13 CONCLUSIONS AND RECOMMENDATIONS

13.1 Introduction

This chapter discusses conclusions and recommendations based on the analyses described in the preceding chapters. Most of the conclusions relate to the results of the analyses, not the methods used to obtain results. The recommendations are intended to address unresolved issues that have arisen during the course of the work. The Savannah River Site Health Effects Subcommittee (SRSHES) raised some of these unresolved issues during presentations and discussions on this work. Other unresolved issues arise from the analysis but have not been resolved because they are beyond the scope of the current task. In general, while the resolution of these issues is not expected to change the major conclusions of this work, it is expected to enhance confidence in the conclusions.

13.2 Conclusions

The following bullets summarize the major conclusions of this dose reconstruction. These conclusions are then described in greater detail in the subsequent subsections.

- Doses and risks are small for all receptors and scenarios relative to doses and risks from background radiation over the 39-year period of the study.
- For people who ate fish from the Savannah River or Lower Three Runs Creek, fish ingestion was the most significant pathway, and the most important radionuclides were generally ^{137}Cs, ^{32}P, and ^{90}Sr.
- For people who did not eat fish from bodies of water contaminated by releases of radionuclides to water, milk and beef were the most significant pathways and ^{131}I and tritium were the most important radionuclides.
- Immersion in ^{41}Ar was a generally small, but constant contributor to dose; however, for some receptors, it was the largest fraction of a small dose.
- Larger doses occurred in years corresponding to larger releases from the Savannah River Site (SRS), especially ^{131}I; for the Adult Male, Adult Female, and Child Born in 1955, a large fraction of the total dose was received during the years 1955-1961.
- There were important differences in doses, pathway significance, and radionuclide significance between children born in 1955 and children born in 1964—those born in 1955 experienced the large I releases early in the site history, while those born in 1964 did not experience them.
- Doses caused by ingesting fish from Lower Three Runs Creek were significantly higher than doses caused by ingesting fish from the Savannah River.
- For air releases, the variations in air dispersion of radionuclides from the site generally produced a significant, but not dominant, variation in estimated doses.
- Consideration of uncertainty in the variables used to estimate doses could cause an estimated dose to be higher or lower than the corresponding point-estimate result. The mean of the distribution of total dose for any receptor ranged between 2.15 to 1.07 times the corresponding point-estimate dose; thus, the means of the uncertain doses were close to the corresponding point-estimate values.
- The use of hypothetical scenarios to demonstrate the interactions of a range of receptor behaviors with the site and release characteristics was an effective analytical tool.

13.2.1 Doses and Risks Are Small

Calculated doses and risks to the hypothetical receptors appear to be small. The largest point-estimate dose was 9.4 milliSieverts (mSv) (0.94 rem) over the 39-year period studied for the Outdoor Family Child Born in 1955; the corresponding risk of cancer incidence is 0.10 percent, and the corresponding risk of cancer fatality is 0.024 percent. By way of comparison, the annual average radiation exposure for a member of the U.S. population is about 3.6 mSv (0.36 rem) (1), mainly from naturally occurring sources of radiation and medical sources (e.g., x rays). An annual background dose of 3.6 mSv over a period of 39 years would produce a dose of 140 mSv (14 rem).

Although estimated doses (and the risks of cancer incidence) were higher when uncertainties in variables were considered, the increases are not sufficient to change this conclusion. For example, when uncertainties were considered, the Outdoor Family Child Born in 1955 received the largest mean dose of 13 mSv (1.3 rem) and the largest median dose of 11 mSv (1.1 rem). However, the maximum dose for the same receptor was 60.3 mSv (6 rem) and the minimum dose for the same receptor was 2.53 mSv (0.25 rem).

13.2.2 Important Exposure Pathways and Radionuclides

Chapter 11 discusses the point-estimate doses for each receptor within each of the seven scenarios, including the contributions to these doses by the various radionuclides and exposure pathways. Although each scenario and each receptor within the scenario demonstrated unique characteristics, some generalizations can be made about the radionuclides and exposure pathways contributing most to dose. For any given realization in the uncertainty analysis, the importance of the various radionuclides and scenarios could be different; however, the same general trends that occur in the point-estimate analysis appear to be present. Other conclusions from the uncertainty analysis are presented in Section 13.2.8.

For scenarios exposed to water releases through ingestion of fish taken from the Lower Three Runs Creek and the Savannah River downstream of the SRS (Delivery Family, Outdoors Family, and Near River Family), the dominant radionuclides were ^{137}Cs, ^{90}Sr, and ^{32}P. Table 13-1 shows the fraction of dose resulting from fish ingestion for the 12 receptors in the 3 scenarios exposed to water releases. In many cases (8 out of 12), the percentage of dose from fish ingestion is greater than 50 percent. For 83 percent of the receptors (10/12), fish ingestion was the largest source of dose. Beef ingestion edged out fish ingestion for the two remaining receptors.

