7 RELEASE OF RADIONUCLIDES TO WATER AND TRANSPORT TO AN EXPOSURE LOCATION

This chapter summarizes the Phase III work to estimate the release of radionuclides from the Savannah River Site (SRS) facilities to surface water and their transport by water to locations where hypothetical receptors could be exposed. This work resulted in estimates of the annual concentrations of twenty-two radionuclides at two exposure locations: one in the Savannah River and one in Lower Three Runs Creek. Appendix B lists these annual estimated radionuclide concentrations. This analysis provides the starting point for estimating dose resulting from liquid releases of radionuclides from the SRS. The concentrations of radionuclides in water developed by the methods discussed here are used as input to aquatic food chain transport modeling described in Chapter 8, and external and internal exposure models discussed in Chapter 9.[1]

7.1 Overview of the Problem and Solution

The required end points for considering water releases of radionuclides from SRS facilities are the annual concentrations produced by those releases at locations where receptors might be exposed. These annual concentrations depended on three factors: 1) the exposure locations; 2) the annual radionuclide releases to water from the SRS facilities; and 3) the physical and chemical processes affecting the migration of the radionuclides from the points of release to the exposure locations.

In order to estimate doses from radionuclide releases to water, the GENII[2] code allows the user the flexibility to: 1) specify radionuclide releases to water and the water flow rate for the receiving body of water or 2) specify the radionuclide concentrations. The second option was selected for this study because, as discussed in the following, the estimation of radionuclide concentrations is too complex to perform except external to the GENII code.

7.1.1 Exposure Locations

The scenarios (Chapter 3) outline exposure to radionuclides through various activities, including fishing, hunting, and boating in the SRS vicinity. In order to assess dose from these exposures, it is essential to know the concentrations of radionuclides at the exposure locations. The two locations chosen to represent exposure to water releases from the SRS are:

- The Savannah River below the point of confluence with Lower Three Runs Creek.
- Lower Three Runs Creek at Martin, S.C.

These locations are shown in Figure 7-1.

For this study, the radionuclide concentrations in surface waters are considered to be dependent on liquid releases of radionuclides from SRS facilities to on-site streams and seepage basins. In fact, some radionuclide concentrations in surface waters may have resulted from the deposition of air borne radionuclides onto the surface waters or the land surfaces they drained. These concentrations (and the doses that result from them) are expected to be small compared to the concentrations induced by water releases from SRS facilities. Consequently, exposures of receptors to bodies of water not hydrologically

[1] For Phase III the exposure pathways dependent on water releases of radionuclides include: consumption of fish taken from contaminated river or creek water, external exposure while occupying the shoreline of the contaminated river or creek, external exposure from swimming in the river, inadvertent ingestion of water while swimming in the river, and external exposure from boating on the river

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

downstream of the SRS were assumed to have negligible radionuclide concentrations and were not modeled.

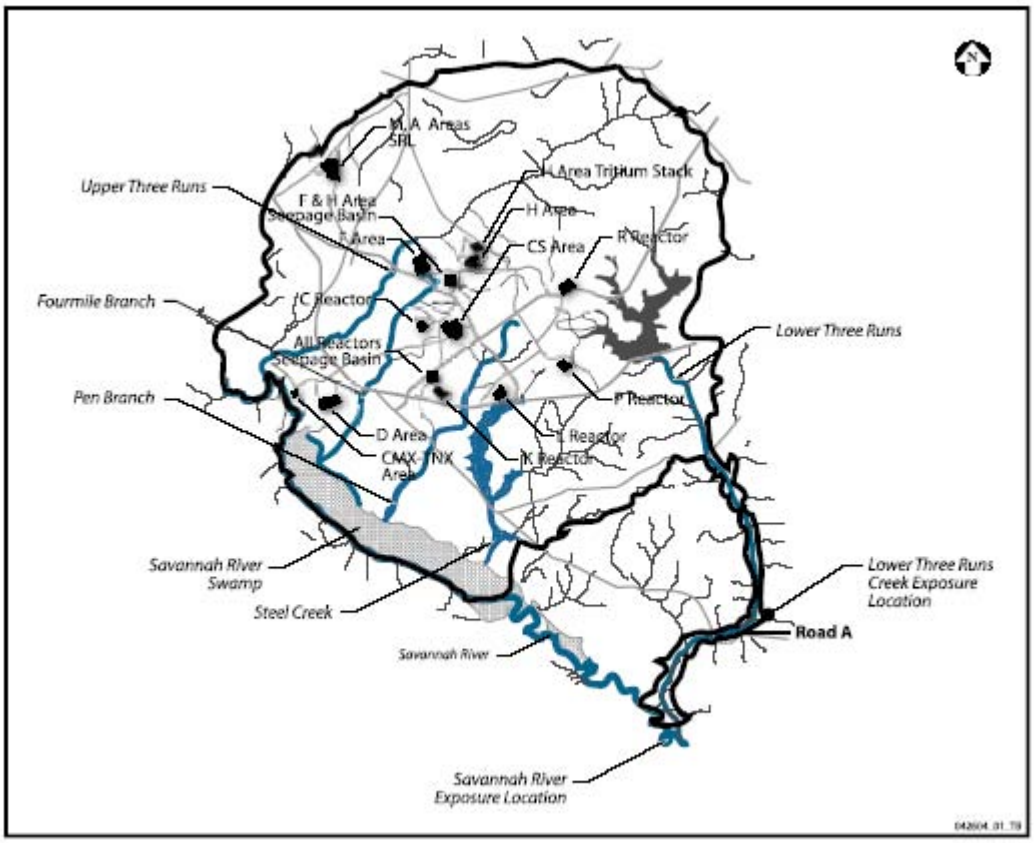

Figure 7-1 Major SRS Sources of Release to Surface Water

7.1.2 Sources of Release to SRS Surface Waters

Figure 7-1 depicts the major facilities releasing radionuclides to surface water bodies on the SRS site:

- The C-, P-, K-, L-, and R-Reactor areas.
- The H- and F-Separations areas.
- The A-Area.
- The M-Area.
- The D-Area and CMS-TNX.
- The Central Shops (CS) Area.

The reactor areas were the sources of most radionuclides released to surface water. Releases from the reactor and separations areas included radionuclides discharged directly to onsite streams as well as radionuclides discharged into seepage basins located in reactor and separations areas. Radionuclides released into seepage basins could leak to underlying sediments and then be carried by groundwater to onsite streams. Surface water releases of radionuclides were highest in the early to middle 1960s and decreased into the 1980s.

7.1.3 Migration of Radionuclides in SRS Surface Waters

As shown in Figure 7-1, there are five major onsite streams that received radionuclides from SRS facilities. Waters from Upper Three Runs Creek, Fourmile Branch, Pen Branch, and Steel Creek pass through a low-lying wetland area adjacent to the Savannah River and the SRS, the Savannah River Swamp, before they discharge into the Savannah River. Water from Lower Three Runs Creek does not pass through the swamp. Figure 7-1 also shows Road A which passes through the SRS from the southeast to the northwest. Road A is significant because environmental monitoring stations are located where Road A crosses these five SRS streams. These Road A monitoring stations are the final points on the SRS site of routine stream monitoring before discharge of the stream water to the Savannah River.

Figure 7-1 illustrates some of the geographic features of the SRS that require consideration while deriving radionuclide concentrations for human contact from surface water. For example:

- Releases to surface water were channeled by way of drainage to one or more of the streams that flowed into the Savannah River. Because of this, radiation exposures could only occur in well-defined geographic locations – i.e., at accessible locations below site discharge points in the Savannah River or along Lower Three Runs Creek.
- Each stream flowing offsite contained the contribution of more than one SRS facility or Area.
- Much liquid effluent was discharged over the years to seepage basins rather than directly to onsite streams. A portion of the radionuclides was eliminated by radioactive decay, which was a major purpose of the seepage basins. Some portion of the volatile and gaseous radionuclides discharged into seepage basins entered the atmosphere, essentially becoming part of the air source term. A portion of the radionuclides in the seepage basins seeped into the soil and entered the groundwater system. Some of this material then seeped into surface streams, where their transportation characteristics were affected by other processes, such as sorption on sediments or migration in the surface water.
- Some of the radionuclides discharged to onsite streams were not immediately transported to locations where the radionuclides could have been contacted by members of the public. (Except for Lower Three Runs Creek, it was assumed that contamination in SRS streams was not accessible by members of the public.) Streams containing radionuclides had to flow for several miles before being discharged to the Savannah River. Through this process many radionuclides may have been sorbed onto stream and swamp sediments, reducing the inventory eventually released offsite.
- All but one (Lower Three Runs Creek) of the major onsite streams discharging radionuclides to the Savannah River passed through the Savannah River Swamp. Because of sedimentation processes characteristic of wetlands, radionuclides were likely deposited into swamp sediments. The swamp, however, historically flooded about 20% of the time. Flooding would tend to re-suspend contaminated sediments and re-dissolve sorbed radionuclides; in this way radionuclides released at earlier times could increase radionuclide content in the Savannah River above that attributed to the site radionuclide releases during a given year.

7.1.4 Summary of Approaches to Estimating Concentrations

Because of these considerations, annual radionuclide concentrations in water at the two exposure locations specified by the Phase III scenarios were estimated by modeling performed outside the GENII computer code. These concentration estimates needed to reflect the complex processes governing radionuclide migration from the release facility to the exposure location; these processes include radioactive decay, surface water transport, sorption on sediments, groundwater transport, sorption on soil, and uptake by biota

Different approaches were used in developing concentration estimates for the Savannah River exposure location and the Lower Three Runs Creek exposure location, because the physical situations for release and transport to these exposure locations were different and the information available to make estimates was different.

As shown in Figure 7-2, the procedure for developing concentration estimates began with the initial, common starting point: those radionuclides identified in Phase II as important for estimating doses. However, as described in the following, different modeling approaches were used for concentration estimates in the Savannah River and those in Lower Three Runs Creek at Martin.

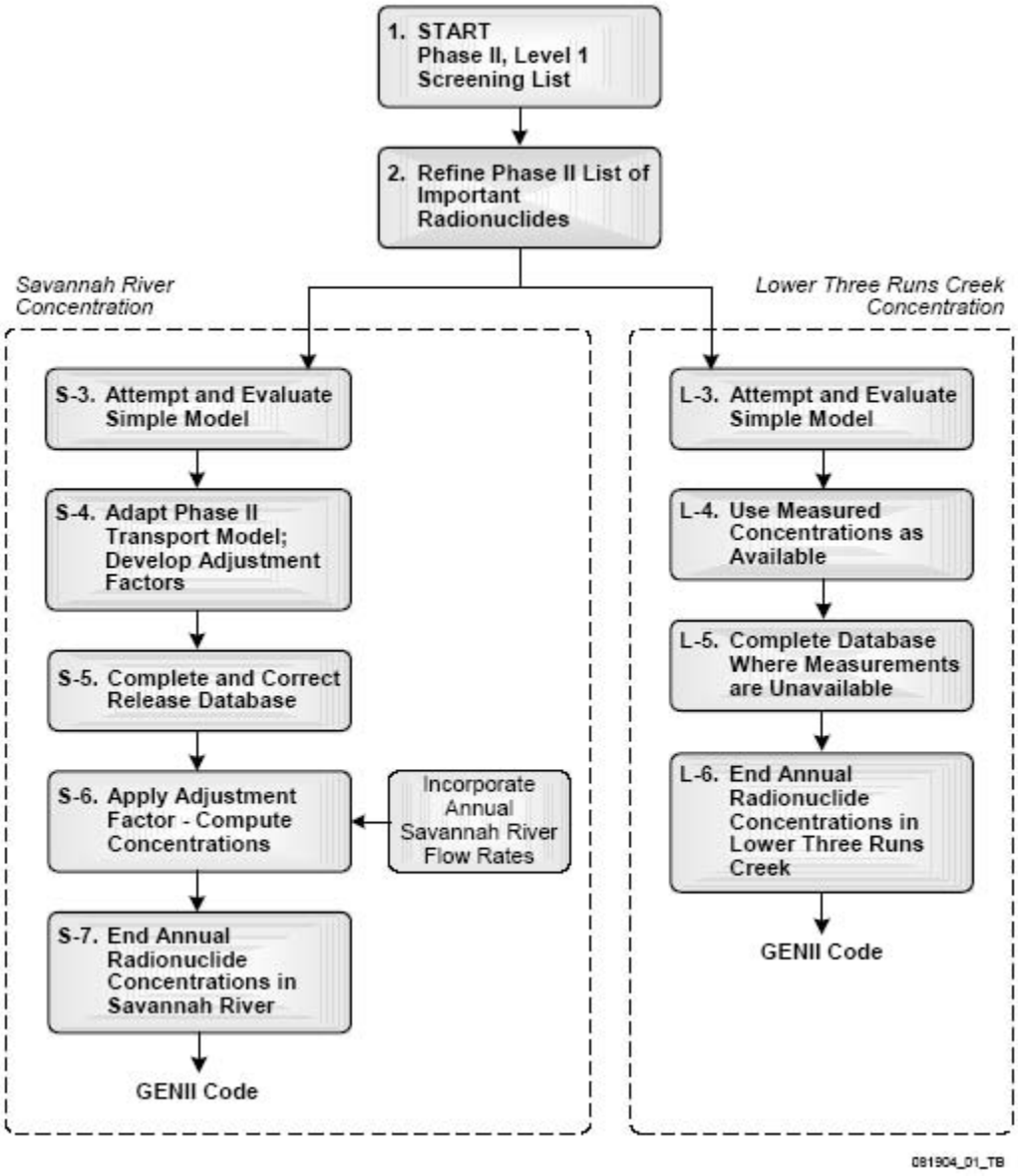

Figure 7-2 Approaches to Estimating Radionuclide Concentrations in Water at Exposure Locations

These procedural steps for developing the source term are briefly described in the following list. Then each subsection that follows discusses these steps in more detail.

Common Steps:

1. START: List of important radionuclides from Phase II, Level 1 screening analysis.
2. Refine list of radionuclides. Two isotopes of uranium were added to refine the treatment of health effects. ^{91}Y was deleted because it fell below the requirement for inclusion.

