x10^{-4}$	<0.1
	Shoreline	0.32	15.6	0.32	14.6	0.32	10.2	0.22	12.7
	Swimming	$1.6x10^{-4}$	<0.1	$1.6x10^{-4}$	<0.1	$1.6x10^{-4}$	<0.1	$9.8x10^{-5}$	<0.1
Ingestion	Beef	0.13	6.5	0.21	9.5	0.59	18.8	0.011	0.6
	Eggs	0.0018	0.1	0.0030	0.1	0.0027	0.1	0.0018	0.1
	Fish	1.46	71.0	1.46	66.2	1.1	35.4	1.4	82.3
	Fruit	0.010	0.5	0.0098	0.4	0.037	1.2	0.0056	0.3
	Grain	$7.0x10^{-4}$	<0.1	$8.4x10^{-4}$	<0.1	0.0023	0.1	$4.0x10^{-4}$	<0.1
	Inadvertent swimming ingestion	0.0011	0.1	0.0011	0.1	0.0019	0.1	0.0017	0.1
	Leafy Vegetables	0.016	0.8	0.016	0.7	0.026	0.8	0.0010	0.1
	Milk	0.062	3.0	0.083	3.7	0.89	28.3	0.033	1.9
	Poultry	0.0010	<0.1	0.0013	0.1	0.0013	<0.1	$8.4x10^{-4}$	<0.1
	Root Vegetables	0.0070	0.3	0.0097	0.4	0.013	0.4	0.0045	0.3
	Soil*	$6.4x10^{-7}$	<0.1	$6.4x10^{-7}$	<0.1	$9.7x10^{-6}$	<0.1	$1.1x10^{-7}$	<0.1
Inhalation	Air Inhalation	0.039	1.9	0.052	2.4	0.10	3.3	0.012	0.7
	Resuspende d Soil	$5.3x10^{-5}$	<0.1	$7.2x10^{-5}$	<0.1	$5.0x10^{-5}$	<0.1	$1.0x10^{-5}$	<0.1
Total		2.1	100	2.2	100	3.1	100	1.8	100

*Doses from the soil ingestion pathway were no more than 0.0003% of any family member's entire 39-year dose.

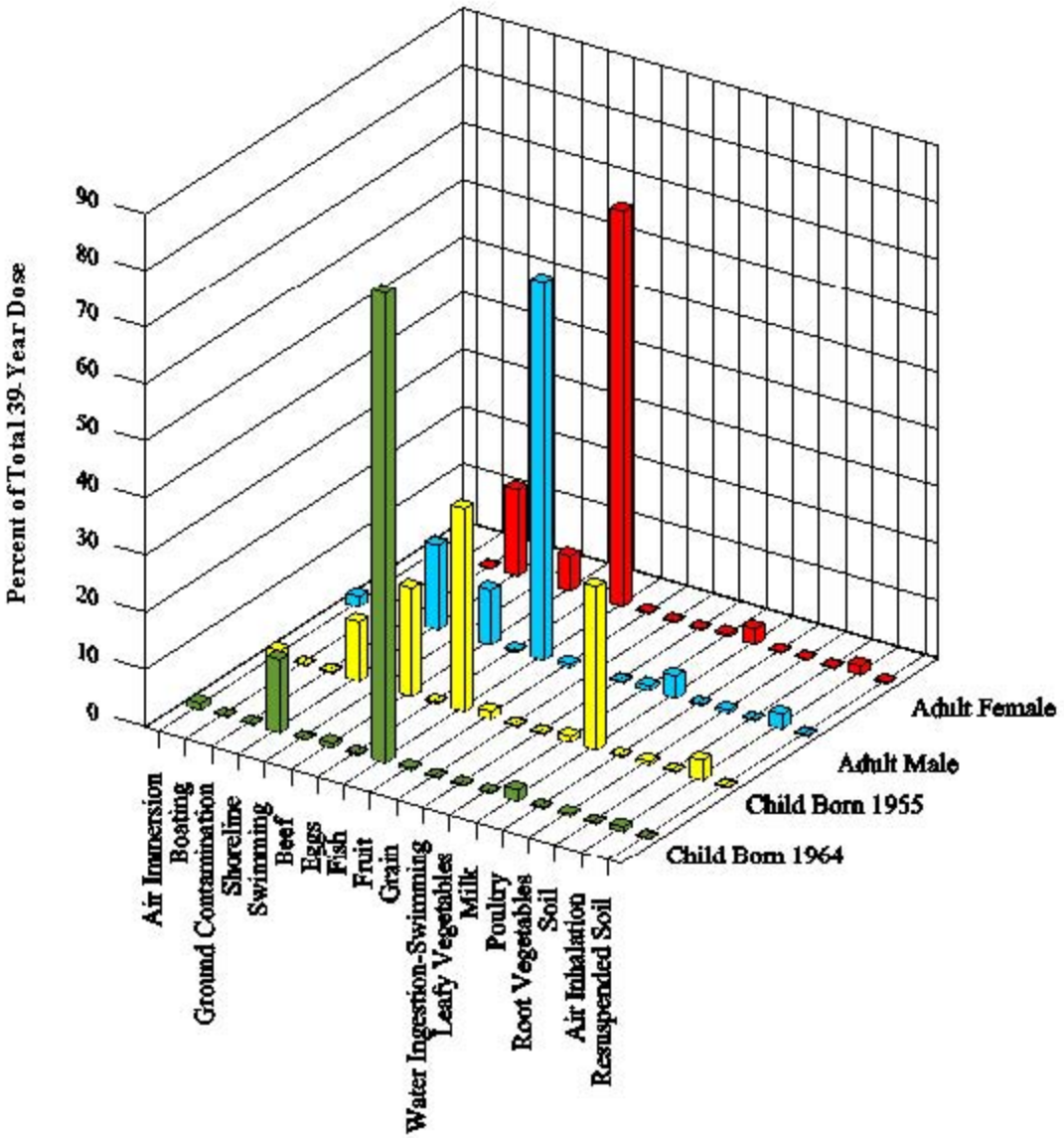

Figure 11-54 Percent of 39-Year Effective Dose by Exposure Pathway for Near River Family

11.3 References

1. International Commission on Radiation Protection (ICRP) (1991). Recommendations of the International Commission on Radiation Protection. ICRP Publication 60. Pergamon Press. Oxford, England.

2. U.S. Environmental Protection Agency (EPA) (2002, April). Federal Guidance Report 13: CD Supplement. EPA 402-C-99-001, Rev. 1. Oak Ridge National Laboratory and U.S. EPA.