Table 13-2 shows the percent of total dose over 39 years for a selected set of radionuclides. ^{137}Cs, ^{90}Sr, and ^{32}P were the dominant radionuclides for exposures to water releases by fish ingestion. This is shown most clearly by the large percentage of dose from these isotopes for all members of the Delivery Person Family. However, for the Child Born in 1955 for the Delivery Person Family, ^{131}I (from ingestion of terrestrial foods contaminated by air releases) was a significant source of dose; for the Children Born in 1964 in the Outdoors Family and the Near River Family, ^{32}P was the most important isotope. For the Adults in the Near River Family, ^{137}Cs was the most important radionuclide. For the Adults in the Outdoors Family, ^{131}I was the most important radionuclide.

Thus, it can be seen that the fish ingestion pathway accounted for a large fraction of the dose for most of the receptors exposed to water releases. The important radionuclides producing dose through this pathway depended, in part, on the timing of the exposure; for Children Born in 1964, important radionuclides tended to shift from ^{137}Cs to ^{32}P for water resources (see Section 13.2.5 for additional discussion). In addition, for the Children Born in 1955, ^{131}I, which is not related to fish ingestion, was an important isotope (the most important isotope for two scenarios).

Table 13-1 Percent of Total Dose from Fish Ingestions for Various Receptors in the Three Scenarios Exposed to Water Releases

Scenario	Receptor	Percent of Total Dose from Fish Ingestion
Delivery Person Family	Adult Female	92.8*
	Adult Male	90.2*
	Child Born in 1955	57.9*
	Child Born in 1964	92.9*
Outdoors Family	Adult Female	48.2*
	Adult Male	34.6
	Child Born in 1955	11.8
	Child Born in 1964	79.3*
Near River Family	Adult Female	71.0*
	Adult Male	66.2*
	Child Born in 1955	35.4*
	Child Born in 1964	82.3*

*For these receptors, fish ingestion was the largest source of dose.

Table 13-2 Percent of Total Dose from Fish Ingestions for Various Receptors in the Three Scenarios Exposed to Water Releases

Scenario	Receptor	Percent of Total Dose				
		^{137}Cs	^{90}Sr	^{32}P	^{131}I	Sum
Delivery Person Family	Adult Female	77.0	9.7	4.3	4.3	95.3
	Adult Male	74.8	9.5	4.2	6.0	94.5
	Child Born in 1955	39.8	11.3	5.4	37.9	94.4
	Child Born in 1964	49.5	25.1	15.0	*	89.6
Outdoors Family	Adult Female	18.8	*	17.5	42.2	59.7
	Adult Male	14.4	*	12.6	45.3	57.9
	Child Born in 1955	2.5	1.6	6.0	82.9	93.0
	Child Born in 1964	8.5	5.0	57.5	4.7	75.7
Near River Family	Adult Female	29.7	6.5	25.4	10.8	72.4
	Adult Male	28.1	6.2	24.1	14.5	72.9
	Child Born in 1955	9.0	5.0	18.0	50.8	82.8
	Child Born in 1964	10.9	5.7	59.7	*	76.3

*5% or less.

Thus, it can be seen that the fish ingestion pathway accounted for a large fraction of the dose for most of the receptors exposed to water releases. The important radionuclides producing dose through this pathway depended, in part, on the timing of the exposure. For the Children Born in 1964, the important radionuclides tended to change from ^{137}Cs to ^{32}P for water releases (see Section 13.2.5 for additional discussion). In addition, for the Children Born in 1955, ^{131}I, which is not related to fish ingestion, was an important isotope (the most important isotope for two scenarios).

13.2.3 Important Exposure Pathways and Radionuclides for Air Releases

(Note: the general comments made in the initial paragraph of Section 13.2.2 apply here as well.) For scenarios not exposed to water releases by ingesting fish (Rural Families One and Two, Urban/Suburban Family, Migrant Family), the most significant radionuclides were ^{131}I and tritium, and the most significant exposure pathways were ingestion of milk and beef.

Table 13-3 shows the percent of total dose from beef and milk ingestion, and the combination for scenarios not exposed to water releases from the SRS. Of these receptors, 75 percent (12/16) obtained more than half their dose from these two pathways. For the remaining four receptors, these two pathways together accounted for the largest fraction of dose with air immersion also an important pathway.