Savannah River Steps:

S-3. Attempt a simple model: estimate annual concentrations in the Savannah River by dividing annual release rate by the annual flow rate. This did not provide acceptable results when compared to measured concentrations in the river, **so the simple model was not used**.

S-4. Adapt the Phase II model; develop scaling factors for all radionuclides based on K_D. Phase II modeled radionuclide releases to the Savannah River for three important radionuclides based on several factors influencing transport from the point of release to the river. Adjustment factors were derived based on these modeled releases and tabulations of annual amounts of radionuclides released at the point-of-release. These adjustment factors were to be applied to each remaining radionuclide not modeled in Phase II, depending on its geochemical K_D.

S-5. Complete and correct the release data base; release data for some years not compiled in the Phase II report and files were supplied from other sources. Corrections for unidentified alpha emitters and unidentified beta-gamma emitters were added. Other minor anomalies were corrected.

S-6. Apply adjustment factors; the adjustment factors based on the Phase II modeling were used to estimate annual concentrations from the tabulated values of annual releases. In order to calculate concentrations, incorporate data on annual flow rates in the Savannah River.

S-7. END: Concentrations by year and radionuclide in the Savannah River.

Lower Three Runs Creek Steps:

L-3. START: Attempt a simple model; estimate annual concentrations in Lower Three Runs Creek by dividing annual release rate by the annual flow rate. This did not provide acceptable results when compared to measured concentrations in the creek.

L-4. Use measured concentrations for three radionuclides, ^{137}Cs, ^{90}Sr, ^{3}H; there were inadequate or no measurements for the remaining nuclides of interest;

L-5. Complete the concentration data base for ^{137}Cs, ^{90}Sr, and ^{3}H, for instances where directly measured concentration data were unavailable by extrapolation from available measurements, e.g. non-volatile beta activity.

L-6. END: Concentrations for ^{137}Cs, ^{90}Sr, and ^{3}H by year and radionuclide in Lower Three Runs Creek.

7.2 Identify Important Radionuclides Based on Phase II

Phase II of the SRS Dose Reconstruction Project identified the radionuclides that were released to the surface water from SRS, performed a screening assessment to identify a smaller group of radionuclides to be addressed in more detail, and estimated radionuclide quantities released into water over much of the time period of nuclear material production. This information was used as the starting point for estimating the water concentrations of radionuclides at the exposure locations of interest.

7.2.1 Phase II Screening Assessment

The Phase II screening assessment started with a master list of radionuclides that had been reported as released into surface water from SRS facilities. Preliminary estimates of their yearly average release rates were made for a 36-year period. A screening assessment was performed to identify a smaller list of key radionuclides that were the dominant contributors to radiation dose and cancer risk (Phase II). This screening assessment was performed using a two-step method recommended by the National Council on Radiation Protection and Measurements (NCRP) (56).

The initial screening analysis conservatively assumed that all radionuclides were discharged into a single body of surface water with a fixed flow rate. Using the NCRP methodology referenced above, estimated 36-year average releases (representing 1954-1989), and an average dilution flow rate of 7.7 x 109 m^3/y of water, the total effective doses were estimated for each radionuclide. A total dose was estimated by summing the incremental doses from each radionuclide. A screening factor was computed for each radionuclide equal to the ratio of the incremental dose from each radionuclide to the total dose. Those radionuclides that contributed at least 0.1% to the screening factor were given further consideration in estimation of the source term. The radionuclides that Phase II identified as meeting this criterion were "^{137}Cs, ^{60}Co, ^{3}H, ^{129}I ^{131}I, ^{32}P, ^{238}Pu, ^{239,240}Pu, ^{89}Sr, ^{90}Sr, ^{35}S, ^{99}Tc, uranium, ^{91}Y, ^{65}Zn, and ^{95}Zr/Nb"[3]. A summary of the Level 1, Phase II screening results is presented in Table 7-1. A second, Level -2 screening, which ranked radionuclides according to their relative importance by exposure pathway, was also performed. Seven radionuclides identified in this fashion were: ^{3}H, ^{137}Cs, ^{90}Sr, ^{60}Co, ^{32}P, ^{131}I, and uranium.

Table 7-1 Radionuclides Identified as Significant in the Level 1 Screening Analysis in Phase II

Radionuclide	Percent of Total Screening Value
^{141}Ce, ^{144}Ce*	0.91
^{134}Cs	0.52
^{137}Cs	75.23
^{60}Co	1.80
^{3}H	0.74
^{131}I	0.91
^{32}P	5.64
^{239}Pu, ^{240}Pu*	0.48
^{238}Pu	0.21
^{103}Ru, ^{106}Ru*	1.39
^{89}Sr, ^{90}Sr*	9.35
^{35}S	0.68
^{99}Tc	0.13
Uranium*	0.57
^{65}Zn	0.68
^{95}Zr, ^{95}Nb*	0.38
Total	**99.6**

*^{140}Ba, ^{140}La were screened as ^{140}Ba; ^{141}Ce, ^{144}Ce as ^{144}Ce; ^{239}Pu, ^{240}Pu as ^{239}Pu; ^{103}Ru, ^{106}Ru as ^{106}Ru; ^{124}Sb, ^{125}Sb as ^{125}Sb; ^{89}Sr, ^{90}Sr as ^{90}Sr; uranium as ^{235}U and ^{238}U; and ^{95}Zr, ^{95}Nb as ^{95}Zr.
Source: Phase II Rad-Screening.xls Excel spreadsheet (Phase II).

Note that although ^{91}Y and ^{129}I were included as significant based on the Level 1 Phase II screening analysis, the numerical analysis in Phase II does not appear to support their inclusion based either on the Level 1 or Level 2 screening criteria. The screening value for ^{91}Y was 0.0345% of the total screening value and the screening value for ^{129}I was 0.0589% of the total screening value, both of which are below the 0.1% screening value criterion for Level 1 screening. Neither did they rank among the top three radionuclides for any surface water exposure pathway considered in the Level 2 screening analysis. Although ^{134}Cs did exceed the 0.1% screening criterion (as shown in Table 7-1), it was not included in the list.

[3] Page 3-7, reference 54.

7.2.2 Modify List of Radionuclides and Properties

As shown in Figure 7-2, the second generic step in defining the source term for liquid releases was to modify the list of radionuclides identified as important in Phase II. The initial list of important radionuclides resulting from the Phase II Level 1 screening analysis was modified in several ways:

1. Some groups of radionuclides were partitioned into separate isotopes. This was done to provide a more refined treatment of dose modeling. By treating isotopes individually, health effects coefficients specific to those isotopes could be used in the dose modeling. If isotopes were aggregated by element, as in the Phase II screening analyses, a single coefficient (related to the isotope with the greatest health effects) would characterize all the isotopes of the element, possibly greatly overestimating doses and risks. Table 7-2 shows the 22 isotopes modeled for liquid releases in Phase III.
   a. Each member of the mother-daughter pair, ^{95}Nb and ^{95}Zr, was modeled as a separate isotope to account for the slight differences in health effects.
   b. ^{134}Cs and ^{137}Cs were modeled as separate isotopes; furthermore the Level 1 screening value for ^{134}Cs, 0.52%, exceeded the criterion for retention.
   c. ^{89}Sr and ^{90}Sr were modeled separately.
2. Because the releases of Ruthenium were relatively small, all releases were modeled as ^{106}Ru.
3. ^{129}I was included for Phase III even though, like ^{91}Y, its screening value did not meet the 0.1% criterion (its screening value was 0.06%). ^{129}I was included for three reasons: (a) it has similar chemical and physical properties as ^{131}I, which was identified as a key radionuclide; (b) there were concerns about possible health effect after it concentrates in the thyroid; and (c) although the liquid release of ^{129}I is not as well monitored as ^{131}I (1), its long half-life (~1.7x10+07 years) is orders of magnitude longer than that of ^{131}I (~8.04 days), thus making it much longer lasting in the environment. This long half-life could be a differential factor for some scenarios and exposure pathways.
4. One radionuclide, ^{240}Pu was dropped from consideration. The data upon which the Phase II estimates of releases were based did not list ^{240}Pu releases separately, but always combined with other isotopes. Furthermore, the health effects coefficients for ^{239}Pu and ^{240}Pu are very close, so modeling ^{240}Pu as ^{239}Pu will have little effect on the dose estimates. Since there appeared to be no basis and no motivation for differentiating these two isotopes, separate consideration of ^{240}Pu was dropped.

Table 7-2 Modified List of Radionuclides Considered for Water Concentrations in Phase III

^{144}Ce	^{106}Ru
^{134}Cs	^{89}Sr‡
^{137}Cs	^{90}Sr‡**
^{60}Co	^{35}S
^{3}H	^{99}Tc
^{129}I*	^{234}U*
^{131}I	^{235}U§
^{95}Nb†	^{236}U*
^{32}P	^{238}U§
^{238}Pu	^{65}Zn
^{239}Pu¶	^{95}Zr†

*These radionuclides were added.
†, ‡, § These radionuclides were paired in the Phase II, Level 1 screening analysis.
¶Unidentified alpha-emitters were modeled as ^{239}Pu
**Unidentified beta-gamma emitters were modeled as ^{90}Sr

5. It was considered appropriate to include as releases radioactivity measured as unidentified alpha or unidentified beta-gamma activity. Although the SRS had recorded releases of such material over the years of site operation, an explicit treatment in Phase II was not apparent. Therefore two additional categories were added for these types of releases. However, to provide bounding estimates of their health effects, the unidentified alpha activity was added to the releases for ^{239}Pu and the unidentified beta-gamma activity was added to the releases for ^{90}Sr. These two classes are indicated in Table 7-2 to indicate that these activities were compiled and tracked separately.

The general approach for partitioning aggregate quantities of radionuclides is summarized in Table 7-3. (See Appendix C for details.) Unlike the analysis of releases to air, there was no need to refine the treatment of certain radionuclides by defining their chemical form; this is because all radionuclides were either dissolved or suspended in water, which dominated the chemistry. For example, tritium would be present as tritiated water.

Table 7-3 Partitioning Assumptions for Radionuclides Released to Surface Water

Constituent	SRS Area	Isotopic Distribution by Activity
^{89}Sr, ^{90}Sr	F&H Areas	75% ^{89}Sr; 25% ^{90}Sr
	A Area	100% ^{90}Sr
	D Area	100% ^{90}Sr
	Central Shops	100% ^{90}Sr
^{95}Nb, ^{95}Zr	All areas	65% ^{95}Nb; 35% ^{95}Zr
^{134}Cs, ^{137}Cs	D Area[4]	100% ^{137}Cs
Uranium	Reactor Areas	91.73% ^{234}U; 1.79% ^{235}U; 6.45% ^{236}U; 0.03% ^{238}U
	F Area	1.27% ^{235}U; 98.73% ^{238}U
	H Area	91.73% ^{234}U; 1.79% ^{235}U; 6.45% ^{236}U; 0.03% ^{238}U
	M Area	1.27% ^{235}U; 98.73% ^{238}U
	A Area (SRL)	91.44% ^{234}U; 1.8% ^{235}U; 6.4% ^{236}U; 0.36% ^{238}U
	CMX/TNX	49.49% ^{234}U; 2.25% ^{235}U; 48.26% ^{238}U
	D Area	91.73% ^{234}U; 1.79% ^{235}U; 6.45% ^{236}U; 0.03% ^{238}U
Total plutonium	All Areas	100% ^{239}Pu
Unidentified alpha	All Areas	100% ^{239}Pu
Unidentified beta-gamma	All Areas	100% ^{90}Sr

7.3 Modeling Releases and Concentrations for the Savannah River

7.3.1 A Simple Model (Step S-3)

As a first step in estimating radionuclide concentrations in the Savannah River, a simple model based on conservation of mass was evaluated (Step 3 in Figure 7-2); however, because this simple model did not

[4] For all areas other than D, releases to water identified as ^{134}Cs were modeled as ^{134}Cs, not as ^{137}Cs.

adequately predict concentrations of radionuclides in the river, **it was not used**. Recall that the point of interest on the Savannah River was located below the confluence with Lower Three Runs Creek; actually, the point of interest is very close to the USGS flow monitoring station at river mile 120 (RM-118.8 in later years) at highway 301 (also designated in various SRS reports as station 10A or R-10). Because the location of interest is downriver from the points where site streams drain into the Savannah River, one can reasonably assume that all liquid releases exiting the site boundary must pass through this point. Since the river flow is measured very close to this point, one can construct a simple mathematical model based on conservation of mass for the average radionuclide concentration at this location:

$$C_{ij} = R_{ij}/Q_j \qquad (7\text{-}1)$$

Where,

C_{ij} is the concentration of radionuclide i in year j (Bq/m^3);
R_{ij} is the quantity of radionuclide i released from the SRS to water in year j (Bq/y);
Q_j is the flow rate of water past the location for year j (m^3/y).

However, as described in Section 7.1.3, the migration of radionuclides from their point of release on the SRS to this location of interest in the Savannah River is not direct or simple. Nevertheless, to test a simple approximation, the quantities of radionuclides released from the facility were assumed to be equal to the quantities ending up in the river, for any given year. Figure 7-3 and Figure 7-4 compare radionuclide concentrations computed according to this simple model to measured concentrations at this location. Comparisons are shown for tritium in Figure 7-3 and ^{137}Cs in Figure 7-4. Measured concentrations at this location were not apparent for years prior to 1960. Two different estimates of flow rate were used to compute the calculated concentrations. In one case the "USGS Actual Flow Rate" was used for each year of the calculation, in full accord with equation (7-1). In the other case, the "39-year Average Flow Rate" was used; i.e., the flow rate was a fixed value (9.49 billion cubic meters) for all years. Note that the measured and calculated concentrations do not agree very well. For tritium, measured values in early years are higher than calculated values; in later years, the peaks and dips do not correspond in time very well. For cesium, early measured values are higher than calculated concentrations, but in middle years calculated values are higher than measured values.

