CHAPTER 14

RADIONUCLIDES IN FISH

ABSTRACT

This chapter discusses radionuclide concentrations measured in fish collected from onsite streams at the Savannah River Site (SRS) and offsite locations in the vicinity of the SRS, including the Savannah River. We evaluated these data with regard to their potential usefulness for dose reconstruction. We also attempted to validate the data by comparing concentrations reported in as many sources as possible. These data included original, hand-written compilations for many years. We have found these original data to consistently correspond to the data reported in monthly, semi-annual, and annual summary reports.

We compiled and examined fish data and other environmental information to determine their usefulness for source term verification, model validation, and direct exposure assessment. In general, the fish data are most valuable for direct exposure assessment, but they may also be useful for source term verification and model parameter development. Appendix K further discusses potential uses for environmental monitoring data.

INTRODUCTION

The SRS buffer area (about 300 mi^2) includes five major streams that flow into the Savannah River. This buffer area was designed to allow for direct discharge of reactor effluent to these streams with sufficient dilution occurring before the streams reached their confluence with the Savannah River, thereby minimizing offsite distribution of radionuclides. However, it was evident by the mid-1950s that fish populations in the Savannah River, particularly near the mouths of onsite streams, were being impacted by SRS activities.

Fish from the Savannah River represent a potentially important exposure pathway to people who may have relied on them for a significant portion of their diet. Although locations within the plant boundary have not been legally accessible to the general public, it is possible that some people poached fish from onsite locations. To estimate potential exposure to people ingesting fish from either the Savannah River or onsite locations during a later phase of this project, we must compile and evaluate radionuclide concentrations that have been measured in fish collected from these areas.

This section summarizes reported information regarding radionuclide concentrations in fish collected from locations on or in the vicinity of the SRS. We examined several sets of routine semiannual and annual environmental monitoring reports, prepared by the SRS contractor and spanning the years 1953 through 1992. See Chapter 7, Table 7-1 for a complete description of the various monitoring report series.

Several additional documents have been reviewed for information pertaining to fish monitoring at the SRS. These include monthly monitoring reports from 1962 through 1965, weekly monitoring reports from 1959 through 1962, and aperture card printouts (handwritten data entry sheets) from 1970 through 1981. In general, the data reported in these documents is consistent with data provided in the monitoring reports. The radionuclides for which data are available for fish include gross alpha/beta and nonvolatile beta activity, ^{137}Cs, $^{89,90}Sr$, ^{65}Zn, ^{32}P, and ^{3}H. Appendix A details analytical and counting procedures for fish. Mercury concentrations have also routinely been reported for fish and are discussed in Chapter 20.

Routine collection of fish began in July 1957 in response to increased releases of reactor effluent to Four Mile Creek, Steel Creek, Lower Three Runs Creek, and ultimately the Savannah River, resulting from a series of fuel element failures. Before July 1957, small numbers of fish were randomly sampled from onsite streams and the Savannah River.

Fish were collected by angling and trapping, with no mention of the specific type of trap(s). Before 1962, the frequencies of collection and analysis are unclear. From 1962 through July 1968, fish were collected and flesh and bone samples were composited for weekly and monthly analysis, respectively. A composite is a single sample comprising a number of individual fish. From August 1968 through 1970, fish were collected weekly, and flesh and bone samples were composited for monthly analysis at each location. Beginning in 1971, individual whole fish were analyzed for ^{137}Cs, except at Par Pond and Pond B, where samples were composited for monthly analysis, and bone tissue was composited for monthly $^{89,90}Sr$ analysis at all locations. The Site reports suggest that Par Pond and Pond B fish samples were composited for analysis through 1983, after which individual whole fish were analyzed. Sample collection frequencies are unclear since 1971, but they appear to have varied depending on the collection location, based on data provided in aperture card printouts from 1971 through 1983.

Little classification of fish species was made before 1971. The types of fish collected were reported to be predominantly bream including shellcracker, bluegill, and redbreast of the genus *Lempomis*. The bluegill (*Lempomis macrochirus*), a surface and bottom feeding omnivore, was reportedly selected in 1962 by the SRS as indicative of maximum uptake of radionuclides by edible species of fish (Harvey and Rabon 1965). This selection was based on the results of a nine month study conducted on bluegill, catfish, and largemouth bass collected from Par Pond in 1962 (Harvey 1963). The study indicated $^{134,137}Cs$ and $^{89,90}Sr$ to be distributed similarly in the three species of fish, but ^{65}Zn accumulated to higher levels in bluegill than in catfish or largemouth bass.

Beginning in 1971, the types of fish collected were further differentiated; the list included bream, catfish (predominantly yellow cat of the genus *Ictalurus*), and bass (predominantly large mouth of the genus *Micropterus*). Beginning in 1981, numerous other fish species were routinely reported, including carp, eel, mullet, perch, crappie, war mouth, bowfin, shad, flounder, gar, trout, suckers, chain pickerel, croaker, jack, whiting, spot, menhadden, and bluefish. Table 14-1 shows the percentages of bream, bass, catfish, and other fish collected at several locations since 1971, when classification of separate species began. The years during which these data were reported are also included.

BASIS FOR ANALYSIS

While concentrations for several different species have been reported, a detailed examination of concentrations for individual species would be tedious and difficult to interpret. In addition, no species distinctions were made before 1971 when concentrations were significantly higher than in later years. For the purposes of both brevity and clarity, and more importantly, for comparison to concentrations measured before 1971, we examined average concentrations across all species. Based on the reported concentrations for various species of fish, there is some evidence to suggest that this method of evaluation may result in data bias. Ratios of ^{137}Cs concentrations reported for bream and catfish compared to those reported for bass from 1971 through 1976 for all onsite stream and Savannah River locations (Table 14-2) reveal some potential differences in concentration as a function of species. These years were used because species distinctions were first made in 1971, and concentrations were still significantly above the detection limit, particularly for onsite streams. Based on median ratios, concentrations in bass appear slightly higher than those reported for bream and catfish.

Table 14-1. Percentage of Bream, Bass, Catfish, and Other Fish and the Total Number of Fish Collected for Radionuclide Analysis[a] at Locations on or in the Vicinity of the SRS

		Percentage				
Location	Years	Bream	Bass	Catfish	Other	Total number
Clark's Hill/Thurmond Lake	1981–90	51.6	17.8	22.8	7.8	320
Savannah River						
Above SRS (R-2)	1971–91	37.7	4.2	46.1	12.0	1155
Adjacent to SRS (R-8)	1971–91	43.2	5.7	40.9	10.2	1083
Below SRS (R-10)	1971–91	49.9	3.5	36.5	10.2	1389
River Total		*44.0*	*4.4*	*40.9*	*10.8*	*3627*
Steel Creek						
At Road A	1971–79, 1984–91	42.8	26.2	21.6	9.5	1015
2 mi downstream from Rd. A	1971–72	65.8	14.2	20.0	0	295
Near mouth	1971–79	55.9	9.4	34.6	0	381
Four Mile Creek						
At Road 3	1971–79, 1986–91	80.4	11.2	5.2	3.2	561
Cassel's Pond	1971–79, 1984–86	65.5	17.7	14.9	2.0	666
Lower Three Runs						
At Patterson's Mill	1971–79, 1984–91	52.8	14.9	27.7	4.6	591
Reservoirs						
Par Pond	1971–78, 1984–91	33.8	50.2	1.3	14.7	920
Pond B	1984–91	43.3	47.0	7.5	2.2	268
Onsite Total		*52.5*	*15.6*	*25.6*	*6.3*	*4697*
Grand Total		48.8%	16.3%	26.6%	8.2%	8324

[a] Data are from annual environmental monitoring reports, 1971–1991.

Trophic level increases have been observed for ^{137}Cs concentrations in fish (Pendleton et al. 1965; Whicker et al. 1972). These effects result from similar assimilation of cesium and potassium but greater retention of cesium (Whicker and Schultz 1982). Whicker et al. (1990) reported ^{137}Cs concentrations for fish collected from Pond B at the SRS, and a catfish to bass concentration ratio of 0.7 and a bluegill to bass concentration ratio of 0.6 can be calculated based on these data. Similarly, a catfish to bass ratio of 0.8 and a bluegill to bass ratio of 0.4 can be calculated based on data reported by Mohler et al. (1997). Based on data provided by Harvey (1963), a catfish to bass ratio of 1.1 and a bluegill to bass ratio of 0.8 can be calculated. Such fish species are at or near the top of the food chain, would be expected to have higher concentrations than smaller baitfish, and likely represent concentrations for most commercial and sport fish. However, based on data from these studies, ^{137}Cs concentrations in bass may be as much as a factor of 2.5 greater than those measured in bluegill (bream) and a factor of 1.5 greater than those measured in catfish. During subsequent phases of the dose reconstruction process (e.g., direct exposure assessment from ingestion of fish), it may be necessary to account for the potential differences in ^{137}Cs or other radionuclide concentrations that may exist for different species of fish.

Arithmetic mean concentrations have been historically reported by the SRS, and many of the trends and comparisons made in this section are based on these reported concentrations. Radiocesium concentrations, however, commonly fail to show a normal frequency distribution in environmental samples (Pinder and Smith 1975). This was evident with concentrations of ^{137}Cs measured in deer tissue (see Chapter 11). Medians, percentiles, and ranges are often more appropriate descriptors of these types of data. Examining concentrations for individual fish collected from Steel Creek and Four Mile Creek in 1972 and 1974 suggests a lognormal distribution, particularly for lower concentrations such as those measured in the Savannah River and in the lower parts of onsite streams. If this is the case, then arithmetic mean concentrations likely represent a conservative estimate of the central tendency for radiocesium concentrations in fish flesh.