Table 13-3 Percent of Total Dose from Beef and Milk Ingestion, and the Combination, for Scenarios not Exposed to Water Releases from the SRS

Scenario	Receptor	Percent of Total Dose from Beef Ingestion	Percent of Total Dose from Milk Ingestion	Sum of Percent from Two Pathways
Rural Family One	Adult Female	50.7	16.1	66.8
	Adult Male	57.1	15.3	72.4
	Child Born in 1955	43.2	43.9	87.1
	Child Born in 1964	15.3	35.4	50.7
Rural Family Two	Adult Female	52.4	16.1	68.5
	Adult Male	58.8	15.3	74.1
	Child Born in 1955	43.7	44.2	87.9
	Child Born in 1964	14.6	32.4	47.0
Urban/Suburban Family	Adult Female	42.6	24.1	66.7
	Adult Male	27.4	13.1	40.5
	Child Born in 1955	30.4	55.7	86.1
	Child Born in 1964	11.6	31.7	43.3
Migrant Family	Adult Female	52.1	11.6	63.7
	Adult Male	58.7	11.0	69.7
	Child Born in 1955	48.2	36.2	84.4
	Child Born in 1964	17.8	22.4	40.2

*Since the Migrant Worker Family was only present near the SRS for six months, it may be more appropriate for comparison purposes to double these doses.

Table 13-4 shows the percent of total dose from ^{131}I, tritium, and ^{41}Ar, and their combination, for scenarios not exposed to water releases from the SRS. In these families, the Adult Male, Adult Female, and Child Born in 1955 had most of their dose from ^{131}I from a combination of ingesting milk and beef. In these same families, the Child Born in 1964 had most of its dose from tritium from a combination of ingesting milk and beef.

Table 13-4 Percent of Total Dose from ^{131}I, tritium, and ^{41}Ar, and their Combination, for Scenarios not Exposed to Water Releases from the SRS

Scenario	Receptor	Percent of Total Dose			
		^{131}I	Tritium	^{41}Ar	Total
Rural Family One	Adult Female	73.8	12.0	8.0	93.8
	Adult Male	76.9	11.3	5.7	93.9
	Child Born in 1955	93.3	3.8	1.5	98.6
	Child Born in 1964	9.3	63.9	16.6	89.8
Rural Family Two	Adult Female	76.5	9.9	7.7	94.1
	Adult Male	79.4	9.4	5.5	94.3
	Child Born in 1955	94.2	3.0	1.4	98.6
	Child Born in 1964	10.4	59.9	18.8	89.1
Urban/ Suburban Family	Adult Female	75.5	14.1	5.1	94.7
	Adult Male	50.0	10.6	34.8	95.4
	Child Born in 1955	93.5	3.5	2.1	99.1
	Child Born in 1964	9.9	63.9	18.8	92.6
Migrant Family*	Adult Female	74.7	8.9	8.6	92.2
	Adult Male	77.9	8.4	6.2	92.5
	Child Born in 1955	93.7	2.8	1.8	98.3
	Child Born in 1964	10.7	52.4	23.1	86.2

*Since the Migrant Worker Family was only present near the SRS for six months, it may be more appropriate for comparison purposes to double these doses.

Thus, it can be seen that two ingestion pathways (milk and beef ingestion) accounted for a large fraction of the dose for most of the receptors exposed only to air releases of radionuclides. The important radionuclides producing dose through these pathways depended, in part, on the timing of the exposure; for the Children Born in 1964, important radionuclides tended to shift from ^{131}I to tritium for air releases (see Section 13.2.5 for additional discussion); for the other receptors, ^{131}I was the most important radionuclide.

13.2.4 Significance of Immersion Dose from ^{41}Ar

Releases of ^{41}Ar produced a small but persistent dose for all receptors from immersion in the plume. Generally, doses of 0.02 to 0.09 mSv (2 to 9 millirem [mrem]) over 39 years were produced. An exception was the Adult Male for the Outdoors Family who received 0.31 mSv (31 mrem) over 39 years. In most cases, this air-immersion dose was minor, but for receptors with small doses from other sources, it could be a significant contributor. For example, for the Child Born in 1964, air-immersion dose from

^{41}Ar accounted for almost 17 percent of the total dose in Rural Family One and almost 24 percent of the total dose in Rural Family Two and the Urban/Suburban Family. Immersion dose accounted for almost 39 percent of the dose to the Adult Male in the Urban/Suburban Family principally because he worked a significant amount of time onsite. For scenarios exposed to water releases, the percentage of dose from air immersion was generally small (less than 10 percent) for all receptors.