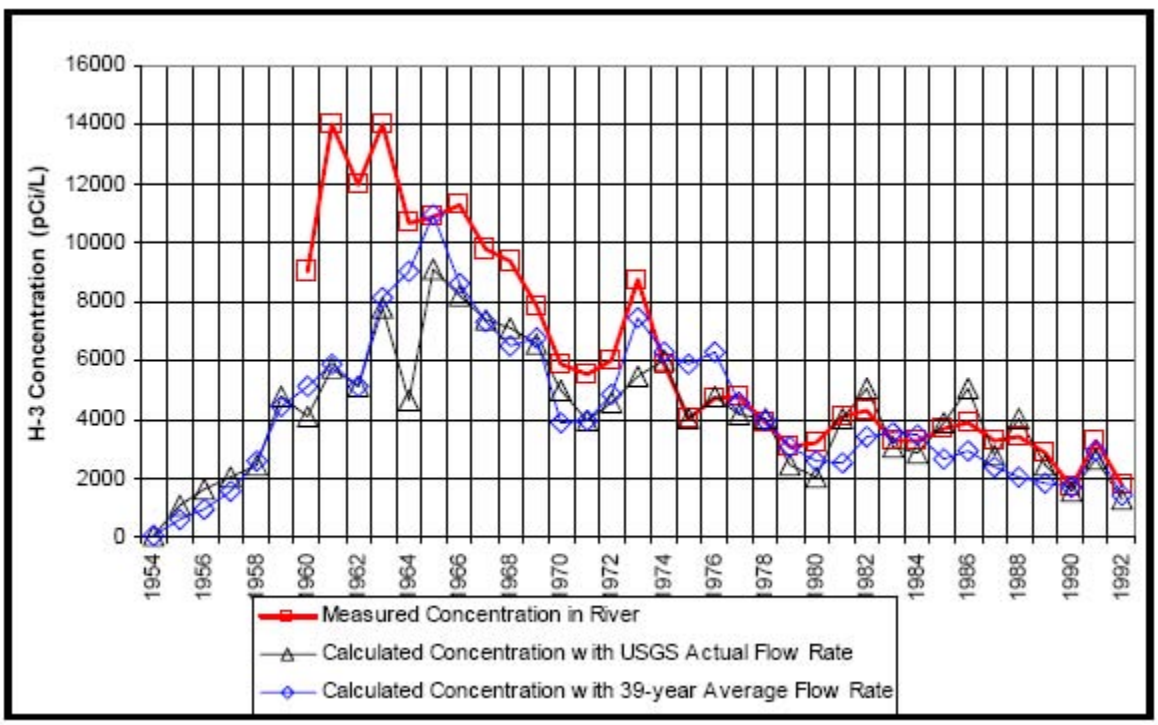

Figure 7-3 ^3H Concentration in Savannah River (pCi/L)

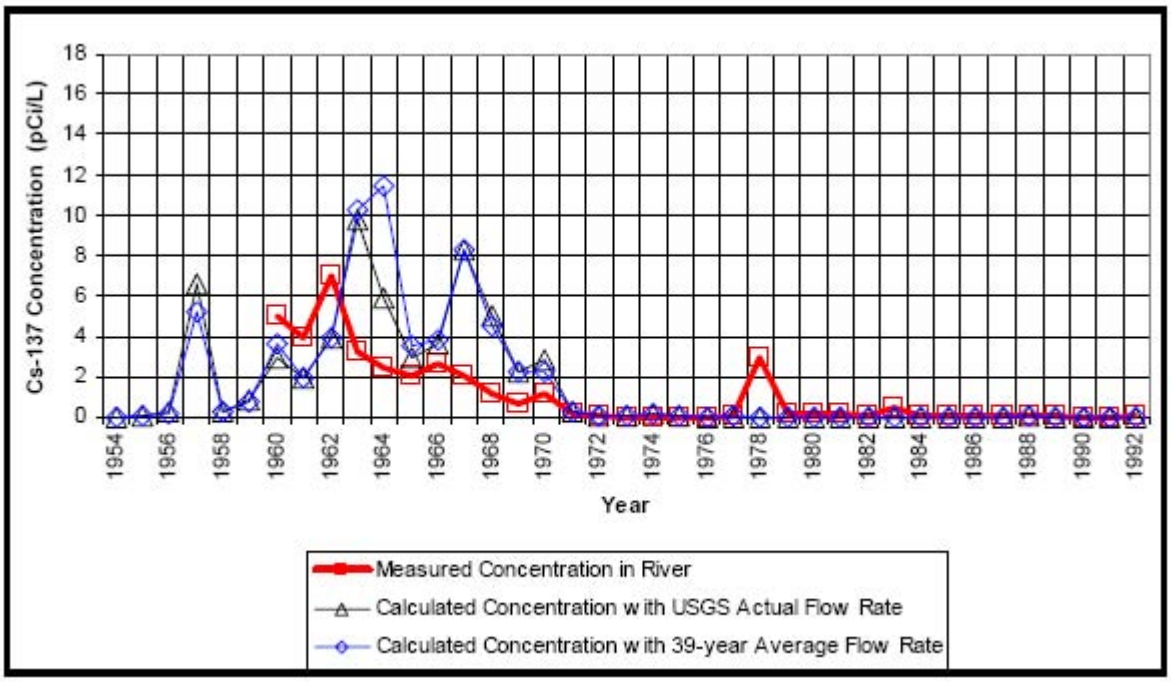

Figure 7-4 137Cs Concentration in Savannah River Water (pCi/L)

Because of this lack of agreement with measured concentrations, use of this simple modeling approach was abandoned. However, this presented the problem of exactly how this necessary input for the dose reconstruction (i.e., radionuclide concentrations in the Savannah River) would be obtained. Although there were measured concentrations for a few radionuclides (^{3}H, ^{137}Cs, ^{131}I, ^{90}Sr, and others), this was not a suitable solution because:

- The goal of the dose reconstruction was to represent doses from the set of 22 radionuclides selected (Table 7-2) and there were no measured values for most of these.
- The measured concentrations were frequently near detection limits for the instruments used, so the accuracy of the measurements was questionable; in some cases, the detection limit (or half the detection limit) was listed as the measured value.
- Consistent measurements of concentrations were not available during some of the important early years of site operation, when releases were known to be large.
- The estimates of average annual measured concentrations were based on periodic samples that were subject to substantial uncertainties:
  - The possibility that major releases were not effectively or consistently sampled.
  - The possibility that the turbulent, unsteady flow in the river steered contaminated water toward or away from the sampling locations.

7.3.2 Adapt the Phase II Water Transport Model for Savannah River Concentrations (Step S-4)

In order to overcome the difficulties encountered with a simple model of radionuclide concentrations in the Savannah River, the model developed in Phase II for a few radionuclides was adapted and extended for Phase III. This is shown as Step 4 in Figure 7-2.

7.3.2.1 Phase II Water Transport Model

Section 7.1.3 of this report and Chapter 5 of the Phase II report (59) discusses why the accounting of releases to the surface water pathway ***at the point of release*** is not an accurate estimate of the actual

releases from the SRS site to the Savannah River. Chapter 5 of the Phase II report describes how a relatively simple model was used to estimate the release to the Savannah River of ^{3}H, ^{90}Sr, and ^{137}Cs, based on concentrations of these constituents measured at the sampling stations along Road A, the sampling point closest to the river (59). These three radionuclides were identified in Phase II as important possible contributors to either offsite release or dose and had been monitored extensively during the years of nuclear material production.

The Phase II model explicitly considers the following factors:

1. Transport of radionuclides through surface water as dissolved and suspended constituents.
2. Release of previously retained radionuclides by periodic flooding of the Savannah River Swamp.
3. Measurement uncertainty.

The effects of the various physical and chemical interactions of released radionuclides with the soil, biota, and other features of the SRS generally decreased the modeled radionuclide quantities reaching the Savannah River. On the other hand, many of the radionuclide measurement uncertainties, when incorporated into the Phase II model, increased the modeled quantities discharged to the Savannah River.

The SRS Swamp was observed to flood about 20% of the time (74 days per year on the average) from 1958 to 1967. It was assumed that additional releases to the Savannah River from the swamp occurred when there was flooding. This uncertainty was considered a source of bias that increased releases of radionuclides such as cesium and strontium that were retained in the swamp. For most years, releases were increased for cesium and strontium by 20% (with a range of 10%-30%). For years with very high rainfall amounts like 1964 and 1971, a value of 40% (with a range of 25%- 60%) was assumed. For years with low rainfall, it was assumed that the swamp flooded only about 10% of the time (with a range of 5%-15%) (59). (Detailed records existed for annual rainfall). Uncertainties associated with the releas e estimates were considered to originate from analytical errors in measurement of flow and in sampling and analysis of radionuclide concentrations in the water. Because tritium was not impacted heavily by flow through the SRS swamp, sampling and analytical uncertainties were the major sources of uncertainty in the release estimates for tritium. The effluent volume to the site streams was monitored reasonably well by both the Site and the USGS (Phase II). Estimates of error for the routine concentration measurements varied with the radionuclide, the sample preparation and with the counting procedure (59).

Measurements of effluent releases and concentrations for ^{137}Cs and ^{90}Sr at the Road A monitoring locations specific were not made in early years. Prior to 1960, only nonvolatile beta activity was measured. To estimate annual ^{137}Cs releases for times when ^{137}Cs specific measurements were not made, a ratio was calculated of ^{137}Cs to nonvolatile beta activity when both measurements were made at the same time and location. This ratio was used along with the nonvolatile beta activity measurements to estimate levels of ^{137}Cs activity in the site streams at the Road A monitoring locations for years when ^{137}Cs -specific measurements were not made. A similar procedure was used for ^{90}Sr.

7.3.2.2 Adaptation of Phase II Model for Savannah River Concentrations

A mathematical model of the transport of individual radionuclides to the Savannah River, similar to that used in Phase II, would require significant resources to develop and validate. The complex nature of radionuclide transport by surface water at the SRS requires consideration of the loss mechanisms, time delays, and uncertainties that influence radionuclide concentrations reaching the Savannah River. Because each chemical species has unique aqueous transport properties, developing a model that would accommodate the variations in chemical-physical transport was beyond the scope of Phase III.

However, Phase II had modeled the quantities of three specific radionuclides (^{3}H, ^{90}Sr, ^{137}Cs) released into the Savannah River, taking into account the complex phenomena and issues governing their migration. The release quantities estimated by the Phase II model are different from the sum of all releases from each facility (point of release quantities) compiled in Phase II and in the SRS historical data. These differences represent the effect of the phenomena causing radionuclide decay, storage, and release, during migration in site streams, from seepage basins, and through the Savannah River swamp and measurement uncertainty. A quantitative measure representing these phenomena is just the ratio of the modeled release activity to the facility release activity:

$$F_{jk} = R_{Mjk}/R_{Fjk} \qquad (7\text{-}2)$$

Where,

F_{jk} is the factor representing the effects of radionuclide migration for year j and modeled radionuclide k;
R_{Mjk} is the modeled release of radionuclide k for year j;
R_{Fjk} is the release from all SRS facilities of radionuclide k for year j tabulated from site data.

Note that the index "k" is used to denote the radionuclide here, rather than the index "i" used in equation (7-1), because "k" refers only to one of the three radionuclides (^{3}H, ^{90}Sr, ^{137}Cs) modeled in Phase II, while "i" refers to any radionuclide.

The fundamental assumption made to extend these results of Phase II modeling to the analysis in Phase III is that the distribution coefficient (K_D – a measure of the degree to which a particular radionuclide is sorbed to soil, sediment, and some biota) of a radionuclide would be the primary factor affecting the influence of the site, as represented by the factor, F_{jk}. Using this assumption, one could extend the modeling of the three radionuclides performed in Phase II to the entire suite of radionuclides modeled in Phase III. As will be described in more detail, this extension was based on three categories of K_D into which the Phase III radionuclides were binned. A more precise rendering of aqueous chemistry was not considered warranted given the extent of other uncertainties.

As stated in Section 7.3.2.1, other factors incorporated into the Phase II model were periodic flooding of the Savannah River swamp and uncertainties in measuring the quantities of released radionuclides. Clearly, K_D does not encompass these factors. However, the factors representing river flooding were tied to precipitation records and were adjusted from year to year; similarly, the factors representing measurement uncertainty were adjusted annually, with larger uncertainties in earlier years. Thus, the annual variations in the factor defined by equation (7-2) should incorporate these other facets of the Phase II model. However, some of the uncertainties related to measuring tritium in environmental samples are unique to tritium. This may mean that factors developed for tritium, if applied to other radionuclides, may overestimate the degree of measurement uncertainty.

A complication in applying equation (7-2) is that R_{mjk}, the modeled release of radionuclide k for year j, is a random variable, not a single value, because the model used in Phase II was probabilistic. However, the median value of the distribution was chosen as a measure of the central tendency of these quantities.

The remaining steps needed to estimate releases of any radionuclide of interest to the Savannah River, based on the factors defined by equation (7-2) are:

1. Determine the annual radionuclide water releases for each radionuclide from all SRS facilities, for the three modeled radionuclides, R_{Fjk}, and for all other radionuclides, R_{Fij}.
2. Compute the ratios, F_{jk}, indicated by equation (7-2).
3. Bin the radionuclides by K_D group.

4. Apply the ratios for each group of radionuclides to annual releases from all site facilities, thereby obtaining adjusted annual releases by radionuclide. However, the release data base needed to be completed and corrected before applying the adjustment factors (discussed in Section 7.3.3), so this aspect is discussed in Section 7.3.4.

7.3.2.2.1 Annual Radionuclide Release at Points of Release

The principal reference used to develop the annual radionuclide point-of-release data files, (i.e. files containing R_{Fjk}, the facility release of radionuclide k for year j tabulated from site data) was Cummins, et al. (2). To develop the data files, a guiding decision had to be made about the specific releases to be included.

Liquid releases from the site can be placed into three categories:

1. Category 1 - Direct releases to onsite streams.
2. Category 2 - Migration from seepage basins into onsite streams.
3. Category 3 - Direct releases to seepage and containment basins.

Although the total release to site streams could be the sum of Categories 1 and 2, the Phase II report generally used the sum of Categories 1 and 3 to represent the liquid source terms in the screening assessment. There appear to be at least two reasons for this choice:

1. Because migration from the seepage basins is distributed in time and space, measurements of concentrations immediately downstream of the seepage basins may under-represent the total flux from the seepage basins to the streams.