Table 14-2. Sample Sizes and Average Concentrations of ^{137}Cs Reported for Bream and Catfish Relative to Average Concentrations Reported for Bass from 1971 through 1976[a]

	Bass	Bream			Catfish		
		Ratio of ^{137}Cs concentration in bream to that in bass[b]			Ratio of ^{137}Cs concentration in catfish to that in bass[b]		
Year	Sample size	Mean	Median	Sample size	Mean	Median	Sample size
Jan–June 1971	75	0.8	0.7	379	0.7	0.6	174
July—Dec 1971	54	0.7	0.7	329	0.9	0.9	168
Jan—June 1972	119	1.7	1.2	313	1.3	1.3	143
July—Dec 1972	76	1.0	0.6	297	2.2	1.0	192
July—Dec 1973	150	1.1	0.5	649	0.9	0.9	328
1974	163	0.5	0.5	411	0.7	0.6	278
1975	117	0.7	0.5	203	1.0	1.0	218
1976	12	1.6	1.0	29	1.1	1.0	33
Average		*1.0*	*0.7*		*1.1*	*0.9*	

[a] Data are from semi-annual and annual environmental monitoring reports, 1971–1976.

[b] Ratios were calculated based on the average concentrations reported for each location, and median and mean values were calculated based on these ratio values.

RADIONUCLIDE CONCENTRATIONS IN FISH FROM THE SAVANNAH RIVER AND ONSITE STREAMS

Assessing potential exposure to the general public from fish consumption is difficult because fish are able to move freely in Four Mile Creek, Steel Creek, and Lower Three Runs Creek, and they can potentially migrate to the Savannah River. The SRS has, however, maintained an extensive fish sampling program that, between 1962 and 1991, collected and reported concentrations for more than 13,300 fish (more than 5800 from the Savannah River and more than 7500 from onsite streams). This total is based on the collection numbers that have been reported in the monitoring reports (the number of onsite samples was not provided in 1962). This total also does not include fish sampled from Upper Three Runs Creek from 1987 through 1991. These data were not compiled because the ^{137}Cs concentrations in fish from Upper Three Runs Creek were not significantly elevated relative to concentrations in fish from the Savannah River, which were at or near the detection limits during this time period. Before 1962, more than 4200 fish were collected and analyzed from the Savannah River and onsite locations. Figure 14-1 shows the number of fish sampled from the Savannah River and onsite locations from 1963 through 1991.

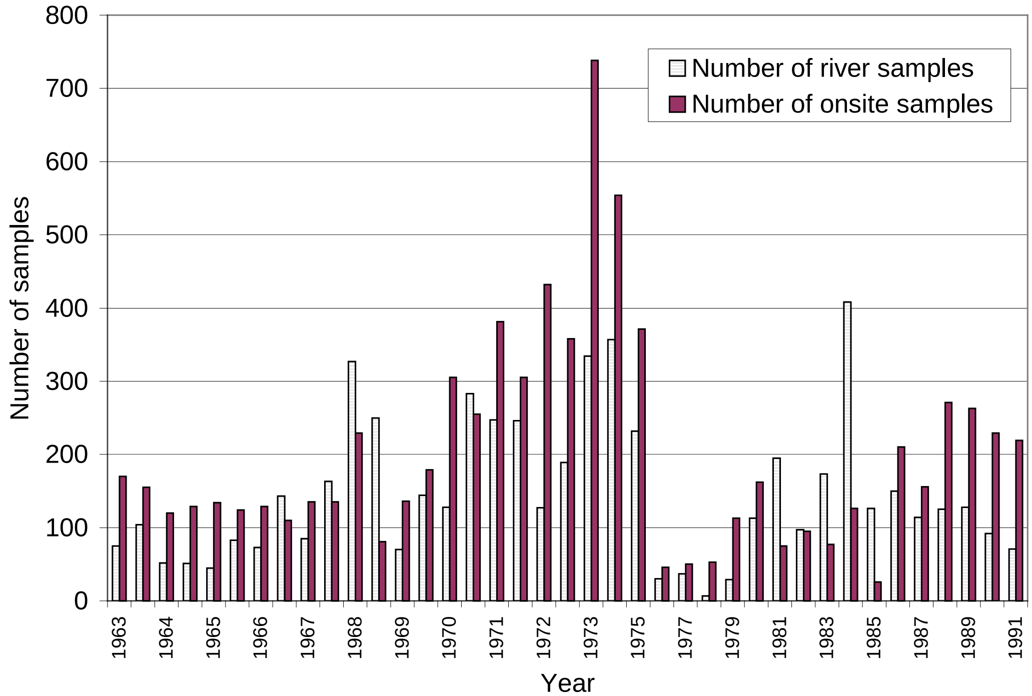

Figure 14-1. Number of fish collected from the Savannah River and onsite locations by SRS personnel from 1963 through 1991. Link to tabulated figure data.

Onsite stream sampling locations (Figure 14-2) were such that average and maximum concentrations in fish at and downstream from the most contaminated areas could be determined. Offsite locations were positioned along the Savannah River and indicate the average and maximum concentrations that have been measured in fish that were potentially caught by the general public. Concentrations in fish from two onsite reactor cooling reservoirs, Par Pond and Pond B, have also been routinely measured. However, fish in these reservoirs are isolated from the Savannah River and, therefore, are inaccessible for legal consumption by the general public. The SRS has collected fish from the Savannah River above the plant boundary, at Clark Hill/Thurmond Lake (approximately 60 mi. upriver from the SRS), and at Stoke's Bluff (approximately 60 mi. downriver from Lower Three Runs) to serve as control locations. While concentrations have not been reported continuously since 1957 for all locations, concentrations have been reported continuously since 1957 for three Savannah River sampling locations: R-2 (above SRS), R-8 (adjacent to SRS), and R-10 (below SRS). Table 14-3 provides a general summary of the routine sampling and analyses that have been completed for fish since the inception of the monitoring program.

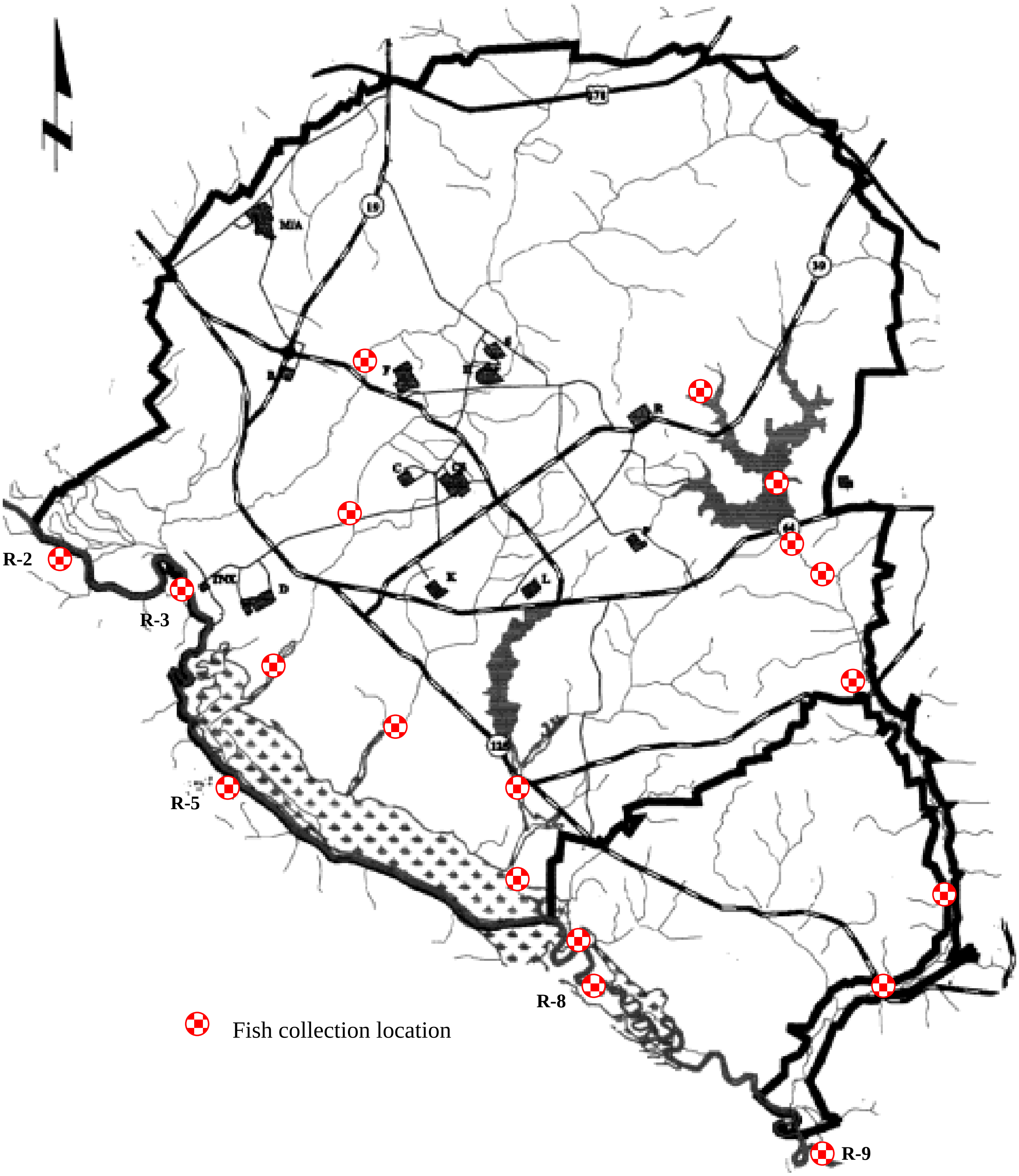

Figure 14-2. Onsite and Savannah River fish collection locations. The Clark Hill Reservoir (control) and R-10 locations are not shown. Clark Hill Reservoir is approximately 60 mi upriver from the SRS, and the R-10 location is approximately 10 mi below the SRS at the Highway 301 bridge.