13.2.5 Major Dose Fraction for many Receptors from Large Releases in 1955-1961

Large releases of ^{131}I that occurred at the SRS in a period around 1955 to 1961 produced a major fraction of the dose in many receptors. This is shown in the tables of annual effective dose as a function of time in Chapter 11 (i.e., Tables 11-4, 11-7, 11-10, 11-13, 11-16, 11-19, and 11-22). Because the Children Born in 1964 did not experience these large ^{131}I releases, their doses tended to result from other radionuclides, principally tritium and ^{137}Cs. The Adult Female, Adult Male, and Child Born in 1955 for those scenarios exposed only to air releases had a majority of their dose from ^{131}I releases during this time frame. For those scenarios exposed to water releases, the Adult Female, Adult Male, and Child Born in 1955 had a significant fraction of dose delivered in later years (mid-1960's), when the liquid releases were greater. In some cases, the majority of the dose came from these later water releases, but this depends on the degree to which doses from fish ingestion dominate.

13.2.6 Differences in Children Born in 1955 and 1964

Significant differences exist between doses for Children Born in 1955 and Children Born in 1964, and these differences are observed to greater or lesser degrees in all seven scenarios. These differences in doses include the magnitude of the doses, the radionuclides primarily responsible for producing the doses, and the exposure pathways through which the doses are received. Table 13-5 compares for Children Born in 1955 to the Children Born in 1964 for each scenario: 1) the total doses, 2) the radionuclide/pathway pair contributing most to this dose, and 3) the fraction of the total dose accounted for by this major radionuclide/pathway pair.

For the first four scenarios in Table 13-5, which are only exposed to air releases from the SRS, the differences between the Child Born in 1955 and the Child Born in 1964 are similar. Considering the Child Born in 1955, for three out of four scenarios the pathway was beef ingestion and the radionuclide was ^{131}I; for the remaining scenario, the pathway was milk ingestion but the radionuclide remained ^{131}I. The contribution to total dose was about 40 percent in three cases and 70 percent in one case. This shows that that the large ^{131}I releases early in the site history dominate the dose mechanisms for the Children Born in 1955. Considering the Child Born in 1964, for three out of four scenarios the pathway was milk ingestion and the radionuclide was tritium; for the remaining scenario, the pathway was air immersion and the radionuclide was ^{41}Ar. The contribution to total dose was about 25 percent in three cases and 37 percent in one case. This behavior illustrates that because the Children Born in 1964 did not experience the large ^{131}I releases early in the site history, radionuclides other than ^{131}I and its dominant pathways became more evident. However, the dominance of doses caused by these other radionuclides is smaller than those caused by the early releases of ^{131}I. Both ^{41}Ar and tritium were more persistently released over time than ^{131}I.

For the last three scenarios in Table 13-5, the children are exposed to both air and water releases from the SRS. For the Outdoor Family and the Near River Family, the air release of ^{131}I caused the dominant dose for the Children Born in 1955; however, the dominant pathway for the Outdoor Family is beef ingestion and milk ingestion for the Near River Family. For the Children Born in 1964 for the Outdoor Family and the Near River Family, the dominant pathway is fish ingestion and the dominant radionuclide is ^{32}P; in both scenarios, about 60 percent of the dose is produced this way. For the Delivery Person Family, unlike the other scenarios in Table 13-2, the Children Born in 1955 and 1964 have the same dominant pathway

and dominant radionuclide; for both, about 40-50 percent of the dose is caused by fish ingestion and ^{137}Cs. This is the result of the very high doses produced by ingesting fish taken from Lower Three Runs Creek.

Table 13-5 Comparison of the Dominant Cause of Dose for Children Born in 1955 and Children Born in 1964 for all Seven Scenarios

Scenario	Child Born in	Dose (mSv/mrem)	Major Radionuclide-Pathway Pair		Percent of Total Dose
Rural Family One	1955	1.6/160	^{131}I	Beef Ingestion	42
	1964	0.072/7.2	Tritium	Milk Ingestion	29
Rural Family Two	1955	3.8/380	^{131}I	Beef Ingestion	43
	1964	0.14/14	Tritium	Milk Ingestion	26
Urban/Suburban Family	1955	2.7/270	^{131}I	Milk Ingestion	70
	1964	0.11/11	Tritium	Milk Ingestion	37
Migrant Worker Family*	1955	2.2/220	^{131}I	Beef Ingestion	37
	1964	0.083/8.3	^{41}Ar	Air Immersion	23
Delivery Person Family	1955	5.2/520	^{137}Cs	Fish Ingestion	40
	1964	2.1/210	^{137}Cs	Fish Ingestion	49
Outdoors Family	1955	9.4/940	^{131}I	Beef Ingestion	46
	1964	1.8/180	^{32}P	Fish Ingestion	57
Near River Family	1955	3.1/310	^{131}I	Milk Ingestion	27
	1964	1.8/180	^{32}P	Fish Ingestion	60

*Since the Migrant Worker Family was only present near the SRS for six months, it may be more appropriate for comparison purposes to double these doses.