2. The sum of Categories 1 and 3 should be a conservative estimate of liquid releases to site streams.

Exceptions are ^{3}H and ^{131}I, where only direct releases to streams (Category 1) were considered for the screening assessment.

For these reasons, the annual sums of releases from Categories 1 and 3 were chosen as representative of SRS releases to site streams. This meant that tritium evaporated from seepage and containment basins was excluded from the point-of-release data file created for tritium. Evaporated tritium was included in the Phase III atmospheric releases (Chapter 5). It also meant that the estimated ^{137}Cs desorption from the Four Mile Creek bed that was reported by Cummins, et al. (2) was not included in the data files. The activity reported in this desorption was already included in the Category 1 and 3 releases as described above. Including these desorption estimates would have caused double counting.

7.3.2.2.2 Adjustment Factor Development

Adjustment factors were calculated according to equation (7-2) by dividing the median values of radionuclide release computed by the Phase II release model for each of three modeled radionuclides by the radionuclide releases for these radionuclides from all facilities. These modeled and tabulated releases are listed in Table 7-4. The resultant adjustment factors are listed in Table 7-5.

Table 7-4 Tabulated Releases from Facilities and Median Value of Modeled Releases Used for Adjustment Factors (Ci)

	Tabulated Releases from Facilities			Median Value of Modeled Releases		
Year	^{3}H	^{137}Cs	^{90}Sr	^{3}H	^{137}Cs	^{90}Sr
1954	$3.66x10^{+02}$	$1.80x10^{-01}$	$3.90x10^{-02}$	$7.64x10^{+03}$	$1.41x10^{-01}$	$4.13x10^{-02}$
1955	$5.87x10^{+03}$	$1.37x10^{0}$	$8.16x10^{-01}$	$1.32x10^{+04}$	$2.65x10^{-01}$	$1.45x10^{-01}$
1956	$9.39x10^{+03}$	$3.43\ x10^{0}$	$1.04x10^{+01}$	$1.50x10^{+04}$	$1.11\ x10^{0}$	$3.60x10^{-01}$
1957	$2.24x10^{+04}$	$8.40x10^{+02}$	$1.96x10^{+02}$	$2.16x10^{+04}$	$1.16\ x10^{0}$	$1.54\ x10^{0}$
1958	$2.88x10^{+04}$	$1.04x10^{+02}$	$1.58x10^{+01}$	$2.88x10^{+04}$	$9.51\ x10^{0}$	$8.30x10^{-01}$
1959	$5.17x10^{+04}$	$4.14x10^{+01}$	$2.18x10^{+01}$	$6.29x10^{+04}$	$3.59\ x10^{0}$	$1.80\ x10^{0}$
1960	$6.09x10^{+04}$	$4.36x10^{+01}$	$2.36x10^{+01}$	$6.98x10^{+04}$	$7.60\ x10^{0}$	$1.76x10^{+01}$
1961	$8.11x10^{+04}$	$4.06x10^{+01}$	$9.85\ x10^{0}$	$8.28x10^{+04}$	$1.03x10^{+01}$	$4.22\ x10^{0}$
1962	$7.23x10^{+04}$	$1.03x10^{+02}$	$1.04x10^{+01}$	$6.47x10^{+04}$	$1.92x10^{+01}$	$6.78\ x10^{0}$
1963	$9.66x10^{+04}$	$1.23x10^{+02}$	$2.10x10^{+01}$	$9.69x10^{+04}$	$1.68x10^{+01}$	$1.07x10^{+01}$
1964	$1.17x10^{+05}$	$1.30x10^{+02}$	$1.41x10^{+01}$	$1.21x10^{+05}$	$5.15x10^{+01}$	$1.13x10^{+01}$
1965	$1.28x10^{+05}$	$5.56x10^{+01}$	$1.17x10^{+01}$	$1.06x10^{+05}$	$2.35x10^{+01}$	$5.22\ x10^{0}$
1966	$1.33x10^{+05}$	$5.36x10^{+01}$	$6.12\ x10^{0}$	$9.56x10^{+04}$	$2.72x10^{+01}$	$4.46\ x10^{0}$
1967	$1.04x10^{+05}$	$6.87x10^{+01}$	$6.72\ x10^{0}$	$8.75x10^{+04}$	$3.80x10^{+01}$	$4.82\ x10^{0}$
1968	$1.07x10^{+05}$	$7.08x10^{+01}$	$9.19\ x10^{0}$	$8.39x10^{+04}$	$2.08x10^{+01}$	$5.46\ x10^{0}$
1969	$7.88x10^{+04}$	$5.14x10^{+01}$	$1.02x10^{+01}$	$7.64x10^{+04}$	$1.04x10^{+01}$	$3.58\ x10^{0}$
1970	$6.61x10^{+04}$	$4.43x10^{+01}$	$7.26\ x10^{0}$	$4.25x10^{+04}$	$1.02x10^{+01}$	$3.89\ x10^{0}$
1971	$4.47x10^{+04}$	$1.05x10^{+01}$	$3.14\ x10^{0}$	$4.44x10^{+04}$	$1.69\ x10^{0}$	$3.81\ x10^{0}$
1972	$6.09x10^{+04}$	$9.14\ x10^{0}$	$1.25\ x10^{0}$	$4.68x10^{+04}$	$6.28x10^{-01}$	$1.92\ x10^{0}$
1973	$8.69x10^{+04}$	$7.48\ x10^{0}$	$9.01x10^{-01}$	$6.10x10^{+04}$	$4.44x10^{-01}$	$2.07\ x10^{0}$
1974	$5.61x10^{+04}$	$8.09\ x10^{0}$	$4.27x10^{-01}$	$5.41x10^{+04}$	$7.01x10^{-01}$	$1.72\ x10^{0}$
1975	$5.15x10^{+04}$	$7.75\ x10^{0}$	$9.12x10^{-01}$	$4.93x10^{+04}$	$3.61x10^{-01}$	$1.46\ x10^{0}$
1976	$7.32x10^{+04}$	$8.94\ x10^{0}$	$4.76x10^{-01}$	$4.64x10^{+04}$	$1.46x10^{-01}$	$1.18\ x10^{0}$
1977	$4.59x10^{+04}$	$6.58\ x10^{0}$	$5.55x10^{-01}$	$4.03x10^{+04}$	$2.45x10^{-01}$	$9.04x10^{-01}$
1978	$3.76x10^{+04}$	$1.04x10^{+01}$	$2.06\ x10^{0}$	$3.55x10^{+04}$	$1.04x10^{-01}$	$6.20x10^{-01}$
1979	$4.52x10^{+04}$	$6.27\ x10^{0}$	$2.68\ x10^{0}$	$2.84x10^{+04}$	$1.04x10^{-01}$	$6.24x10^{-01}$
1980	$3.54x10^{+04}$	$1.83\ x10^{0}$	$1.55x10^{-01}$	$3.00x10^{+04}$	$7.72x10^{-02}$	$5.05x10^{-01}$
1981	$3.94x10^{+04}$	$2.81\ x10^{0}$	$1.04\ x10^{0}$	$2.51x10^{+04}$	$1.16x10^{-01}$	$4.61x10^{-01}$
1982	$3.15x10^{+04}$	$2.85\ x10^{0}$	$6.98x10^{-01}$	$3.08x10^{+04}$	$8.36x10^{-02}$	$3.95x10^{-01}$
1983	$4.06x10^{+04}$	$3.43\ x10^{0}$	$2.35x10^{-01}$	$3.24x10^{+04}$	$7.74x10^{-02}$	$3.84x10^{-01}$
1984	$3.58x10^{+04}$	$6.13\ x10^{0}$	$9.44x10^{-02}$	$3.23x10^{+04}$	$1.22x10^{-01}$	$4.25x10^{-01}$
1985	$3.40x10^{+04}$	$6.23\ x10^{0}$	$1.70x10^{-01}$	$2.21x10^{+04}$	$5.14x10^{-02}$	$2.25x10^{-01}$
1986	$4.52x10^{+04}$	$1.13x10^{+01}$	$1.28x10^{-01}$	$2.21x10^{+04}$	$5.51x10^{-02}$	$3.26x10^{-01}$
1987	$2.75x10^{+04}$	$1.54x10^{+01}$	$5.69x10^{-02}$	$2.04x10^{+04}$	$1.98x10^{-01}$	$3.63x10^{-01}$
1988	$1.44x10^{+04}$	$6.39\ x10^{0}$	$4.40x10^{-02}$	$1.82x10^{+04}$	$2.92x10^{-01}$	$2.63x10^{-01}$
1989	$3.97x10^{+03}$	$2.10x10^{-01}$	$1.68x10^{-02}$	$1.76x10^{+04}$	$1.82x10^{-01}$	$2.56x10^{-01}$
1990	$2.62x10^{+03}$	$4.83x10^{-02}$	$4.28x10^{-01}$	$1.53x10^{+04}$	$4.29x10^{-02}$	$5.41x10^{-01}$
1991	$1.06x10^{+04}$	$2.64x10^{-02}$	$8.91x10^{-02}$	$2.64x10^{+04}$	$2.57x10^{-02}$	$1.14x10^{-01}$
1992	$2.00x10^{+03}$	$1.02x10^{-01}$	$7.86x10^{-01}$	$1.30x10^{+04}$	$8.46x10^{-02}$	$8.84x10^{-01}$

Table 7-5 Adjustment Factors by Radionuclide Group and Year

Year	Group 1 ^{3}H	Group 2 ^{90}Sr	Group 3 ^{137}Cs	Year	Group 1 ^{3}H	Group 2 ^{90}Sr	Group 3 ^{137}Cs
1954	1.0000*	1.0582	0.7813	1976	0.6346	2.4755	0.0163
1955	2.2482	0.1773	0.1927	1977	0.8775	1.6271	0.0372
1956	1.6024	0.0345	0.3224	1978	0.9418	0.3006	0.0101
1957	0.9645	0.0079	0.0014	1979	0.6284	0.2326	0.0165
1958	1.0004	0.0527	0.0918	1980	0.8490	3.2573	0.0423
1959	1.2175	0.0824	0.0867	1981	0.6378	0.4416	0.0412
1960	1.1465	0.7467	0.1744	1982	0.9787	0.5655	0.0294
1961	1.0203	0.4284	0.2528	1983	0.7962	1.6370	0.0226
1962	0.8954	0.6499	0.1871	1984	0.9031	4.5042	0.0200
1963	1.0024	0.5079	0.1362	1985	0.6496	1.3263	0.0083
1964	1.0340	0.8037	0.3964	1986	0.4893	2.5464	0.0049
1965	0.8273	0.4443	0.4223	1987	0.7426	6.3833	0.0128
1966	0.7190	0.7290	0.5078	1988	1.2619	5.9846	0.0456
1967	0.8421	0.7171	0.5530	1989	4.4292	15.1968	0.8696
1968	0.7872	0.5945	0.2933	1990	5.8478	1.2652	0.8899
1969	0.9703	0.3495	0.2026	1991	2.5013	1.2751	0.9724
1970	0.6430	0.5361	0.2313	1992	6.4926	1.1252	0.8279
1971	0.9923	1.2122	0.1611				
1972	0.7686	1.5321	0.0687	**Mean**	1.3325	1.7623	0.2339
1973	0.7021	2.3023	0.0593	**Median**	0.9589	0.8037	0.0918
1974	0.9644	4.0233	0.0866	**Max**	6.4926	15.1968	0.9724
1975	0.9589	1.5961	0.0467	**Min**	0.4893	0.0079	0.0014

*Originally this value was calculated as 20.8814.

Note that the adjustment factor initially calculated for tritium in year 1954 was 20.8814, which is three times larger than the next highest tritium adjustment factor and about 20 times larger than the median value of all adjustment factors over 39 years. This large factor was calculated because of the inclusion of estimated releases from D-Area in the Phase II modeling of tritium release to the Savannah River. In Phase II, 17,530 curies of tritium from D-Area was assumed to be released surface waters in 1954 (59). This D-Area release, however, is not documented in Cummins, et al. (2). For Phase III, it was reasoned that if tritium release from D-Area were the only reason for such a large adjustment factor in 1954, the other radionuclides in this group (i.e. ^{129}I, I^{131}, ^{99}Tc, and ^{35}S) should not be similarly adjusted lest the true releases of these radionuclides be significantly overestimated. Another reason for not using such a large adjustment factor for the tritium group in 1954 was that the functionality of D-Area was heavy water rework, and site effluent release data (2) does not show iodine, technetium, and sulfur being released from that facility in 1954. The factor 1.0 was thus used for the tritium group in 1954 to avoid overestimation of other radionuclide releases.

7.3.2.2.3 Binning Radionuclides by Distribution Coefficient, K_D

As stated above, the adjustment factors developed in the previous section are to be applied according to the geochemical characteristics of the released radionuclides as indicated by the distribution coefficient. The soil-to-water distribution coefficient K_D is a measure of the partitioning between solid and liquid phases that a radionuclide experiences as it passes through environmental media. As radioactive contaminants move through the soils, sediments, and the swamp at the SRS site, they will be attracted to various surfaces. This attraction results in a delay (retardation) of the transport of the contaminant through the system relative to the flow of water. The amount of a particular radionuclide that will reach the Savannah River is expected to depend on this retardation phenomenon and the radiological half-life of the radionuclide.

The K_D values of the radionuclides considered in this analysis span many orders of magnitude. However, to simplify the analysis, the radionuclides have been divided into only three groups: 1) $K_D \leq 10$, 2) $10 \leq K_D \leq 1000$, and 3) $K_D > 1000$.

These groups correspond to the nominal K_D values used in the Phase II modeling of water releases: 0, 100, and 10,000, respectively for ^{3}H, ^{90}Sr, and ^{137}Cs. All radionuclides analyzed in Phase III were assigned to a particular group and were assigned the same annual adjustment factor calculated for that group. The group assigned to each radionuclide is stated in Table 7-6. Table 7-6 also provides the K_D value(s) used to determine the group assigned to each radionuclide. Note that the "Adjustment Factor Group" in the last column in Table 7-6 corresponds to the index "k" in equation (7-2).