Table 14-3. Summary of Routine SRS Radiological Monitoring for Fish[a]

	Sampling locations									Radiological analyses				
	Savannah River				Onsite									
Year	R-2, R-8, and R-10	R-3, R-5, and R-9	Clark Hill Reservoir	Stoke's Bluff	Par Pond (Pond B[b])	Upper Three Runs	Steel Creek	Four Mile Creek	Lower Three Runs	Gross nonvolatile beta	Cesium-137	Strontium-89,90	Zinc-65	Tritium[c]
July 1957	x						x	x	x	x				
1958	x	x		x	x		x	x	x	x				
1959	x	x		x	x	x	x	x	x	x				
1960	x	x		x	x	x	x	x	x	x				
June 1961	x	x		x	x	x	x	x	x	x				
July 1961	x			x	x	x	x	x	x	x	x	x	x	
1962	x				x		x	x	x	x	x	x	x	
1963	x				x		x	x	x	x	x	x	x	
1964	x				x		x	x	x	x	x	x	x	
1965	x				x		x	x	x	x	x	x	x	
1966	x				x		x	x	x	x	x	x	x	
1967	x				x		x	x	x	x	x	x	x	
1968	x				x		x	x	x	x	x	x	x	
1969	x				x		x	x	x	x	x	x	x	
1970	x				x		x	x	x		x	x	x	x
1971	x				x		x	x	x		x	x		x
1972	x		x		x		x	x	x		x	x		x
1973	x		x		x		x	x	x		x	x		x
1974	x		x		x		x	x	x		x	x		x
1975	x		x		x		x	x	x		x	x		x
1976	x		x		x		x	x	x		x	x		x
1977	x		x		x		x	x	x		x	x		x
1978	x		x		x		x	x	x		x	x		x
1979	x		x		x		x	x	x		x	x		x
1980	x		x		x		x	x	x		x	x		x
1981	x		x		x		x	x	x		x			x
1982	x		x		x		x	x	x		x			
1983	x		x		x		x	x	x		x			
1984	x		x		x		x	x	x		x			
1985	x		x		x		x	x	x		x			
1986	x		x		x		x	x	x		x			
1987-1991	x		x		x	x	x	x	x		x			

[a] This table is intended to provide the reader with general time periods only for collection and analysis of samples at routine locations and is not an exact representation of all collected data
[b] Reporting for Pond B began in 1974
[c] Tritium results were reported for R-2, R-8, and R-10 Savannah River locations only

Average Nonvolatile Beta, Cesium, and Strontium Concentrations

A summary for average ^{137}Cs concentrations measured in all fish at most sampling locations for 1975 and 1979 through 1991 was provided in Arnett et al. (1992). However, it was not clear how these averages were determined. In some cases the averages appeared to be calculated based on mean concentrations for each species without regard for the relative number of each species. In other cases the relative number of each species appeared to be taken into account. To maintain consistent methodology, we recalculated the weighted arithmetic average concentrations across all species based on the tabulated mean concentrations for each species considering the relative number of each species. In some cases insufficient data were available (e.g., mean for a given species was not provided), and we used the maximum measured concentration for that particular species for calculating the average across all species. In general, the recalculated averages were consistent with those reported in the 1991 report, with some slight differences.

Before 1971, concentrations for individual species were not given, so the actual tabulated data were used. Between 1980 and 1983, only concentrations measured at locations along the Savannah River were provided (concentrations measured at the control location, Clark Hill, were also provided from 1981 through 1983), so we used the average concentrations reported for onsite locations in the 1992 report (discussed above). In addition, concentrations measured in Pond B were not reported until 1974.

The radionuclide of most interest in terms of dose reconstruction is ^{137}Cs because it behaves like its nutrient analog, potassium, and tends to accumulate in muscle tissue, the portion of fish typically consumed. Strontium-89,90, ^{65}Zn, and ^{32}P may not present as important an exposure pathway since they tend to accumulate primarily in bone tissue, which is not typically consumed. However, we discuss radionuclide burdens in bone because it is possible that some people may have made fishcakes from Savannah River fish, which include some portion of bone. Also, small fish can be pan-fried without removing the skin and scales, which have been shown to contain higher concentrations of bone-seeking radionuclides than the muscle tissue (Rope and Whicker 1985).

For dose reconstruction, it is more realistic to use average measured concentrations for estimating potential exposure to individuals who may have relied upon Savannah River fish for a significant portion of their diet (e.g., 19 kg y^{-1} [Hamby 1991]). For this reason, the majority of the discussion regarding radionuclide concentrations in fish focuses on average concentrations. However, maximum concentrations are briefly discussed to provide an understanding of the maximum concentrations to which smaller numbers of individuals may have been exposed. Detailed information regarding use factors and ingestion rates for the Savannah River can be found in Hamby (1991), Turcotte (1983), and Hutto and Turcotte (1983). This type of information will be important in a future phase of this project when doses and risks are estimated.

Savannah River

The Health Physics Section at the SRS conducted Site surveys before plant startup to determine the quantities of radionuclides in several environmental media. Two reports were available for review (Reinig et al. 1953; Reinig 1952). Reinig et al. (1953) provided data for approximately 80 fish that were collected from the environs of the Savannah River Plant between

June 1951 and January 1953, before the first liquid effluent discharge to Lower Three Runs Creek from R Reactor in June 1954. The entire fish was analyzed in most cases, but specific tissues were analyzed for some fish. These fish were analyzed for nonvolatile beta concentrations, and most fish averaged less than 15 pCi g^{-1} (the apparent detection limit) with a maximum of 38 pCi g-1 detected in the flesh of one fish. Reinig (1952) provided data for approximately 46 fish collected before August 1952. The average nonvolatile beta concentration detected in the flesh and bones of these fish was 5.0 and 11.7 pCi g^{-1}, respectively.

Because only nonvolatile beta concentrations were reported before 1962, it is instructive to examine the years during which both nonvolatile beta and ^{137}Cs concentrations were reported. Table 14-4 shows the concentrations of nonvolatile beta, ^{137}Cs, and ^{89,90}Sr measured in fish collected from Savannah River locations from July 1958 through 1969. It is assumed that these reports provided information for the same fish, but slightly different sample numbers were reported for several years.

Table 14-4. Nonvolatile Beta[a], ^{137}Cs[b], and ^{89,90}Sr[b] Concentrations (pCi g^{-1}) Measured in Fish Flesh and Bone Collected from the Savannah River Above, Adjacent to, and Below the SRS

		Above SRS (R-2)				Adjacent to SRS (R-8)				Below SRS (R-10)			
		Flesh		Bone		Flesh		Bone		Flesh		Bone	
Year	Month	NB[c]	Cs	NB	Sr	NB	Cs	NB	Sr	NB	Cs	NB	Sr
1958	July—Dec	4		10		4		15		4			
1959	Jan—June	4		10		5		15		4		15	
	July—Dec	4		12		6		28		4		22	
1960	Jan—June	4		14		5		35		4		15	
	July—Dec	4		10		6		21		4		17	
1961	Jan—June	4		13		5		23		4		11	
	July—Dec	4		8		4		13		5		13	
1962	Jan—June	4	nd[d]	13	9	5	1	19	15	4	nd	18	10
	July—Dec	4	nd	21	8	8	2	72	43	6	1	41	14
1963	Jan—June	4	nd	15	3	4	1	22	25	5	1	23	11
	July—Dec	3	1	18	6	4	2	43	19	3	nd	19	14
1964	Jan—June	4	nd	20	8	5	1	22	8	4	1	18	8
	July—Dec	3	nd	19	10	5	nd	57	15	5	nd	29	12
1965	Jan—June	3	1	22	17	9	8	40	12	8	12	28	19
	July—Dec	4	1	27	8	6	2	58	14	9	4	51	32
1966	Jan—June	3	<1	18	8	4	12	23	25	4	2	21	9
	July—Dec	4	<1	18	6	6	4	46	6	4	nd	25	12
1967	Jan—June	5	<1	25	9	7	22	56	19	6	4	28	17
	July—Dec		1		16		12		15		3		12
1968	Jan—June	4	1	21	9	5	11	21	14	6	2	17	13
	July—Dec	5	<1	14	8	8	3	20	10	5	3	20	10
1969	Jan—June	5	1	17	14	10	3	40	17	7	3	24	12
	July—Dec		1		9		5		14		5		15

[a] Data are from Du Pont (1959, 1960a, 1960b, 1961, 1962a, 1962c, 1962d, 1963a, 1963b, 1964a, 1965a, 1965b, 1966a, 1966b, 1967a, 1967b, 1968a, 1968b, 1969a, 1969b)
[b] Ashley (1965, 1966, 1967, 1968, 1969, 1970)
[c] NB = nonvolatile beta.
[d] nd = not detected.