In short, for all but the Delivery Person Family, the scenarios show a distinct difference in the size and dominant causes of dose between the Children Born in 1955 and 1964.

13.2.7 Importance of Lower Three Runs Creek Fish Ingestion Dose

The annual concentration of a radionuclide in the Savannah River was estimated by dividing the estimated total liquid release of the radionuclide from the SRS in a given year by the annual volume of flow in the Savannah River. For Lower Three Runs Creek, measured concentrations were used for tritium, ^{137}Cs, and ^{90}Sr. Generally, the concentrations in Lower Three Runs Creek were substantially higher than in the Savannah River. For example, the ratios of peak concentrations in the two bodies of water were 23, 10, and 6, respectively, for tritium, ^{137}Cs, and ^{90}Sr. As a consequence, eating fish taken from Lower Three Runs Creek produced higher doses for those receptors so exposed. Table 13-6 demonstrates this trend quantitatively and shows doses to the Adult Female in three scenarios: Rural Family One, the Near River Family, and the Delivery Family.

These three families received, respectively, 0, 100, and 50 percent of their fish from the Savannah River and, respectively, 0, 0, and 50 percent of their fish from Lower Three Runs Creek. When the doses from water releases for the Adult Females in the Near River Family and the Delivery Family are compared, there is a significant difference in dose (i.e., 1.8 mSv [180 mrem] for the Near River Family versus 5.7

mSv [570 mrem] for the Delivery Family). This difference in dose was produced by ingesting the same quantity of fish in both scenarios. However, for the Delivery Family Adult Female, 50 percent of the fish ingested came from Lower Three Runs Creek; for the Near River Family Adult Female, 100 percent of the fish ingested came from the Savannah River. By replacing 50 percent of the fish consumed from the Savannah River with fish from Lower Three Runs Creek, the dose from water releases was increased by more than a factor of three. By assuming the dose is linearly proportional to the quantity consumed from the two sources, an algebraic manipulation shows that if a scenario obtained 100 percent of the fish it consumes from Lower Three Runs Creek, the dose to the Adult Female would be 9.6 mSv (960 mrem). This implies that the contamination level in the water (and therefore in the fish ingested) is on average a factor of 5 greater in Lower Three Runs Creek than in the Savannah River. This is generally consistent with the concentration data presented in Chapter 7 for Cs-137 concentrations in the two bodies of water.

Table 13-6 Comparison of Fish Consumption and Dose for the Adult Female by Family Location

% of Dose From Fish Consumed from Different Sources	Rural Family #1	Near River Family	Delivery Family
Lower Three Runs Creek	0	0	50
Savannah River	0	100	50

	Dose (mSv/mrem)	Percent	Dose (mSv/mrem)	Percent	Dose (mSv/mrem)	Percent
Total Dose	0.3/30	100	2.1/211	100	6.1/610	100
Water Release Dose	0/0	0	1.8/180	85	5.7/570	93
Air Release Dose	0.3/30	100	0.3/31	15	0.4/40	7

13.2.8 Variations in Air Dispersion Significant but not Dominant

In this study, careful attention was paid to the geographical locations of the releases to air from the SRS, the geographical locations of various receptors, and the air-dispersion patterns at the SRS. One might be tempted to compare total doses from air releases to measure the impact of air dispersion; however, total dose from air releases is not a good indicator of the importance of air-dispersion variability because it does not directly reflect the concentrations experienced at the residence location for a particular receptor. The following are some of the complicating factors that prevent total dose from being a good indicator of air dispersion at the primary exposure locations:

- For several scenarios, foodstuffs (milk, deer meat, and beef) were brought to the residence location from other exposure locations (including the SRS) as mandated by the scenario specifications.
- In other cases, the receptor (especially the Adult Male) experienced exposure at a work location (including the SRS).

However, dose to the Adult Female by air immersion is a relatively good indicator of the differences due to variations in air dispersion. This is because the Adult Female was assumed to stay most of the time at the residence location (except for small amounts of time spent in recreation or at church) and because air

immersion is a good surrogate for the time integral of concentration of gamma-emitting radionuclides at the residence location.