Table 7-6 Grouping of Radionuclides According to K_D Values

Radionuclide	Soil-to-Water Distribution Coefficient, K_D			Adjustment Factor Group
	Phase II Value	Soil Value*	Swamp Value†	
^{3}H	**0**	0		^{3}H
^{129}I, ^{131}I		1.55		^{3}H
^{99}Tc		2.49		^{3}H
^{35}S		7.5		^{3}H
^{103}Ru, ^{106}Ru		55		^{90}Sr
^{60}Co		60		^{90}Sr
^{89}Sr, ^{90}Sr	**100**	3040	1676	^{90}Sr
^{95}Nb		160		^{90}Sr
^{32}P		173		^{90}Sr
^{65}Zn		200		^{90}Sr
^{141}Ce, ^{144}Ce		490	255	^{90}Sr
^{95}Zr		600		^{90}Sr
U		1000	170	^{90}Sr
Pu		4100		^{137}Cs
^{134}Cs, ^{137}Cs	**10,000**	59		^{137}Cs

*Source: (3).
†Source: (4).

It should be noted that the K_D's used in Phase II are orders of magnitude different from those reported in recent SRS literature (3). In the Phase II modeling, a range of K_D's having a median value of 10,000 were used for cesium, whereas the range of values used for strontium had a median value of 100. Median K_D's

reported by Kaplan, et al. for agricultural soils are 59 for cesium and 3041 for strontium (3). Another report by Kaplan gives a K_D value of 1676 for ^{90}Sr in the swampy soils (4). The scaling based on K_D values was used in lieu of running the Phase II model, which was not readily accessible. Hence the Phase II values of K_D may be considered to be just parameters in the model that produced a certain output for the three radionuclides modeled. However, the choice of which of the three adjustment factors to use was based on the Phase III values of K_D. This type of adjustment was not made for release quantities of tritium, Cs, and Sr, since Phase II provided results for these radionuclides.

7.3.3 Completion and Correction of the Release Data Base (Step S-5)

The data base describing liquid releases from various SRS facilities was compiled in electronic format largely from SRS tabulations (2). This initial set of data was completed and corrected as follows:

1. Data for releases in the years 1990-1992 were added by examining the appropriate Site Environmental Reports (5); (6); (7); (8).
2. Releases categorized as unidentified beta-gamma activity were added to the ^{90}Sr releases on an annual basis.
3. Releases categorized as unidentified alpha activity were added to the ^{239}Pu releases on an annual basis.
4. Releases of ^{131}I (half-life of 8.04 days) into seepage basins were not included because it was assumed the activity would substantially decay before the iodine could migrate from the seepage basins to the surface streams; i.e., for ^{131}I only category 1 releases were included.
5. The Phase II report and SRS reports indicate a total release of 3 Ci of ^{129}I for the period from 1955-89. This 3 Ci release was apportioned evenly over these years, since no more defined information was available. As with other radionuclides, releases for 1990-1992 were obtained from SRS Environmental Reports.
6. Conflicting values for releases of ^{90}Sr from the L-reactor were obtained from the Cummins report for 1989, depending upon whether radionuclides were summed by facility or radionuclide indexes. What appear to be two spurious entries for ^{90}Sr releases from the L-reactor in 1989 were not included.

7.3.4 Apply Adjustment Factors and Compute Concentrations for Savannah River (Step S-6)

The completion and correction of release data from all SRS facilities described in the preceding section resulted in a tabulation of the quantity of contaminants released by year and radionuclide for the 22 radionuclides listed in Table 7-2. These corrected release quantities from all SRS facilities are used to derive the estimated releases by year and radionuclide to the Savannah River, as follows:

$$R^R_{ij} = R^{CF}_{ij} \cdot F_{jk} \qquad (7\text{-}3)$$

Where,

R^R_{ij} is the release to the Savannah River of radionuclide i and year j;
R^{CF}_{ij} is the Corrected releases from all SRS Facilities of radionuclide i and year j estimated according to the procedure in Section 7.3.3;
F_{jk} is the adjustment factor computed according to equation (7-2).

Note that the correction factor, F_{jk}, depends upon the both the year j and the radionuclide group k; for each radionuclide i the correction factor group is indicated in Table 7-6. When the radionuclide release being adjusted in equation (7-3) was one of those modeled in Phase II (i.e., ^{137}Cs, ^{90}Sr, or ^{3}H), the

computed release to the river, R^R_{ij}, is just the modeled release from Phase II for each year. However, this is not entirely the case for ^{90}Sr. Because the corrected release from all SRS facilities for ^{90}Sr included unidentified beta-gamma activity, the computed releases to the river, R^R_{ij}, is higher than the releases modeled in Phase II.

Figure 7-5 shows the yearly activity estimated by the procedure described above for release of tritium to the Savannah River from the SRS. This graph is consistent with the median (50th percentile) of the Phase II model discussed in Section 7.2.3 Releases rise to a peak in 1964 and then decrease. Figure 7-5 shows the yearly activity estimated in Phase III for release of ^{137}Cs and ^{90}Sr to surface water on the SRS site. Somewhat like tritium, releases of ^{137}Cs rise to a rough peak in 1964, and then decrease, although a second, smaller peak is seen in 1967. The large peak for ^{90}Sr in 1967 reflects the release into the K-Area containment basin of over 100 curies of unidentified beta-gamma activity during that year.

Once the radionuclide releases to the Savannah River have been obtained by the procedure described above, the concentrations of the radionuclides in the river can be easily computed by a variant of equation (7-1):

$$C_{ij} = R^R_{ij}/Q_j \qquad (7\text{-}4)$$

These concentrations were computed in this fashion, tabulated in a spreadsheet, and input to the GENII code. Concentrations in the Savannah River for various radionuclides computed in the manner described above are shown in Figure 7-6. Note the peaks in activity seen for ^{32}P, ^{137}Cs, and ^{90}Sr in the years 1966 and 1967. Chapter 11 discusses how the peaks caused high doses in receptors exposed to the contaminants released to the water through fish ingestion.

In order to compute the concentrations indicated in equation (7-4) the annual flow rates, Q_j, for the Savannah River were required. Annual flow rates for the Savannah River were derived in two ways:

1. For the years 1954 through 1969 and for the years 1983 through 1992, flow rates for the Savannah River as measured at Burtons Ferry Bridge (Highway 301) near Millhaven, Georgia, were obtained from the USGS [60]. This monitoring station is located about 500 feet downstream of the bridge on U.S. Highway 301 linking Screven County, GA, with Allendale County, SC. Hence, it is downstream of all surface water discharge points into the Savannah River from SRS.
2. No information was available from USGS for this monitoring station for the years 1970 through 1982. For these years, flow rates were projected from flow rates measured at Augusta, GA. The projected flow rates were derived using a relationship from Hayes and Marter (54). This reference reports a strong linear relationship (r = 0.98) between the flows at the Burtons Ferry Bridge and Augusta monitoring stations: $Flow_{BFB} = 1.15\ Flow_{AUG} + 202$.

The flow rates derived for this report are listed in Table 7-7 in units of cubic feet per second (cfs). Table 7-7 also presents the Savannah River volumes (liters) calculated for Phase III assuming 365 days per year (except for 366 days per year every leap year).

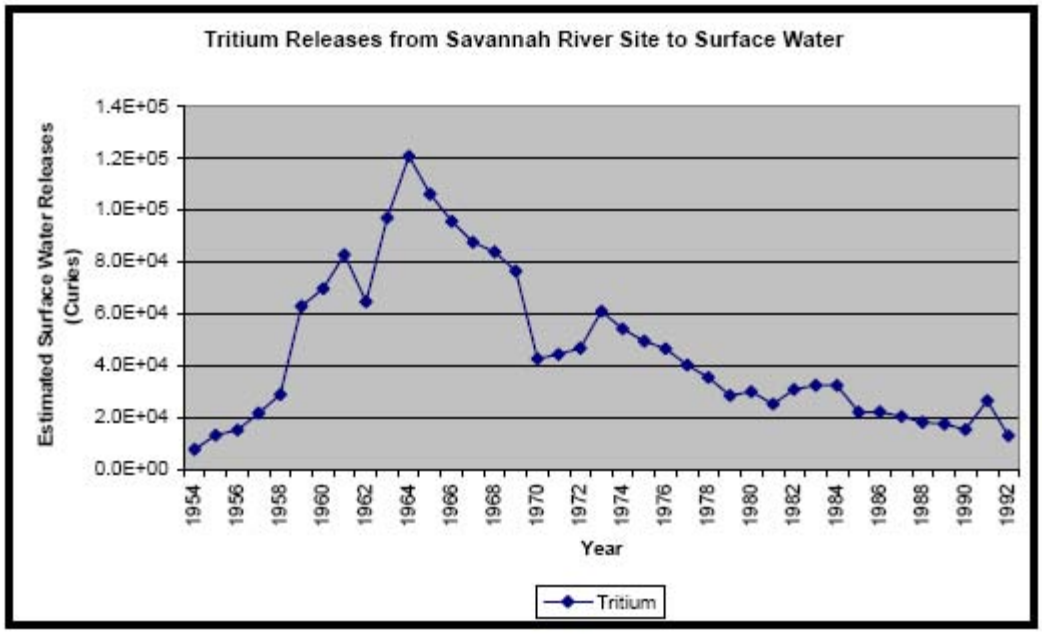

Figure 7-5 Tritium Release to Savannah River (Ci/y)

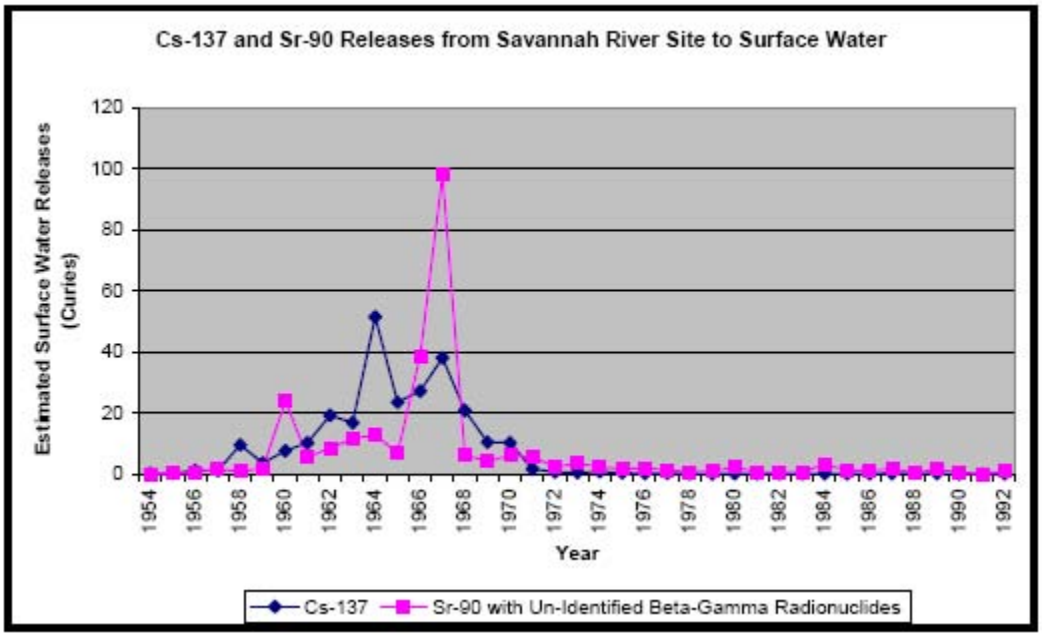

Figure 7-6 ^{137}Cesium and ^{90}Strontium Release to Savannah River (Ci/y)

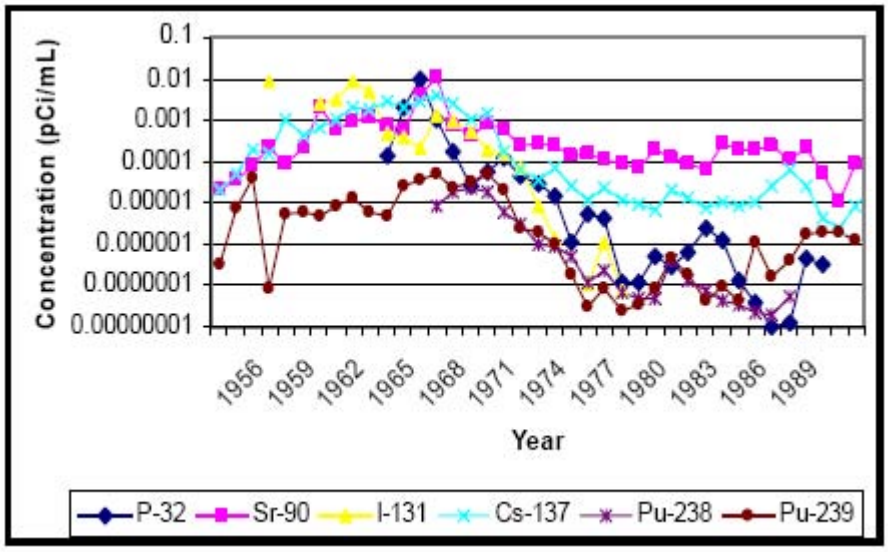

Figure 7-7 Estimated Concentrations of Selected Radionuclides in Savannah River (pCi/mL)

Table 7-7 Savannah River Flow Rates and Annual Volumes as Determined for Burtons Ferry Bridge (Highway 301)

Year	Leap Year	Annual Mean Value* (cfs)	Water Volume (Liter)	Year	Leap Year	Annual Mean Value* (cfs)	Water Volume (Liter)
1954		7,382	$6.60x10^{+12}$	1974		11,101	$9.93x10^{+12}$
1955		5,974	$5.34x10^{+12}$	1975		15,408	$1.38x10^{+13}$
1956	L	6,309	$5.66x10^{+12}$	1976	L	13,914	$1.25x10^{+13}$
1957		8,312	$7.43x10^{+12}$	1977		11,646	$1.04x10^{+13}$
1958		11,038	$9.87x10^{+12}$	1978		10,522	$9.41x10^{+12}$
1959		9,748	$8.72x10^{+12}$	1979		13,252	$1.18x10^{+13}$
1960	L	13,112	$1.18x10^{+13}$	1980	L	13,201	$1.18x10^{+13}$
1961		10,909	$9.75x10^{+12}$	1981		6,599	$5.90x10^{+12}$
1962		10,580	$9.46x10^{+12}$	1982		7,169	$6.41x10^{+12}$
1963		11,138	$9.96x10^{+12}$	1983		12,348	$1.10x10^{+13}$
1964	L	20,497	$1.84x10^{+13}$	1984	L	12,759	$1.14x10^{+13}$
1965		12,785	$1.14x10^{+13}$	1985		7,167	$6.41x10^{+12}$
1966		11,175	$9.99x10^{+12}$	1986		6,175	$5.52x10^{+12}$
1967		10,573	$9.45x10^{+12}$	1987		8,955	$8.01x10^{+12}$
1968	L	9,624	$8.63x10^{+12}$	1988	L	5,364	$4.81x10^{+12}$
1969		10,945	$9.79x10^{+12}$	1989		7,966	$7.12x10^{+12}$
1970		8,208	$7.34x10^{+12}$	1990		11,860	$1.06x10^{+13}$
1971		10,686	$9.55x10^{+12}$	1991		11,670	$1.04x10^{+13}$
1972	L	11,235	$1.01x10^{+13}$	1992	L	11,860	$1.06x10^{+13}$
1973		14,431	$1.29x10^{+13}$				

* Flow Rate From USGS Station ID: 02197500

These modeled concentrations were compared against measured concentrations in the Savannah River as obtained at the Highway 301 Bridge.[5] These measurements represent annual averages. For the years 1964 through 1992, the concentrations were obtained from SRS environmental reports. For the years 1960 through 1963, measured water concentrations were obtained from Health Physics Regional Monitoring Semiannual Reports or Semiannual Progress Reports.