Nonvolatile beta concentrations reported for fish flesh and bone before 1962 are near or below the concentrations reported from 1962 through 1969 and near or below the concentrations reported for fish collected before plant startup. Between June 1954 (date of first liquid effluent discharge) and July 1958, concentrations for Savannah River fish were not explicitly provided, but the Health Physics Regional Monitoring semi-annual reports stated that nonvolatile beta concentrations in bone and flesh from the few sampled Savannah River fish were negligible or insignificant. It appears, though, that these conclusions were based on very few fish. Muscle tissue from 10 clams collected from Lower Three Runs Creek upstream from R-Area effluent in 1957 had average and maximum nonvolatile beta concentrations of 5 and 12 pCi g^{-1}, respectively (Mealing and Horton 1957).

The nonvolatile beta data in Table 14-4 are graphically depicted in Figures 14-3 and 14-4. Based on both flesh and bone concentrations, it is clear that Savannah River fish collected from locations adjacent to and below the SRS were impacted by SRS activities. Based on fish flesh concentrations, the above SRS location does not appear to have been significantly affected by SRS activities. Bone concentrations for the above SRS location are also lower than the other two locations, but they are elevated between 1962 and 1969 compared to between 1958 and 1961. It is difficult to know whether this is a result of SRS activities or atmospheric fallout. Atmospheric deposition was greatest in 1963, with a considerable drop off during the last half of the 1960s (see Chapter 6). A similar trend is evident for fish tissue concentrations although measured concentrations near the detection limit preclude examining this data in detail.

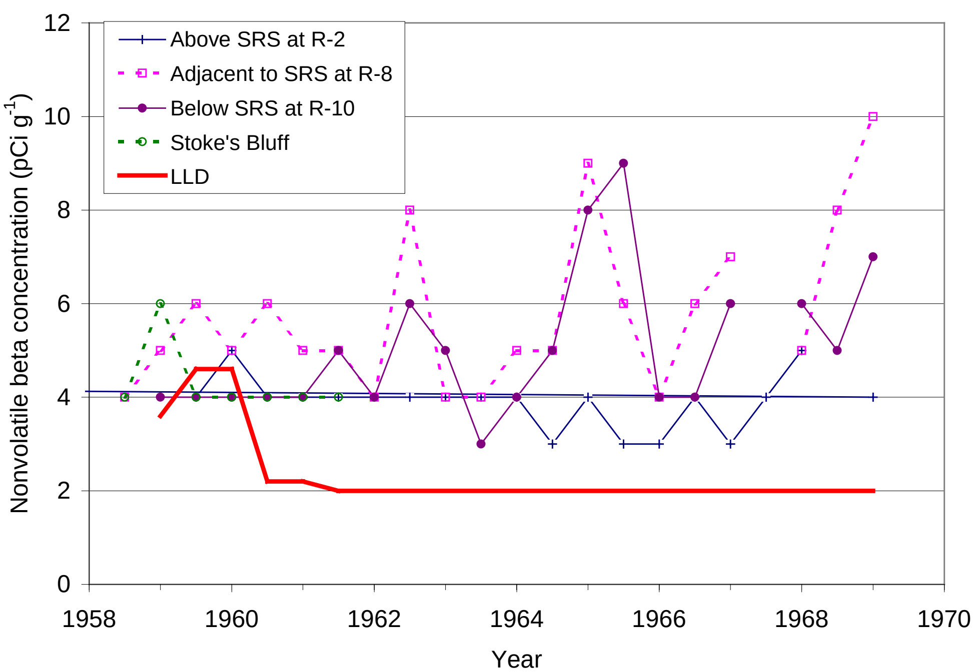

Figure 14-3. Average nonvolatile beta concentrations measured in fish flesh collected at four Savannah River locations from July 1958 through 1969 shown with the reported lower limit of detection (LLD). Link to tabulated figure data.

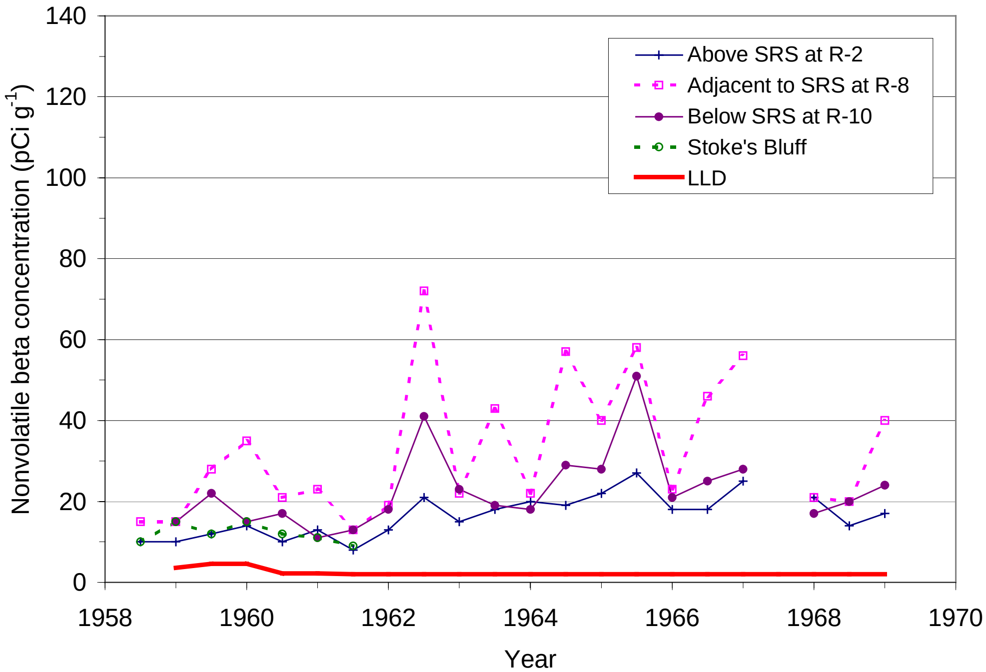

Figure 14-4. Average nonvolatile beta concentrations measured in fish bone collected at four Savannah River locations from July 1958 through 1969 shown with the reported LLD. Link to tabulated figure data.

Between 1958 and 1961, fish concentrations at the above SRS location are very similar to those at the Stoke's Bluff location, approximately 60 mi downriver from the mouth of Lower Three Runs Creek. This indicates that the above SRS river location may have been an adequate control location (i.e., one that would not have been impacted by SRS activities). Nonvolatile beta concentrations in fish from onsite streams were only reported from July 1957 through 1961 and are not shown, but they were typically about an order of magnitude greater than concentrations at Savannah River locations. Onsite concentrations in both bone and flesh were also generally highest at Lower Three Runs Creek locations during this time period.

Average ^{137}Cs and $^{89,90}Sr$ concentrations reported for fish from Savannah River locations are shown in Figures 14-5 and 14-6, respectively. Cesium-137 concentrations (Figure 14-5) appear elevated at locations adjacent to SRS (R-8) and below SRS (R-10) through about 1971, after which concentrations at all locations are near the lower limit of detection (LLD)[1]. Concentrations above SRS (R-2) have been near the LLD for all reported years, except during the last half of 1970 and the first half of 1971. Cesium-137 concentrations measured in fish from the control location (Clark Hill) are indistinguishable from concentrations measured in fish from river locations since 1986. From 1981 through 1984, the control location concentrations appear slightly lower than R-8 and R-10 locations but similar to R-2 locations.

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[1] The lower limit of detection (LLD) values are provided in various figures throughout this chapter whenever they were reported in the environmental monitoring reports. In many cases, however, the reports state "...the sensitivity of analysis varied due to differing sample size..." and no LLD values were provided.

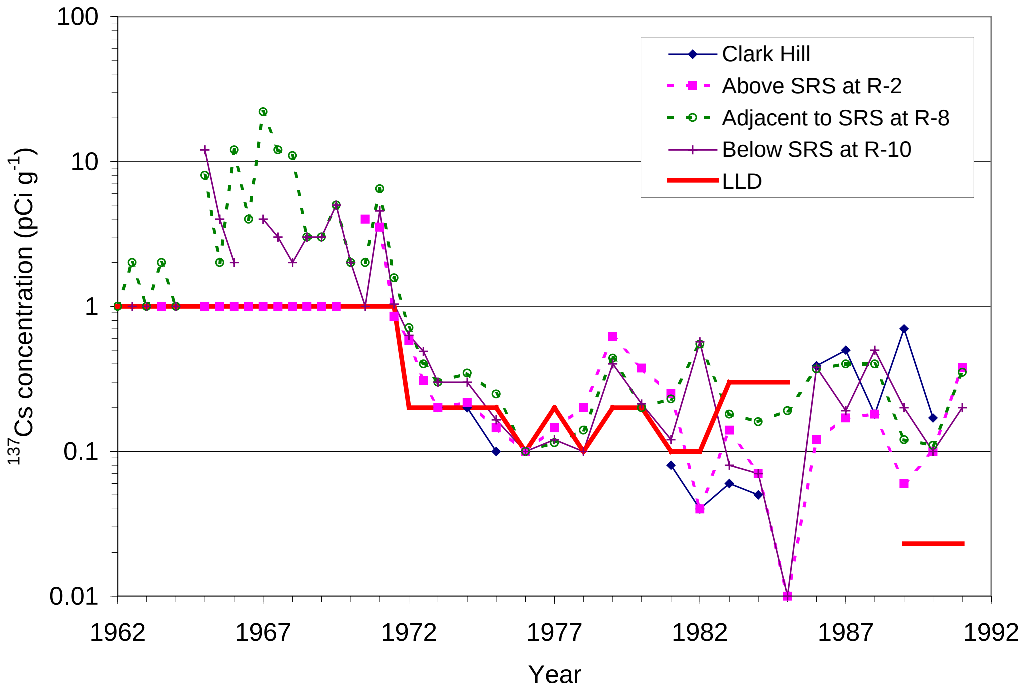

Figure 14-5. Cesium-137 concentrations in fish flesh collected at Savannah River locations above, adjacent to, and below the SRS and at Clark Hill shown with the reported LLD. Link to tabulated figure data.