Table 13-7 compares air-immersion doses for the Adult Female in all seven scenarios. Note that the ratio of these doses to the average dose over the seven scenarios is generally different by less than a factor of 2. The largest deviation from the average is for the Urban/Suburban Family, which has a dose smaller than the average by a factor of 2.6.

Table 13-7 Air-Immersion Doses for the Adult Female in Each Scenario as a Measure of the Effects of Air-Dispersion Differences

Scenario	Air Immersion Dose for Adult Female (mSv/mrem)	Ratio of Dose to Average Dose
Rural Family One	0.024/2.4	0.544
Rural Family Two	0.054/5.4	1.223
Urban/Suburban Family	0.017/1.7	0.385
Migrant Family*	0.039/3.9	0.883
Delivery Person Family	0.055/5.5	1.246
Outdoors Family	0.084/8.4	1.903
Near River Family	0.036/3.6	0.816
Average	0.044/4.4	

*Since the Migrant Worker Family was only present near the SRS for six months, it may be more appropriate for comparison purposes to double this dose.

Comparing the dose for each scenario to the average is parallel to quantifying "tallness" by comparing a person's height to the average height. Although comparing the maximum dose to the minimum dose accentuates the differences in the variation across the site, the ratio in this case is 4.9—a significant but not dominant contributor to variations among receptors. The ratio of maximum total dose to minimum total dose is over 130 as shown in Table 11-2. This implies that many factors other than air dispersion have a significant effect on determining total dose to each receptor. That is, the variations that accentuate differences (e.g., time spent at different locations, quantities of foods ingested from different locations) are more significant than the air-dispersion differences related to average meteorological conditions, receptor locations, and source locations. However, this conclusion excludes consideration of onsite exposures. Due to the proximity of the onsite location to the air-release sources, significantly higher contamination and concentration levels were experienced onsite.

13.2.9 Variable Uncertainty Generally Raises Dose Estimates Slightly

Chapter 12 provides a description of the uncertainty analysis. Consideration of uncertainty in the variables used to estimate doses could cause an estimated dose to be higher or lower than the corresponding point-estimate result. Comparison of the results from the uncertainty analysis to the point-estimate analysis shows that on average the estimated doses from the uncertainty analysis are higher. Table 12-9 compares the mean and median doses from the uncertainty analysis to the point-estimate dose for each of the 28 specified receptors. The ratios of the mean doses to the corresponding point-estimate doses range from a high of 2.15 to a low of 1.07; similarly, the ratio of the median doses to the corresponding point-estimate doses range from a high of 1.54 to a low of 0.86. Thus, the means and medians of the uncertain doses were close to the corresponding point-estimate values. These results

illustrate the behavior of the central tendencies (the means and medians) of the estimated dose distributions.

As discussed in Section 12.5.1, the lognormal distribution is a reasonable fit to the uncertain distributions of dose for each receptor. It is not surprising that most of the uncertain dose distributions could be well described by a lognormal distribution because most of the variables modeled as uncertain in the uncertainty analysis were assigned lognormal distributions based on the information available. Although the receptor doses are not simple functions of the uncertain variables, the general shape of the lognormal distributions used to describe those variables is evident in the receptor dose distributions. Lognormal distributions are skewed toward higher values. For this type of distribution, the mean is always higher than the median. This behavior is evident if the extreme values of the dose distributions are examined. For example, on average, the ratio of the maximum dose from the uncertainty analysis to the point-estimate dose for the same receptor is 7.8. The maximum value of this ratio is 11.5 for the Urban/Suburban Family Child Born in 1955. In addition, on average the ratio of the minimum dose from the uncertainty analysis to the point-estimate dose for the same receptor is 0.36; the minimum value of this ratio is 0.13 for the Urban/Suburban Family Child Born in 1955. In other words, on average, the maximum value is 7.8 time higher than the point estimate while the minimum value is 2.8 times smaller than the point-estimate value.

The medians of the lognormal distributions describing the uncertain input variables were set equal to the variable value used to generate the point estimate. However, except for the Urban/Suburban Family, all the median doses were higher than their corresponding point-estimate doses. This somewhat surprising result seems to be related to several aspects of the analysis, including the properties of the models used to compute the dose and the large uncertainty for some variables. In particular, for scenarios in which exposure to liquid releases by fish ingestion was a dominant pathway, variations in the uptake factors for ^{137}Cs, ^{90}Sr, and ^{32}P seemed to combine in a manner that assured the median doses would be higher than the point-estimate doses.

Although the dose estimates derived by considering uncertainty in the input variables were larger than the point-estimate doses, the means and medians of the uncertain doses were generally no more than a factor of 2 larger than the point-estimate doses. Although this underscores the importance of performing an uncertainty analysis, the basic conclusion of low doses and risks does not change when uncertainty is considered.