For ^{3}H (Figure 7-8), the modeled concentrations generally resulted in smaller annual concentrations than those measured at U.S. Highway 301. The difference between the modeled and measured concentrations is especially seen from 1960 through 1975, which coincides with high release quantities; thereafter, agreement is good. For many of the years between 1960 through 1975, the Phase III set of concentrations is slightly larger than the set comprising release to streams and migration from seepage basins.

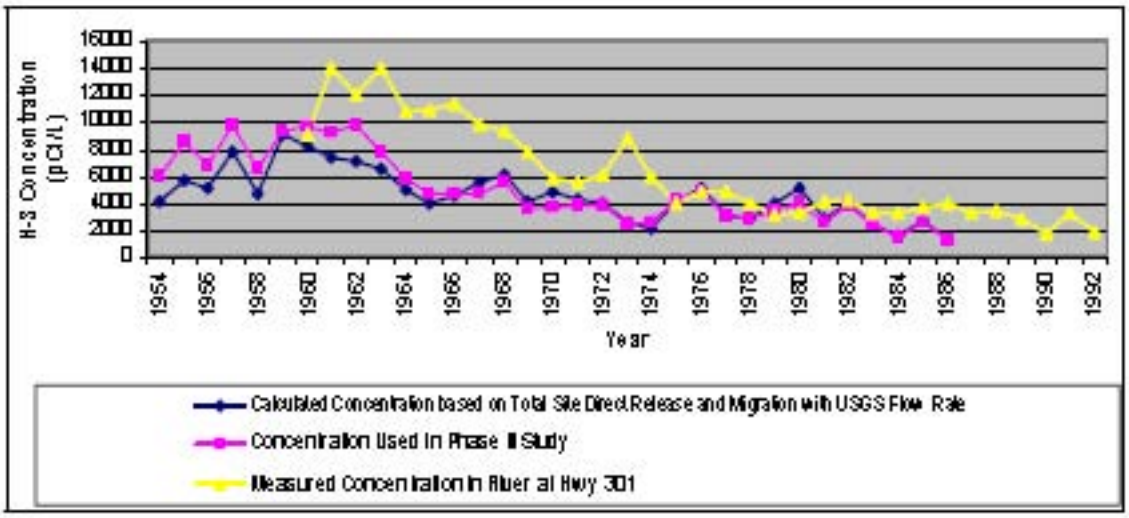

Figure 7-8 ^{3}H Concentrations in Savannah River (pCi/L)

For ^{90}Sr (Figure 7-9), the modeled and measured sets of concentrations show reasonable consistency, except for the years 1961 and 1962. However, for many years (particularly in the 1960s), the concentrations as used in the Phase III study are larger than those comprising the set representing release to streams and migration from seepage basins.

For ^{137}Cs (Figure 7-10), except for the years 1960 through 1963 and 1978, there appears to be a reasonable level of consistency between the Phase III model and measured concentrations. Note that the modeled concentrations considering release to streams and migration from seepage basins are larger than the Phase III modeled concentrations and measured concentrations for most of the 1960s.

For ^{131}I (Figure 7-11), there is little difference between either set of modeled concentrations. Both modeled sets appear to be reasonably consistent with measured concentrations.

[5] SRS environmental reports refer to this monitoring location as the River-10 location. This location is at Savannah River mile 120.

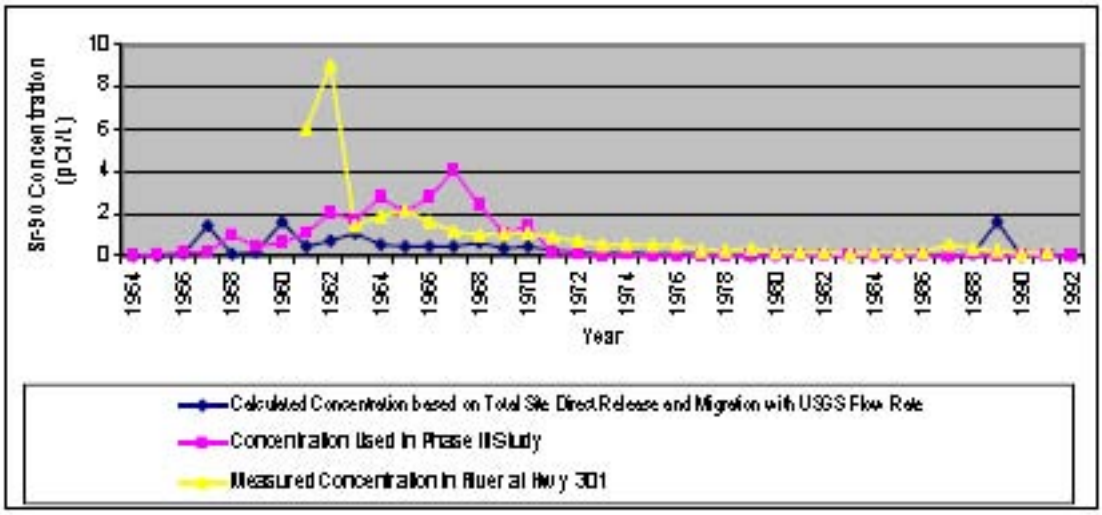

Figure 7-9 ^{90}Sr Concentrations in Savannah River (pCi/L)

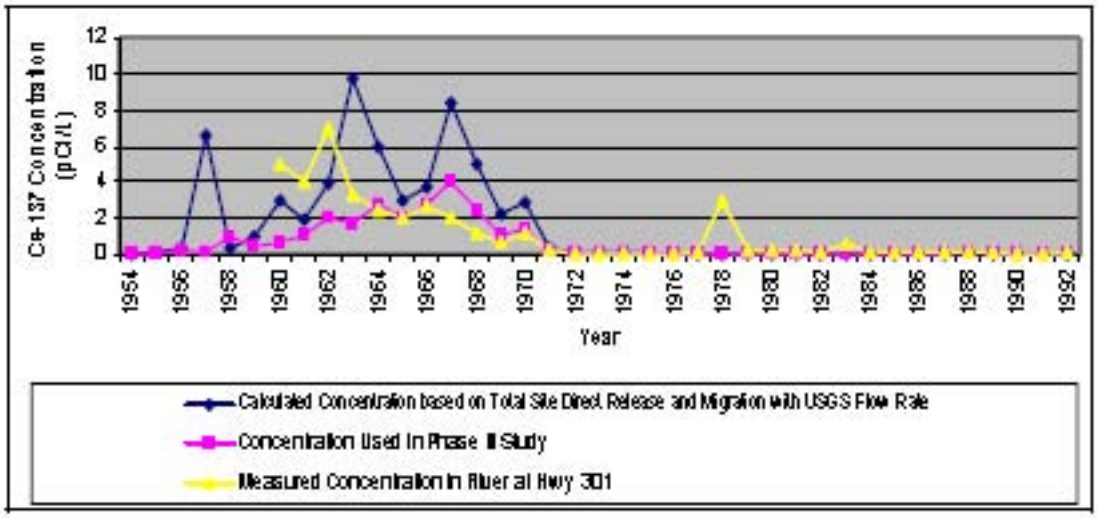

Figure 7-10 ^{137}Cs Concentrations in Savannah River (pCi/L)

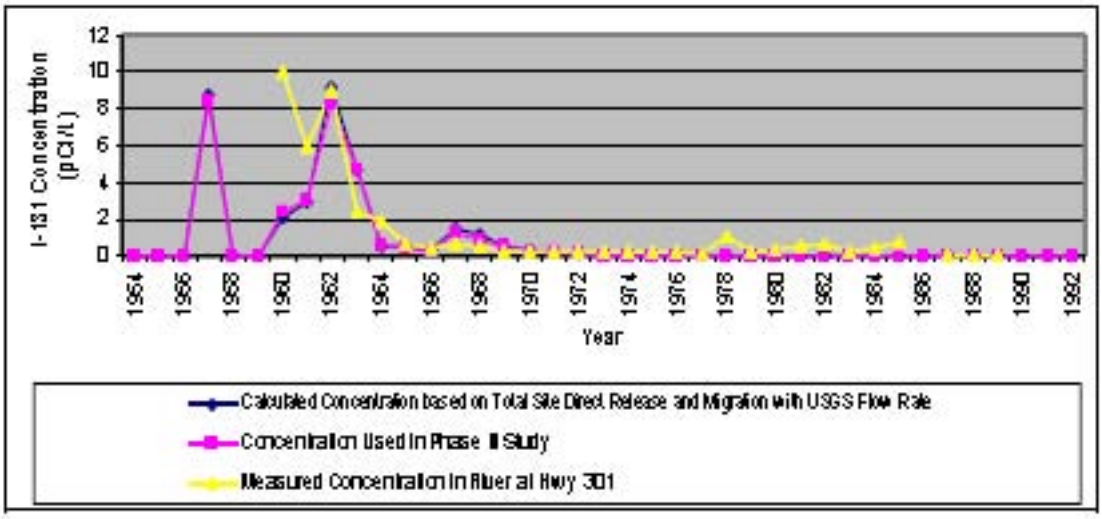

Figure 7-11 ^{131}I Concentrations in Savannah River (pCi/L)

As discussed above, these comparisons are not definitive. Nonetheless, these do appear to provide support to the conclusion that the modeling approach used for the Phase III study was a reasonable way to proceed given the complexity of the problem. It is disappointing that modeled and measured concentrations are not closer, especially in early years of high releases.

7.3.5 Comparison of Phase II Release Estimates and Phase III Source Terms

Because the estimates for concentrations in the Savannah River were based on water releases from the entire SRS, a comparison of the Phase II and Phase III bases is discussed here. The data used as input to Phase III of the SRS Dose Reconstruction Project were checked as part of a Quality Assurance Program. However, to assure appropriate agreement between the Phase II and Phase III analyses, the total releases for all significant radionuclides were compared.

7.3.5.1 Comparison of Phase II Modeled Releases to SRS Point-of-Release Data

For ^{3}H, ^{90}Sr, and ^{137}Cs, the annual medians (50th percentile) of the Phase II Savannah River release model are compared with the annual point-of-release estimates for these radionuclides as compiled from Category 1 and 3 releases documented in Cummins 1991a. The results of this comparison are summarized in Table 7-8.

Table 7-8 Comparison of Phase II Median Releases to Savannah River with SRS Point-of-Release

Radionuclide	Range of Median of Model to Point-of-Release Ratios	Mean, Median of Model to Point-of- Release Ratios
^{3}H	0.379 – 20.881	1.228*
^{90}Sr	0.008 – 6.383	1.379
^{137}Cs	0.001 – 0.972	0.234

*This ratio does not include 1954 estimates for ^{3}H.

It was expected that the median values estimated by the Phase II surface water model should be approximately equal to or smaller than the total releases reported by SRS. With a few exceptions, this was the case. An example exception is the 1954 ratio of the estimated median release to the total tritium release. The ratio is 20.881. The Phase II report stated that releases were adjusted if it was believed that reported releases were too low. This extremely high ratio is probably a reflection of such an adjustment, since reporting of releases in the early years of operations was not as accurate as in later years.

The ratios as a function of time are presented in Figure 7-5. Note that the ratios are dramatically higher during the last years of operations. The late years may reflect that operational releases from facilities in general were reduced, but there were still releases of residual radioactivity from the site. In particular the releases for ^{90}Sr were elevated because unidentified beta-gamma activity was added to the ^{90}Sr inventory. Note that the variations in time are significant. This is due, in part, to the model that increased releases in years with large spring floods to account for the remobilization of radionuclides stored in previous years in the sediments and biota of the swamp. For these reasons, annual adjustment factors were used for Phase III rather than an average adjustment factor covering all years.