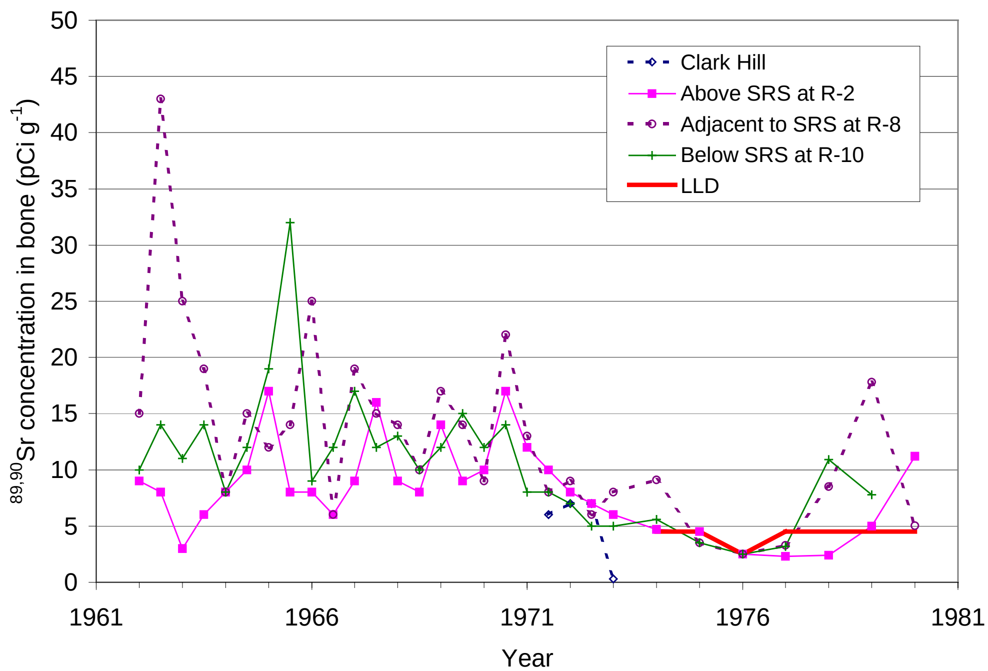

Figure 14-6. Strontium-89,90 concentrations in fish bone collected at Savannah River locations above, adjacent to, and below the SRS and at Clark Hill shown with the reported LLD. Link to tabulated figure data.

The same general trends are evident for $^{89,90}Sr$ in bone (Figure 14-6). River locations R-8 and R-10 appear elevated relative to the upriver location R-2 for most years through about 1972. From 1972 through 1977, concentrations are near the LLD for all locations, and from 1978 through 1980, concentrations appear to increase at all locations. Reporting of $^{89,90}Sr$ concentrations was discontinued after 1980. Concentrations at the control location (Clark Hill) were near the LLD for all years they were reported.

There is some question as to how appropriate the R-2 (above SRS) location was for a control location. However, based on nonvolatile beta concentrations in flesh and bone and on ^{137}Cs and $^{89,90}Sr$ concentrations in flesh and bone, respectively, the R-2 river location appears to have been an adequate control location. Nonvolatile beta flesh concentrations in 1952 and July 1958 through June 1962 and ^{137}Cs flesh concentrations from July 1962 through 1991 are shown for "control" and R-2 locations in Figure 14-7. Control locations are represented by Stoke's Bluff from July 1958 through June 1961 and by Clark Hill from 1972 through 1991. The nonvolatile beta concentration measured in fish before plant start-up is shown for 1952 and is similar to control and river locations from July 1958 through June 1962. Concentrations of radionuclides in fish at Stoke's Bluff and Clark Hill, both of which would not be expected to have been impacted by SRS activities, have been very similar to concentrations in fish from the R-2 Savannah River location. Concentrations measured in fish collected during May 1960 at Union Creek near Port Wentworth, Georgia, were also consistent with concentrations in fish collected from the R-2 river location. Based on these data, the R-2 river location appears to represent background concentrations resulting from atmospheric weapons testing. However, no offriver control data were available from July 1961 through 1972 or from 1976 through 1980. The R-2 river location concentrations during those time periods were at or near the LLD, except during the last half of 1970 and the first half of 1971. An explanation for elevated concentrations during these time periods is not evident, but similar increases were evident for R-8 and R-10 Savannah River locations (see Figure 14-5).

Steel Creek

To assess the potential impact of SRS activities on the environment, it is important to examine concentrations of radionuclides in fish that have been reported for various locations in onsite streams as well as in the Savannah River. Average measured ^{137}Cs and $^{89,90}Sr$ concentrations are shown for fish caught in Steel Creek at Road A, 2 mi below Road A, at the mouth, and in the Savannah River just downriver from the mouth (R-8) in Figures 14-8 and 14-9, respectively. Cesium-137 concentrations in fish caught 2 mi downstream from Road A are significantly lower than those reported for the Road A location. Concentrations measured at the mouth appear elevated relative to those measured at the location just downriver from the mouth of Steel Creek, which has been near the LLD since about 1971. Figure 14-9 shows the same general trends for $^{89,90}Sr$, concentrations of which appear to have been near the LLD since 1975.

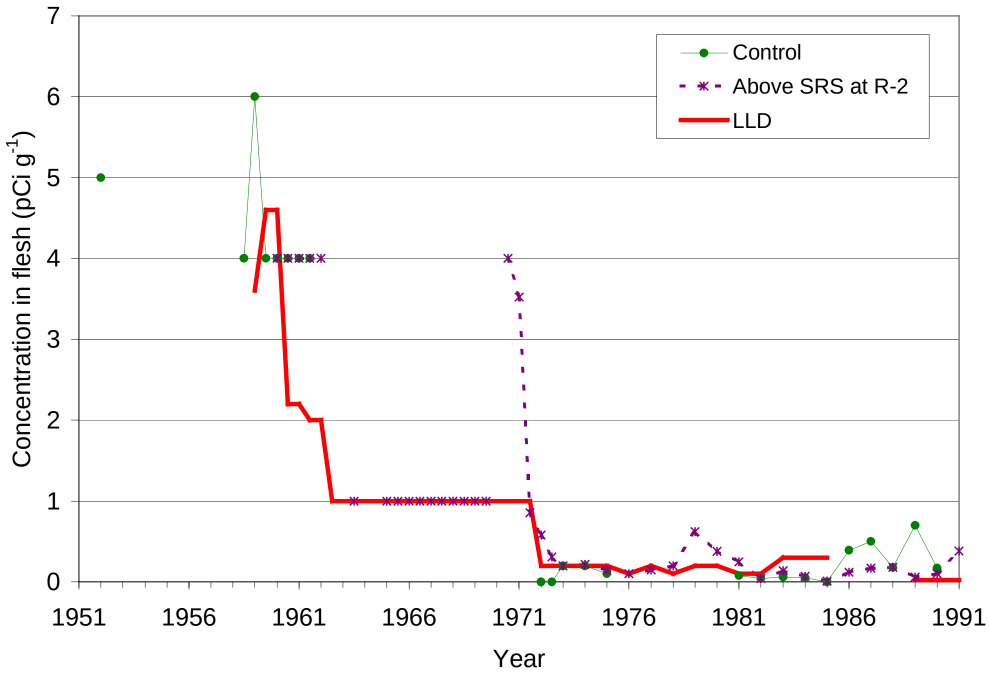

Figure 14-7. Nonvolatile beta (1952 and July 1958 through June 1962) and ^{137}Cs (July 1962 through 1991) concentrations for control (Stoke's Bluff from July 1958 through June 1961 and Clark Hill from 1972 through 1991) and R-2 river locations. Link to tabulated figure data.