13.2.10 Effectiveness of Scenarios

As described in Chapters 1, 3, and 4, the definition and use of hypothetical scenarios to span the range of realistic receptor behavior was an important aspect of implementing this dose reconstruction. The scenarios defined sets of hypothetical receptors whose doses and risks would reflect the interaction of the receptor behaviors with the site and release characteristics. As indicated by many of the conclusions listed previously, this strategy was successful in illustrating how the released radioactive materials interacted with different behavior patterns to yield a range of doses produced by different radionuclides and pathways. In particular, the hypothetical scenarios disclosed:

- A range of 39-year doses that spanned two orders of magnitude.
- Generally higher doses for scenarios in which receptors were exposed to liquid and air releases from the SRS than for scenarios in which receptors were exposed only to air releases. For scenarios exposed to liquid and air releases, fish ingestion was generally the most important pathway and ^{137}Cs the most important radionuclide; for scenarios exposed only to air releases, milk and beef ingestion were the most important pathways, and ^{131}I was generally the most important radionuclide.

- The Children Born in 1955 had substantially different doses and causes for doses than the Children Born in 1964.
- The scenario for obtaining fish from Lower Three Runs Creek experienced higher doses than scenarios for obtaining fish from the Savannah River or from waters not affected by liquid releases from the SRS.

Because use of the scenarios was able to provide this kind of information, use of hypothetical scenarios in this context is supported and the utility of the scenario definitions is confirmed.

13.3 Recommendations

Unresolved technical issues have arisen during the course of the work from two sources: 1) meetings of the SRSHES and 2) the analytical team performing the work. Some of these unresolved issues were raised at public meetings during which this work was presented and discussed. These public meetings were held in the following cities:

- Charleston, South Carolina—March 2003.
- Savannah, Georgia—September 2003.
- Columbia, South Carolina—August 2004.

Other unresolved issues arose during the development of the approach and the analysis of results. These issues have not been addressed to date because they fall generally beyond the scope of the present task. Performing this work is not likely to change the major conclusions listed in the previous section. However, performing this work can be expected to resolve a number of technical issues and thereby enhance confidence in the current conclusions. The following is a list of the recommendations which are then described briefly in the subsequent subsections:

- Look at large, acute releases to see if the pattern of doses would be changed significantly.
- Examine the buildup of long-lived radionuclides in soil to determine if terrestrial doses change significantly.
- Model contamination in reservoirs to see if it causes significant doses.
- Compare modeled concentrations in foodstuffs (fruit, vegetables, grain, beef, deer, etc.) with monitoring data for model validation.
- Perform an auxiliary analysis to determine if the breast-feeding of infants changes dose substantially.
- Perform an auxiliary analysis to determine how in-utero doses change total dose and cancer risk.
- Model consumption of venison more carefully to see if the result changes.
- Model dose from the consumption of drinking water taken from the Savannah River for municipal water supplies some distance downstream from the SRS (i.e., the municipal water intakes at Port Wentworth, Georgia, and Hardeeville, South Carolina, for Beaufort and Jasper Counties).
- Obtain technical peer review of the study by publishing papers on the methods and results in peer-reviewed journals.

The following sections discuss each recommendation briefly.

13.3.1 Acute Releases vs. Annual Average Releases

This present analysis was performed assuming that the reported SRS annual releases occurred uniformly throughout each year. In fact, the Phase II report clearly documents that these annual reported releases

included some acute releases (i.e., relatively large releases over short periods of time). Because the acute releases were subject to air-dispersion conditions during the time of their release, the doses from such acute releases may not have been accurately portrayed by using the multi-year average meteorology that is more appropriate for routine, relatively constant releases. It is recommended that the importance of modeling air releases as acute instead of chronic, annual releases be determined by computing doses for the largest acute releases in two ways: 1) modeled as acute releases with air-dispersion conditions corresponding to the time of release and 2) modeled as chronic releases using the multi-year average meteorology. Differences in dose estimates for the two computational approaches would help to determine whether the approach used in this study has sufficient precision. Only a few of the largest acute releases (the largest 10-25) would need to be studied to make the determination. One problem in performing this evaluation is that air-dispersion conditions were not measured onsite in the early years when many of the larger acute releases occurred. This may introduce additional uncertainty into the evaluation because onsite air-dispersion conditions would need to be extrapolated from nearby but offsite weather stations.