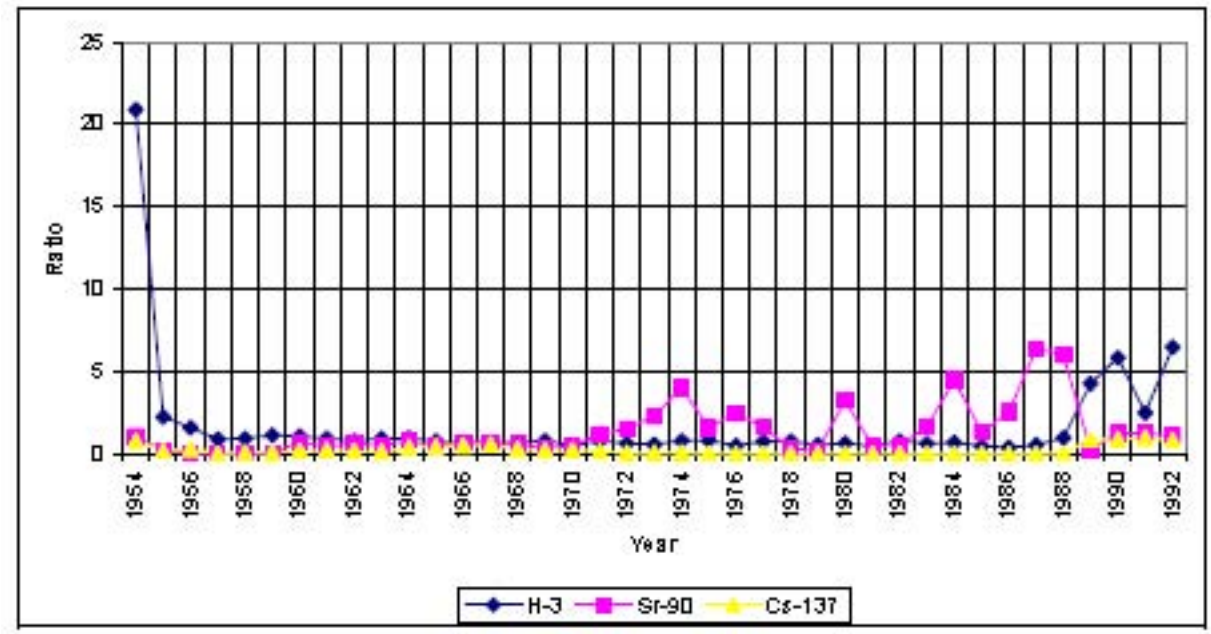

Figure 7-5 Annual Ratios of Phase II Median of Savannah River Release Model to SRS Point-of-Release Data.

7.3.5.2 Comparison of Phase III Releases with Phase II Screening Assumptions

Because of the approach adopted for Phase III, the releases to streams, seepage basins, and containment basins were compiled by radionuclide as point-of-release estimates, as discussed in Section 7.3.2.2.1. There are two comparisons of Phase III release estimates and Phase II release estimates that help to place the Phase III analysis in context:

1. The sum of Phase III releases for each radionuclide and all facilities over 36 years compared to the sum of 36-year, overall site releases for each radionuclide used in the Phase II screening analysis.

2. The sum (36 years and all facilities) of the extrapolated releases used in Phase III compared to sum of 36-year, overall site releases for each radionuclide used in the Phase II screening analysis.

Table 7-9 shows these comparisons.

Comparison 1. The Table 7-9 column headed "Check" compares the unadjusted Phase III values to the Phase II screening values. A star notation indicates that an explanation is warranted. These explanations are provided below.

^{3}H. For tritium, the Phase II study states that both streams and seepage basins were included as the source of releases to the surface water pathway in the screening assessment. It appears from the data presented in the Phase II report that seepage basin data for ^{3}H (and ^{131}I) was not included in the screening assessment. This is indicated by the good agreement between the stream-only source terms. (Phase III estimates releases to streams, seepage basins, and containment basins.)

^{131}I. The entry from the Phase II screening assessment is Category 1 release only; i.e., release to streams only. This appears to be appropriate because of the short, 8-day half-life of ^{131}I. Any

substantial holdup duration would cause the seepage basin inventory to decay away. The Phase III point-of-release data file only includes releases to streams.

^{129}I. In the Phase II report, the 1.2 Ci entry for ^{129}I in the table for the screening calculation was obtained by assuming that 3 Ci entered the seepage basin and 40% of that inventory was released from the basin to the stream (3 Ci * 0.4 = 1.2 Ci). Because Phase III modifies all of the other radionuclide inventories using an adjustment factor, 3 Ci was used.

^{89}Sr, ^{90}Sr. Although the Phase II screening value and the Phase III base value are different by about 15%, this appears to be due to an addition problem in the Phase II report. The screening spreadsheet value should have been about 720 Ci, based on the note in the spreadsheet indicating how the entry was obtained. However, this difference is not important. When ^{89}Sr, ^{90}Sr releases are applied in the dose reconstruction, unidentified beta-gamma releases were added to the ^{90}Sr inventory in the amount of 218.88 Ci (before multiplication by the adjustment factor for ^{90}Sr), this dwarfs any differences between the Phase III basis and screening values.

^{95}Zr, ^{95}Nb. The Phase II report stated that all estimates of reported releases of ^{95}Zr, ^{95}Nb, and ^{95}Zr, ^{95}Nb were combined to ensure a conservative approach. However, the value used in the Phase II screening seems to match only the total of ^{95}Zr and ^{95}Nb.

Comparison 2. The adjustment factors, applied on the basis of K_D, are reflected in the ratios of the Savannah River releases (Phase III) to the screening assessment releases (Phase II). Average ratios for three groups of radionuclides (^{3}H, ^{90}Sr, and ^{137}Cs groups) are given in Table 7-9.

The radionuclides scaled to ^{3}H have, on average, increased values compared with the screening assessment inventories (+28%). The Sr scaled nuclides have, on average, 62.1% of the screening value. The Cs-scaled nuclides have, on average, about 20% of the screening values. This is due to hold-up in the environment, based on use of different K_D values. These values compare, in general, with the adjustment factor values for each scaling group averaged over all the years, which are respectively: 0.749, 0.711, and 0.232. Since the ratio for each nuclide depends on applying the annual adjustment factor for the group to the annual releases for the radionuclide, the sum of the products depends upon the release history of the radionuclide. This accounts for the variability of the ratios within each group.

Table 7-9 Comparison of Phase III Releases with Phase II Screening Assumptions

Releases from Phase II Water-Level 1 Screening		Sum of 36-year Releases from Cummins Data - Basis for Phase III Point-of-Release Estimates			Sum of 36-year Phase III Releases to Savannah River	
Radio-nuclide	**Surface Water Release from SRS (Ci/36 yr)**	**Cat. 1+Cat. 3 Unless Otherwise Noted (Ci/36 yr)**	**Ratio, Screening to Phase III Basis**	**Check**	**Phase III Release to River (Ci/36 yr)**	**Ratio, Phase III River Release to Screening**
^{241}Am	1.00E-02					
^{140}Ba, ^{140}La	2.20E+02					
^{141}Ce, ^{144}Ce	$7.00\times10^{+02}$	$7.08\times10^{+02}$	0.99		$4.58\times10^{+02}$	6.54×10^{-01}
^{244}Cm	8.00E-01					
^{134}Cs	$1.35\times10^{+01}$	$1.35\times10^{+01}$	1.00		2.87	2.13×10^{-01}
^{137}Cs	$1.95\times10^{+03}$	$1.95\times10^{+03}$	1.00		$2.57\times10^{+02}$	1.32×10^{-01}

Releases from Phase II Water-Level 1 Screening		Sum of 36-year Releases from Cummins Data - Basis for Phase III Point-of-Release Estimates			Sum of 36-year Phase III Releases to Savannah River	
Radio-nuclide	**Surface Water Release from SRS (Ci/36 yr)**	**Cat. 1+Cat. 3 Unless Otherwise Noted (Ci/36 yr)**	**Ratio, Screening to Phase III Basis**	**Check**	**Phase III Release to River (Ci/36 yr)**	**Ratio, Phase III River Release to Screening**
^{58}Co	2.73E+00					
^{60}Co	$8.40 \times 10^{+01}$	$8.42 \times 10^{+01}$	1.00		$5.40 \times 10^{+01}$	6.43×10^{-01}
^{51}Cr	5.00E+03					
^{3}H	$1.50 \times 10^{+06}$	$1.53 \times 10^{+06}$	0.98	*	$1.73 \times 10^{+06}$	1.16
^{131}I	$3.03 \times 10^{+02}$	$3.02 \times 10^{+02}$	1.00	*	$2.88 \times 10^{+02}$	9.50×10^{-01}
^{129}I	1.20	3.00	see note	*	2.71	2.26
^{239}Np	1.44E+03					
^{32}P	$1.96 \times 10^{+02}$	$1.96 \times 10^{+02}$	1.00		$1.29 \times 10^{+02}$	6.60×10^{-01}
^{239}Pu, ^{240}Pu	8.00	7.9	1.01		2.95	3.69×10^{-01}
^{238}Pu	4.00	4.0	0.98		7.08×10^{-01}	1.77×10^{-01}
^{103}Ru, ^{106}Ru	$1.80 \times 10^{+03}$	$1.80 \times 10^{+03}$	1.00		$1.30 \times 10^{+03}$	7.25×10^{-01}
^{124}Sb, ^{125}Sb	2.40E+01					
^{89}Sr, ^{90}Sr	$6.20 \times 10^{+02}$	$7.11 \times 10^{+02}$	0.87	*	$4.60 \times 10^{+02}$	7.42×10^{-01}
^{35}S	$1.75 \times 10^{+03}$	$1.75 \times 10^{+03}$	1.00		$1.53 \times 10^{+03}$	8.77×10^{-01}
^{99}Tc	$5.30 \times 10^{+01}$	$5.30 \times 10^{+01}$	1.00		$5.47 \times 10^{+01}$	1.03
^{232}Th	2.00E-01					
^{235}U, ^{238}U	$4.20 \times 10^{+01}$	$4.15 \times 10^{+01}$	1.01		$1.19 \times 10^{+01}$	2.83×10^{-01}
^{91}Y	1.20E+02					
^{65}Zn	$1.50 \times 10^{+02}$	$1.50 \times 10^{+02}$	1.00		$9.64 \times 10^{+01}$	6.43×10^{-01}
^{95}Zr, ^{95}Nb	$1.45 \times 10^{+02}$	$9.64 \times 10^{+02}$	0.15	*	$8.23 \times 10^{+02}$	5.67
						Average Ratio
Tritium Group: ^{129}I, ^{131}I, ^{99}Tc, ^{35}S						1.28E+00
Strontium Group: ^{103}Ru, ^{106}Ru, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{95}Nb, ^{95}Zr, ^{32}P, ^{65}Zn, ^{141}Ce, ^{144}Ce, Uranium						6.21E-01
Cesium Group: ^{134}Cs, ^{137}Cs, Plutonium						2.23E-01

7.4 Modeling Concentrations for Lower Three Runs Creek

Unlike other streams draining the Savannah River Site, Lower Three Runs Creek can be routinely accessed by members of the public. Hence concentrations in the creek needed to be estimated so that potential exposures, in accordance with the scenario specifications, could be assessed.

7.4.1 A Simple Model for Lower Three Runs Creek (Step L-3)

Similar to the approach described in Section 7.3.1 annual concentration estimates of three radionuclides (^{3}H, ^{90}Sr, and ^{137}Cs) for the exposure location at Martin, SC, were computed by finding the ratio of (a) the annual release of each of these radionuclides into Lower Three Runs Creek and (b) the corresponding annual flow rates of Lower Three Runs Creek as determined from USGS monitoring stations. These calculated concentrations were then compared with concentrations of these nuclides as measured over the years at Martin, SC.

Annual flow rates for Lower Three Runs Creek at Martin, SC, were not available for the years 1954 through 1992, although they were available for the years 1998 through 2001. To estimate the flow rate at Martin for the time period of interest, the flow rate was estimated by ratio from the flow rate at a nearby location on the creek. The process for doing so is described in Appendix S.

Calculated Lower Three Runs Creek concentrations of ^{3}H, ^{90}Sr, and ^{137}Cs are compared with directly measured concentrations in Figure 7-6, Figure 7-7, and Figure 7-8. This comparison shows that concentrations in Lower Three Runs Creek based on release inventories and flow rates disagreed with measured concentrations. This disagreement was particularly evident for the case for ^{3}H and ^{137}Cs during the early years of site operation. Par pond was built on Lower Three Runs Creek in the 1960s and the dam would have affected flow rates and the discharge of radionuclides to areas below the dam.

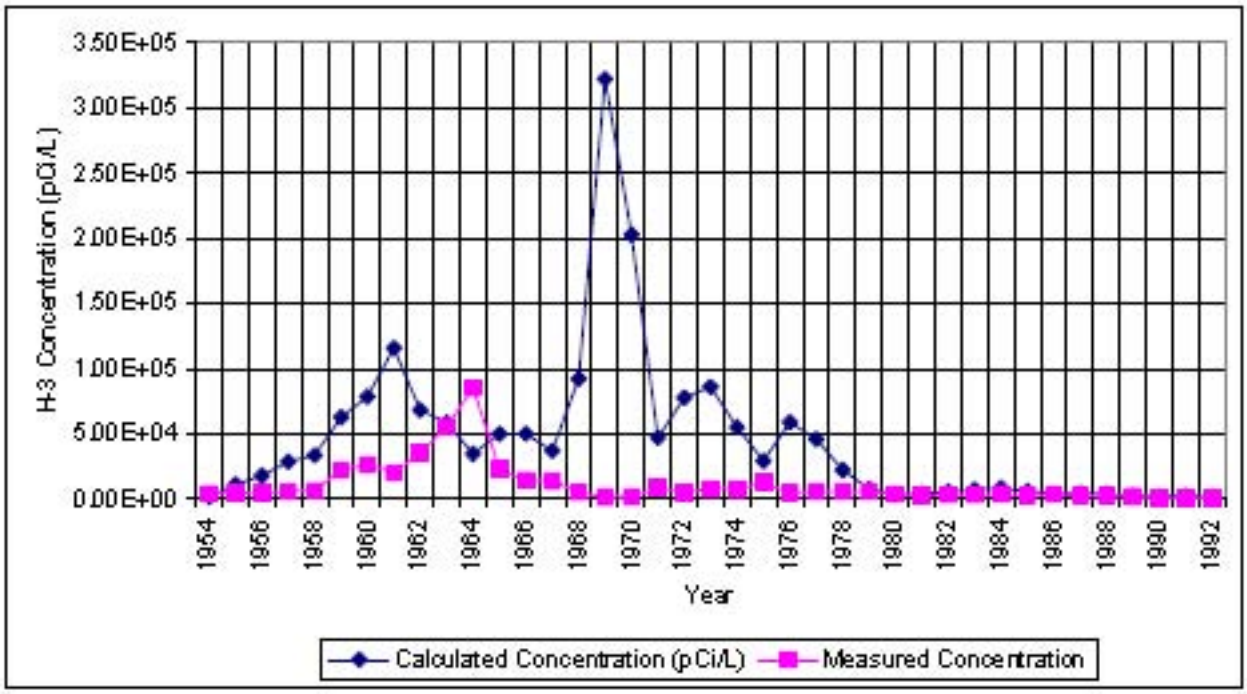

Figure 7-6 Comparison of Calculated to Measured Concentrations of ^{3}H in Lower Three Runs Creek (pCi/L)