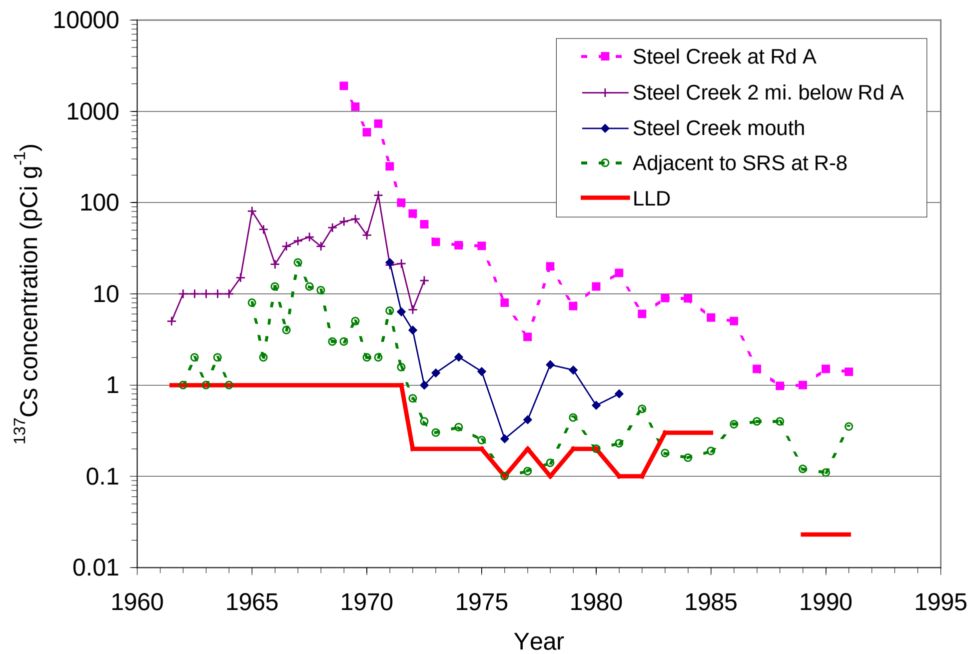

Figure 14-8. Average ^{137}Cs concentrations in fish collected at three locations along Steel Creek and at the R-8 Savannah River location shown with the reported LLD. Link to tabulated figure data.

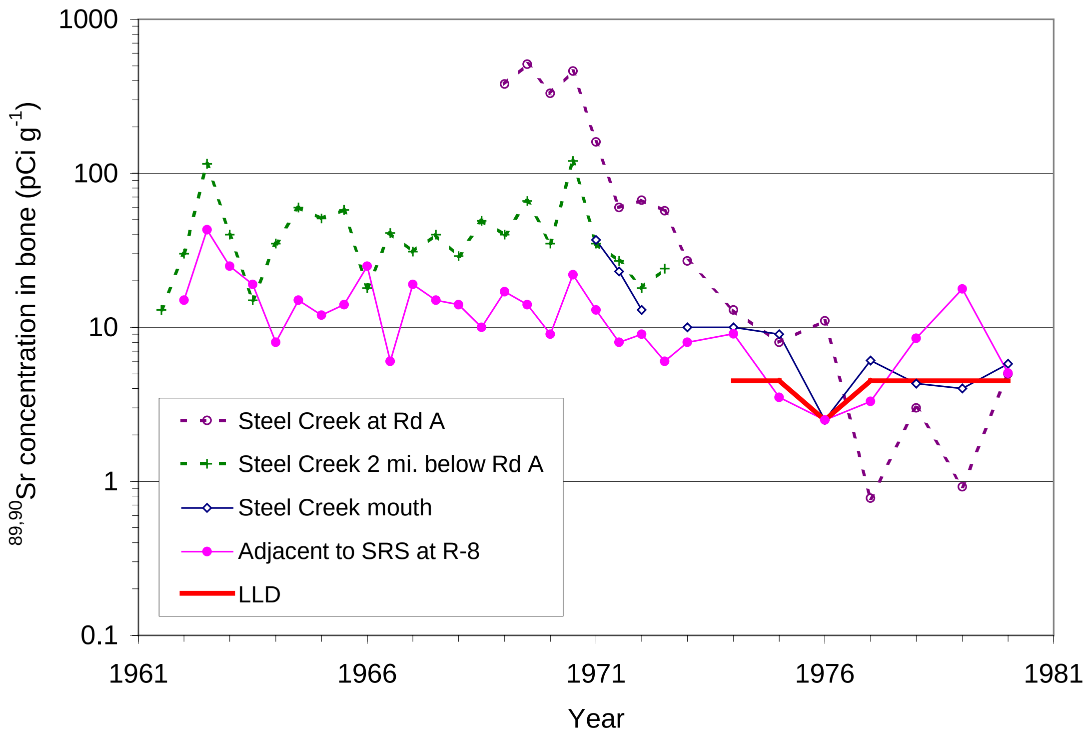

Figure 14-9. Average ^{89,90}Sr concentrations in fish collected at three locations along Steel Creek and at the R-8 Savannah River location shown with the reported LLD. Link to tabulated figure data.

Brisbin et al. (1989), however, failed to demonstrate any location differences in ^{137}Cs concentrations measured in biota collected from Steel Creek in 1981. The authors attributed this to the movement and redeposition of contaminated sediments along the stream channel. Brisbin et al. (1974) also found no differences in ^{137}Cs concentrations measured in sediment collected from upstream and swamp-delta locations in Steel Creek. These studies appear inconsistent with the significant decreases noted for fish concentrations as a function of distance downstream from reactor effluent input.

Four Mile Creek

Nonvolatile beta concentrations were reported for fish from the Four Mile Creek through 1961, but Four Mile Creek sampling was apparently discontinued in 1962 and resumed again in 1970. Figures 14-10 and 14-11 show average measured concentrations of ^{137}Cs and ^{89,90}Sr, respectively, for fish from Four Mile Creek at Road A and at Cassel's Pond (3 mi below Road A). In addition, the reported concentrations in fish from a location several miles downriver from the mouth of Four Mile Creek (R-8) are shown. Again, as with Steel Creek, the concentrations a few miles downstream from Road A are significantly lower than those reported for the Road A location, which are higher than the R-8 river location.

Strontium-89,90 concentrations in fish at Road A decreased significantly in 1976 and 1977, followed by an increase in 1978 and 1979 back to concentrations similar to those measured before 1976 (Figure 14-11). This same trend was also evident at the location 3 mi below Road A. Concentrations in fish from the Savannah River location (R-8) several miles downriver from the mouth of Four Mile Creek also increased in 1978 and 1979. It appears this increase may be related to the significant increases noted for Four Mile Creek locations during that time period because similar increases were not evident in Steel Creek. A similar trend was noted for ^{137}Cs concentrations (Figure 14-10), but an explanation is not apparent. However, sample sizes in 1976 and 1977 were significantly lower than sample sizes for previous years (Figure 14-1).

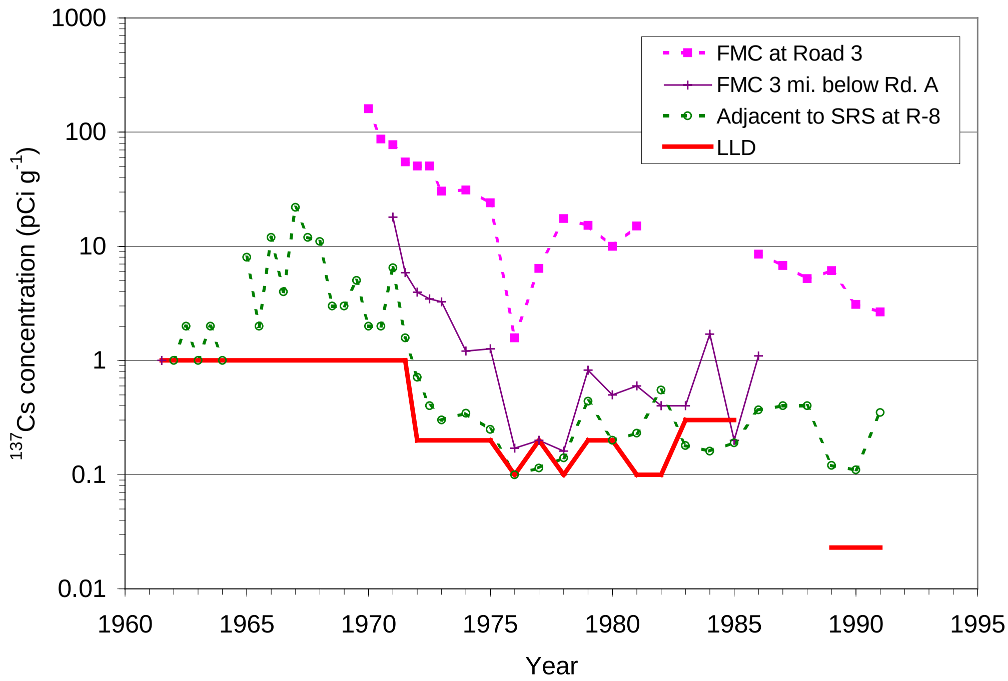

Figure 14-10. Average ^{137}Cs concentrations measured in fish flesh collected at two locations along Four Mile Creek (FMC) and the R-8 Savannah River location shown with the reported LLD. Link to tabulated figure data.