13.3.2 Evaluate Soil Buildup of Long-Lived Radionuclides

A preliminary evaluation was performed while developing the analytical approach to estimate the importance of the buildup of long-lived radionuclides in soil. Because soil buildup did not appear to be significant, the dose modeling was performed without taking into account residual contamination that might have remained in the soil from one year to later years (i.e., the dose from each year was assumed to result only from the releases during that year). A more detailed examination could confirm that this dose from residual radioactivity in the soil was indeed negligible. Because dose pathways associated with such soil buildup were not significant, it is unlikely that the residual doses will be significant. For example, uptake of radionuclides by plant roots from the soil was much smaller than uptake from radionuclides deposited on plant surfaces; also, ground plane dose, which would be increased by residual soil contamination, was a very minor pathway. It is recommended that for a few scenarios (air-release-only scenarios will likely show the largest effect) doses be computed by accounting for soil buildup of radionuclides from one year to the following years to quantify the importance of this effect.

13.3.3 Evaluate Significance of Reservoir Contamination

Air releases of radionuclides could contaminate bodies of water used for drinking in two ways: 1) direct deposition of radionuclides from the air into the body of water (lake, pond, or reservoir) and 2) deposition of radionuclides onto the surface water basin of the water body and subsequent migration to the water body by surface runoff. These transport pathways were not modeled because more direct pathways (i.e., deposition of airborne radionuclides onto crops in the food chain and ingestion of fish from water bodies contaminated directly by SRS water releases) appeared to be more likely to produce significant doses. It is recommended that airborne contamination of otherwise uncontaminated water bodies be modeled to determine the significance of the contamination produced and the potential doses from the contamination. This will indicate whether the dose estimates produced by this study have sufficient precision.

13.3.4 Compare Modeled Contamination in Foodstuffs to Monitoring Data

As a means of enhancing confidence in this intermediate-phase dose reconstruction, a partial validation of the modeling of releases and environmental transport may be desirable. A partial validation of these aspects of the modeling could be accomplished by comparing intermediate modeling results (such as contamination levels in soil and food) to field measurements. These field measurements are contained in the annual site Environmental Reports. Additional computer computations would be required to obtain these intermediate results because they were not permanently recorded during the previous calculations. It is recommended that this partial validation effort be pursued.

13.3.5 Evaluate Significance of Breast-Feeding Infants

The current study did not model the pathway of breast milk ingestion by infants; instead, ingestion of contaminated cow's milk was modeled. There are methods by which the breast-milk pathway could be modeled. The modeling of the cow's milk pathway, as currently implemented, may be more conservative (i.e., may produce a higher dose). It is recommended that the breast milk pathway be evaluated by some comparative modeling to determine its significance.

13.3.6 Evaluate Significance of In-Utero Doses

Some approaches are available to estimate the fetal doses in-utero from pregnant women experiencing environmental exposures to radiation and radioactivity. The current approach did not include this pathway. It is recommended that some of the scenarios with higher dose levels be analyzed first to determine if the fetal doses are significant.

13.3.7 Refine Modeling of Deer Meat Ingestion

The current approach models contaminated venison as "beef" taken from cattle grazing at the various exposure locations incorporated into the analysis. A more precise approximation to venison contamination may be obtainable by modeling uptake of radionuclides by deer ingestion of various plant species typically ingested by deer; such an approach would require modeling the uptake of radionuclides by these additional plant species. Because ingestion of contaminated beef produced large doses from ^{131}I, a likely outcome from this more precise approach dose from venison ingestion may actually be lower calculated doses to humans. However, it is recommended that this more precise approach be pursued to remove a persistent criticism of the current approach.

13.3.8 Estimate Doses from Drinking Water from the Savannah River

None of the scenarios specified for this study considered receptors located far downstream on the Savannah River (e.g., Port Wentworth, Georgia, and Hardeeville, South Carolina, for Beaufort and Jasper Counties) where river water is used for municipal water supplies. The radionuclide content of this drinking water is carefully monitored to comply with the applicable limits on radionuclide concentrations in drinking water promulgated by the U.S. Environmental Protection Agency. Nevertheless, the residual radioactivity content will produce a dose, although it is likely to be small. A problem in estimating doses from this pathway is that the contribution of radionuclides in the drinking water from the SRS may be difficult to distinguish from the contribution of radionuclides from other sources. It is recommended that doses from this pathway be estimated to address this concern raised by the SRSHES.

13.3.9 Obtain Technical Peer Review

It is recommended that technical peer review be obtained for the methods and results of this study. An important avenue to obtain this type of peer review is by publishing papers on the methods used and the results obtained in peer-reviewed technical journal. In addition, further peer review may be acquired by presenting papers on this study at technical conferences. By vetting this study in the technical literature, confidence in the results will be enhanced.

13.4 References

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