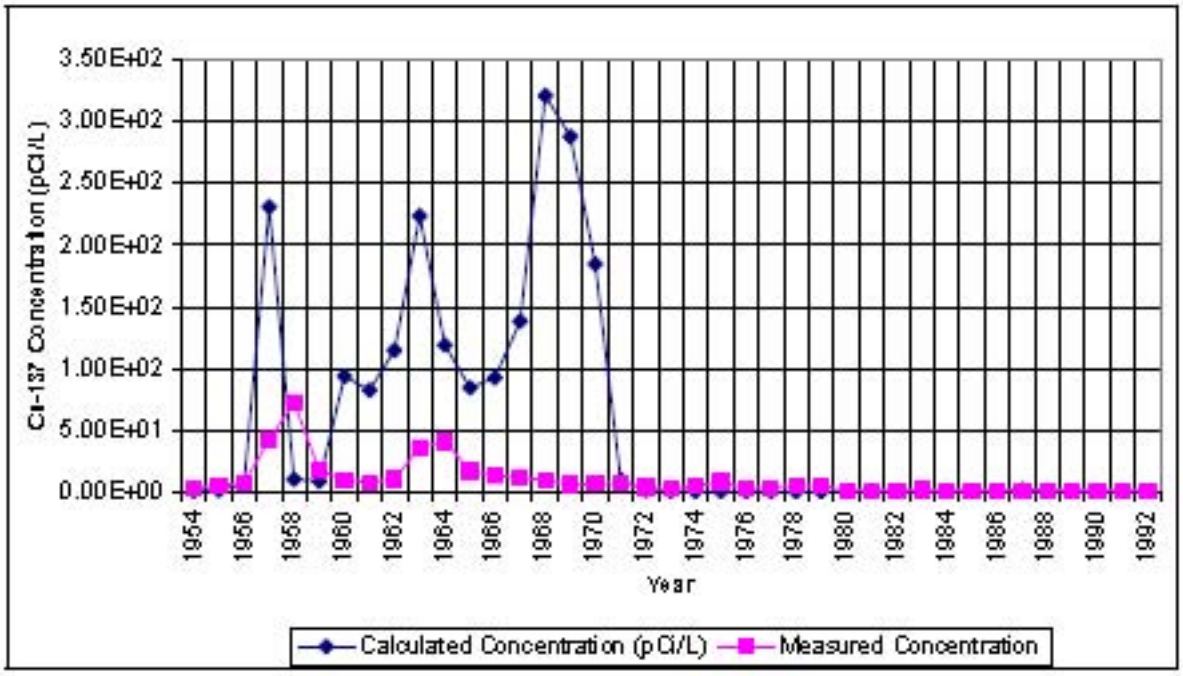

Figure 7-7 Comparison of Calculated to Measured Concentrations of ^{137}Cs in Lower Three Runs Creek (pCi/L)

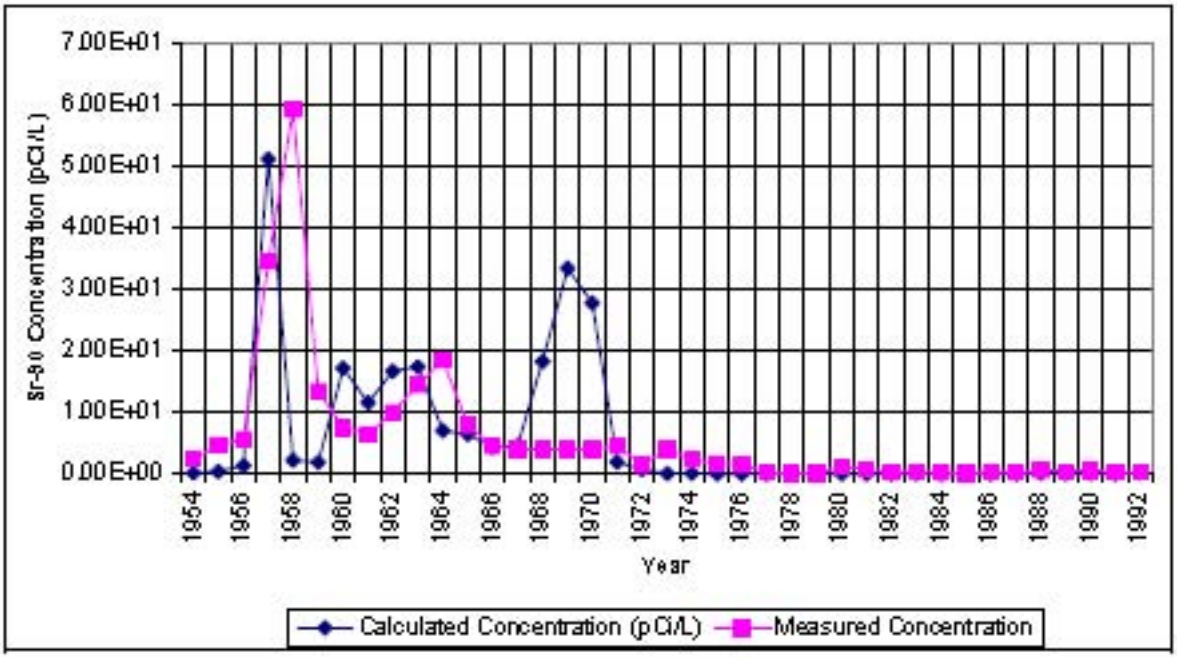

Figure 7-8 Comparison of Calculated to Measured Concentrations of 90Sr in Lower Three Runs Creek (pCi/L)

7.4.2 Use Available Measured Concentrations (Step L-4)

Because the concentrations estimated with a simple model did not agree with measurements, for Phase III the measured concentrations (at Martin, when possible) were used for three critical radionuclides (^{137}Cs, ^{90}Sr, and ^{3}H) to estimate doses at Martin from releases to Lower Three Runs Creek. This change was

especially important for early years when concentrations in the creek were high, but the estimates based on release inventories gave excessively high concentrations.

Short of developing a physically-based model similar to that used in Phase II for releases into the Savannah River, there was no practical alternative to estimating concentrations from SRS releases in Lower Three Runs Creek. Although releases through Lower Three Runs Creek would be expected to experience the same types of loss mechanisms (sedimentation, decay, and sorption or uptake), as other site streams, the influence of these processes was thought to be smaller than for other streams mainly because Lower Three Runs Creek does not pass through the Savannah River Swamp.

The choice of using actual measured concentration in the river had the following advantages:

1. The inventory of radionuclides initially entered into the Lower Three Runs Creek from the site and the annual flow rates in Lower Three Runs Creek became non-important because radionuclide concentrations were obtained directly from the actual measured concentrations in the monitoring reports.
2. The transport mechanisms were reflected in the measured concentrations. Sediment retention, radionuclide decay, biota uptake, periodic flooding, absorption and dilution only influenced how the radionuclides were transported in the creek. The focus in Phase III is to assess the exposures to these radionuclides in the river. Thus the result of radionuclide transport was the most important issue.
3. These three radionuclides (^{137}Cs, ^{90}Sr, and ^{3}H), identified as important in the Phase II Level 1screening, were measured on a regular basis for most of the operational years.

The disadvantages include:

1. Not all of the radionuclides of interest (radionuclides that passed the Level 1 Screening criteria) were routinely measured. As discussed in Chapter 11, doses from the release of ^{32}P to water were significant for exposures to Savannah River water. Since doses from ^{32}P and other radionuclides were not modeled for Lower Three Runs Creek, a potentially significant dose may have not been considered.
2. Contributions from runoff of land-deposited SRS radionuclide releases to air and discharges from non-SRS sources, if present in any significant fashion, could not be effectively distinguished or separated from liquid releases to Lower Three Runs Creek from the SRS.

7.4.3 Complete Data Base for Measured Concentrations (Step L-5)

Annual data for ^{3}H, ^{90}Sr, and ^{137}Cs were compiled from a variety of sources to make the surface water source term for Lower Three Runs Creek.

7.4.3.1 ^{137}Cesium and ^{90}Strontium

Average annual Lower Three Runs Creek concentrations were determined for ^{137}Cs, and ^{90}Sr using a variety of references. For the years 1964 through 1992, annual average concentrations were determined using data published in SRS environmental reports [(5), (10), (11), (12), (13), (14), (15) (16), (17), (18), (19), (20), (21), (22), (23), (24), (25), (26), (27), (28), (29), (30), (31), (32)]. For the years 1954 through 1963, no environmental reports were published. For these years, measured water concentrations in Lower Three Run Creek for nonvolatile beta, radiostrontium, and radiocesium were obtained from Health Physics Regional Monitoring Semiannual Reports or Semiannual Progress Reports [(33), (34), (35), (36), (37), (38), (39), (40), (41), (42), (43), (44), (45), (46), (47), (48), (49), (50)]. In these references, measured nonvolatile beta concentrations are available from 1954 to 1963 while radiostrontium and radiocesium concentrations are only available from the second half year of 1958 through 1963. Measured

average concentrations in Lower Three Run Creek at Martin were cited from these semiannual reports except for the first half year of 1954, when no sampling location is specified.

From the second half year of 1958 to 1962, measured nonvolatile beta, radiostrontium, and radiocesium concentrations provided the basis to calculate average values of the ratios of the concentrations of radiostrontium and radiocesium to the concentrations of nonvolatile beta activity in Lower Three Runs Creek at Martin. These average values are presented in Table 7-10. The average value of the ratio of radiostrontium to non-volatile beta over the period 1958 through 1962 is 0.25. The average value of the ratio of radiocesium to non-volatile beta over this time period was 0.30.

Table 7-10 Ratio of Radiostrontium and Radiocesium to Nonvolatile Beta Activity in LTRC at Martin

Date	Location	NVB* (pCi/L)	Radiostrontium (pCi/L)	Strontium-NVB Ratio	Radiocesium (pCi/L)	Cesium-NVB Ratio
Jul-Dec 1958	Martin	130	28	0.22	38	0.29
Jan-Jun 1959	Martin	74	16	0.22	19	0.26
Jul-Dec 1959	Martin	49	11	0.22	16	0.33
Jan-Jun 1960	Martin	20	6	0.30	8	0.40
Jul-Dec 1960	Martin	40	9	0.23	12	0.30
Jan-Jun 1961	Martin	24	8	0.33	8	0.33
Jul-Dec 1961	Martin	27	5	0.19	7	0.26
Jan-Jun 1962	Martin	50	11	0.22	11	0.22
Jul-Dec 1962	Martin	30	9	0.30	10	0.33
Mean	Martin			0.25		0.30
Standard Deviation	Martin			0.05		0.05

*NVB- Non-volatile beta.

These ratios were used to scale average annual concentrations of ^{90}Sr and ^{137}Cs from average annual nonvolatile beta concentrations for the years 1954 through 1957 when radiostrontium and radiocesium data were not reported. The ratios were also used for 1958 because ^{90}Sr and ^{137}Cs data were not reported for the first half of this year. This scaling approach is the same approach used in Phase II to determine ^{137}Cs and ^{90}Sr concentrations for some years in SRS streams (see Chapter 5, p. 5-49, of Phase II).

7.4.3.2 Tritium

Average annual Lower Three Runs Creek concentrations were determined for tritium for the years 1964 through 1992 using data published in SRS environmental reports [(9), (10), (11), (12), (13), (14), (15), (16), (17), (18), (19), (20), (21), (22), (23), (24), (25), (26), (27), (28), (29), (30), (31), (32), (5)]. For the second half of 1958 through 1963, measured tritium concentrations in Lower Three Run Creek were obtained from Health Physics Regional Monitoring Semiannual Reports and Semiannual Progress Reports [(33), (34), (35), (36), (37), (38), (39), (40), (41), (42), (43), (44), (45), (46), (47), (48), (49), (50)]. Measured average concentrations in Lower Three Run Creek at Martin were cited from these semiannual reports except for the first half year of 1954, when no sampling location is specified.

From 1954 to 1957, tritium releases were monitored in facility effluents but not in Lower Three Runs Creek. For these years, tritium concentrations were estimated using information in the Phase II report. The tritium activity discharged to Lower Three Runs Creek accounted for approximately 5% of the total tritium entering on-site streams. This is based on weekly measured values from 1959-1967 in the streams at the last onsite location before the streams emptied into the Savannah River. A documented annual creek flow rate from 1954 to 1958 could not be located. As a result, the flow rates for these years were estimated as discussed in Appendix S.

7.4.3.3 Interpretation of Monitoring Data in Lower Three Runs Creek

Monitoring data were used in the following manner:

If the concentration of a radionuclide of interest (i.e. tritium, cesium, or strontium) was reported, it was included directly. The reported concentration was used directly if the result was reported as an annual average. When concentration data were provided on a semi-annual basis, the average for the first and second half of the year was taken to represent the annual average concentration. The average was used because the environmental monitoring report only shows the average for the monitored period, although sometimes the number of samples taken was also reported as well as maximum and minimum concentrations for the period.

If the environmental report or other reference showed “ND”, “<MDA”, “Below Detection Limit”, or “Below Sensitivity,” one half of the reported detection limit or sensitivity was used for the indicated period of time. Detection limits or sensitivity are generally listed in every year’s environmental report for different analytical instrumentation, analytical parameters, and sample matrices. When a detection limit or sensitivity is referenced for a particular water sample, the detection limit or sensitivity of the corresponding analytical procedure for the particular radionuclide (i.e. tritium, radiocesium, or strontium) was used.

7.5 References

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