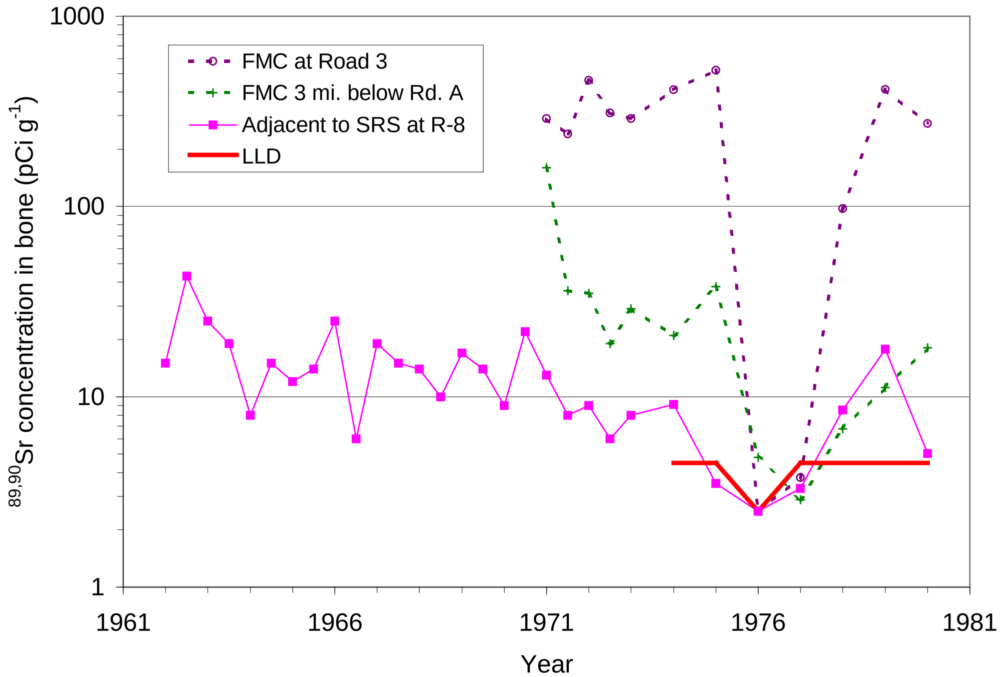

Figure 14-11. Average ^{89,90}Sr concentrations measured in fish bone collected at two locations along Four Mile Creek and the R-8 Savannah River location shown with the reported LLD. Link to tabulated figure data.

Lower Three Runs Creek, Par Pond, and Pond B

Figures 14-12 and 14-13 show the average measured ^{137}Cs and ^{89,90}Sr concentrations in fish, respectively, for Pond B (^{137}Cs only), Par Pond, Lower Three Runs Creek at Patterson's Mill, and for a location 8 mi downriver from the mouth of Lower Three Runs (R-10). Pond B received effluent via R Canal from R Reactor. The effluent stream continued to Par Pond, and water from Par Pond was released directly to Lower Three Runs Creek. Interestingly, ^{137}Cs concentrations in Par Pond appear very similar to concentrations in Lower Three Runs Creek at Patterson's Mill, which are elevated relative to the R-10 river location. However, ^{89,90}Sr concentrations in Par Pond are elevated above concentrations in Lower Three Runs Creek at Patterson's Mill, which are very similar to the R-10 river location. A significant increase in ^{89,90}Sr concentrations is seen in Lower Three Runs Creek at Patterson's Mill during the first and second half of 1970. The cause of this increase is not known, but similar increases were not seen in Par Pond or the R-10 river location. Cesium-137 concentrations in Pond B are roughly an order of magnitude higher than those measured in Par Pond.

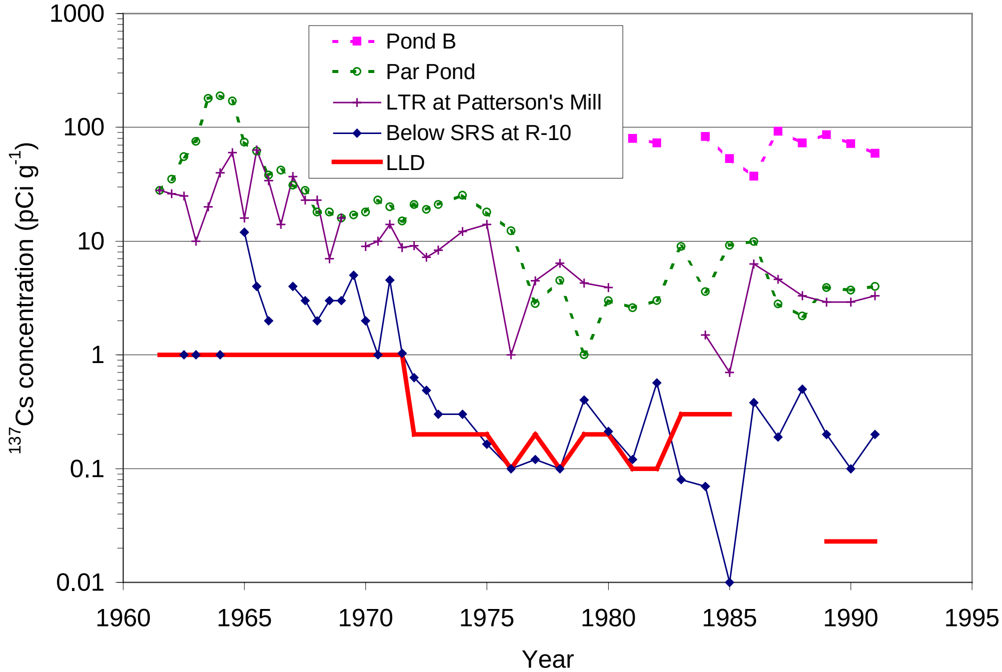

Figure 14-12. Average ^{137}Cs concentrations measured in fish flesh collected at Pond B, Par Pond, Patterson's Mill along Lower Three Runs (LTR) Creek, and the R-10 Savannah River location shown with the reported LLD. Link to tabulated figure data.

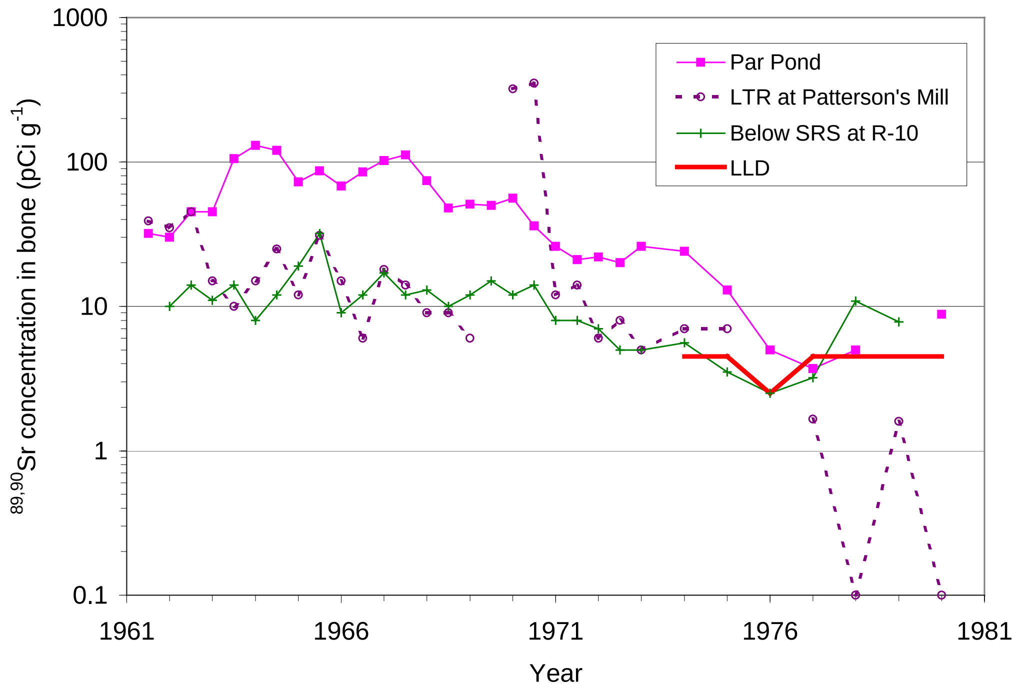

Figure 14-13. Average ^{89,90}Sr concentrations measured in fish flesh collected at Par Pond, Patterson's Mill along Lower Three Runs Creek (LTR), and the R-10 Savannah River location shown with the reported LLD. Link to tabulated figure data.

Since construction of the Par Pond dam in 1958, some flow into Lower Three Runs Creek has originated from Par Pond dam releases. Figures 14-14 and 14-15 show nonvolatile beta concentrations in flesh and bone, respectively, for various locations along Lower Three Runs Creek, Par Pond, and the Savannah River R-9 location (near the mouth of Lower Three Runs Creek) from July 1957 through June 1961. Par Pond was not constructed until July 1958, so distances relative to the dam for that time period were derived from distances relative to R Reactor. It is clear that the R-9 location concentrations are significantly lower than Lower Three Runs Creek concentrations. However, concentrations measured in fish collected from Lower Three Runs at various distances from Par Pond are generally indistinguishable and quite similar to those measured in Par Pond after construction of the dam. Before July 1958, there was a discernable decrease in concentration with increasing distance from the dam. This suggests that flow into Lower Three Runs Creek since July 1958 originated largely from Par Pond dam releases, and dilution with stream water may not have been as significant as for other onsite streams. A similar trend is evident for ^{137}Cs concentrations measured in Par Pond and Lower Three Runs Creek at Patterson's Mill from 1961 through 1991.

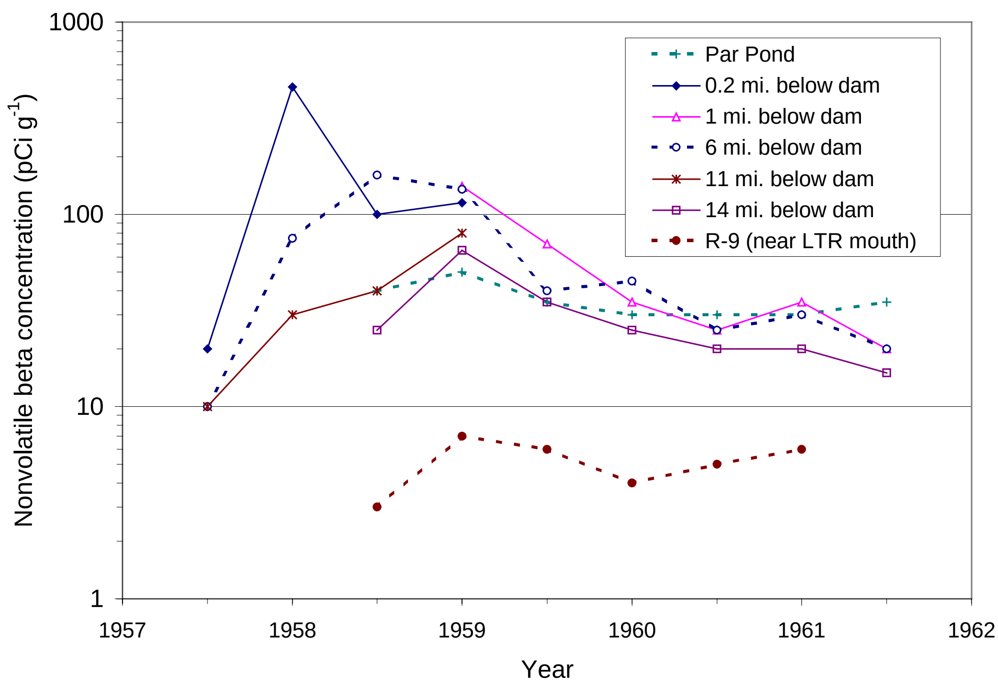

Figure 14-14. Average nonvolatile beta concentrations measured in fish flesh collected from Lower Three Runs Creek at various distances below the Par Pond dam. Link to tabulated figure data.

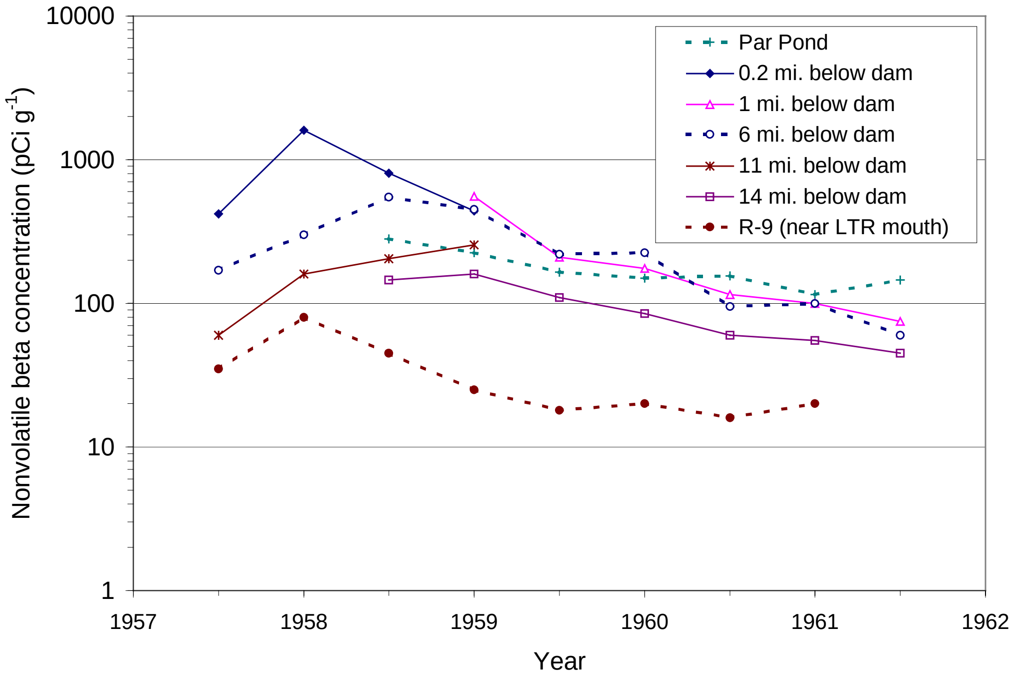

Figure 14-15. Average nonvolatile beta concentrations measured in fish bone collected from Lower Three Runs Creek at various distances below the Par Pond dam. Link to tabulated figure data.

Upper Three Runs Creek

Concentrations have not been reported consistently for Upper Three Runs Creek, which has not received reactor effluent. However, nonvolatile beta concentrations were reported from July 1959 through June 1961, and ^{137}Cs concentrations were reported from 1987 through 1991. During these time periods, concentrations were generally indistinguishable from Savannah River concentrations, indicating little radionuclide contamination in Upper Three Runs Creek. This is helpful for establishing the adequacy of the R-2 river location as representative of background concentrations.

Additional Savannah River Locations

Nonvolatile beta concentrations in flesh were reported for fish collected at six Savannah River locations from July 1958 through June 1961 (Figure 14-16). The R-2, R-8, and R-10 locations were described previously. The R-3 location was near the mouth of Upper Three Runs Creek, the R-5 location was near the mouth of Four Mile Creek, and the R-9 location was near the mouth of Lower Three Runs Creek. Based on these data, concentrations at the R-8 and R-9 locations appear similarly elevated relative to other locations, indicating the influence of Steel Creek and Lower Three Runs Creek on activity levels in fish. During this time period and through 1968, concentrations measured in fish from Steel Creek and Lower Three Runs Creek locations were similar, though concentrations were generally highest in Steel Creek. Concentrations in fish from Four Mile Creek were not significantly elevated during this time period, and the R-5 location concentrations reflect this.

Since 1959, concentrations of radionuclides in fish from onsite streams have generally been highest in Steel Creek, and the R-8 river location has likely been representative of the highest routinely measured Savannah River location fish concentrations. However, concentrations for fish collected at the mouth of Steel Creek, which would be accessible to Savannah River fishermen, were consistently elevated relative to the R-8 river location from 1971 through 1981. Four Mile Creek concentrations were elevated relative to river concentrations since 1970 (concentrations for Four Mile Creek were not reported between 1962 and 1969), so R-5 concentrations may have been impacted. However, Four Mile Creek concentrations have been lower than Steel Creek concentrations, so R-5 location concentrations likely have been lower than R-8 location concentrations. Although Par Pond dam releases may have inhibited dilution with the stream water, concentrations in fish from the R-9 location have also likely been lower than R-8 location concentrations because Lower Three Runs Creek concentrations have been significantly lower than Steel Creek concentrations since 1959. Lower Three Runs Creek fish concentrations were, however, higher than Steel Creek fish concentrations through 1959 so it is possible that Savannah River fish concentrations were highest at the R-9 location from 1954 through 1959.

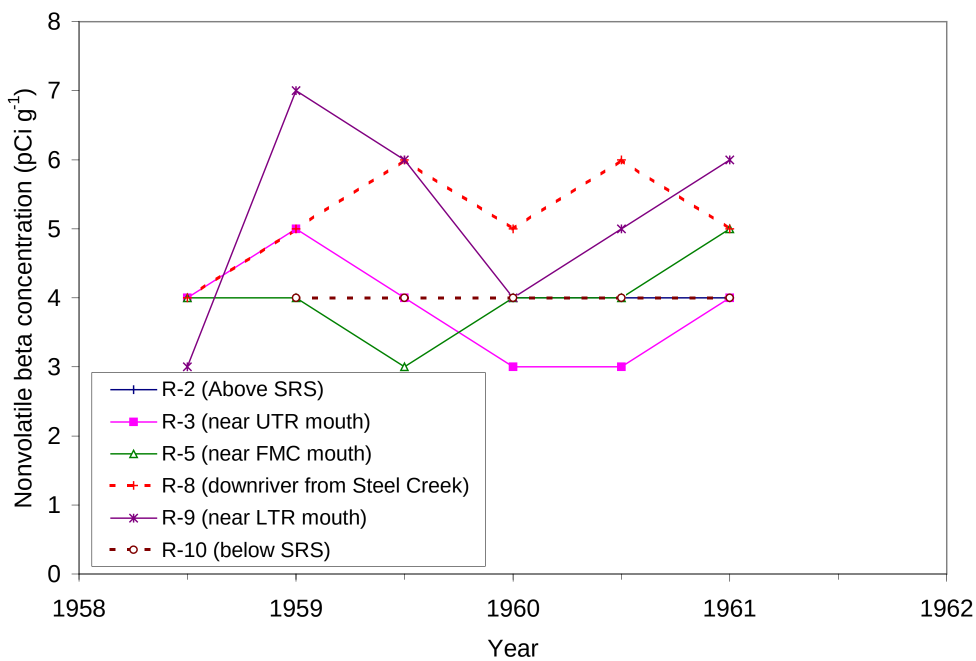

Figure 14-16. Average nonvolatile beta concentrations in fish flesh measured at six Savannah River locations from July 1958 through June 1961. Link to tabulated figure data.

Radionuclide concentrations in fish from onsite streams and ponds have consistently been significantly elevated relative to offsite control locations. There is little question that SRS activities have discharged reactor effluent to onsite seepage basins, streams/canals, and ponds, which has resulted in elevated radionuclide burdens in fish. It is also quite clear that although the SRS buffer area was sufficient to significantly dilute effluent radionuclide concentrations, Savannah River fish have also been impacted by SRS activities. However, average concentrations of radionuclides in fish do not appear to have been impacted at the R-2 river location, and average concentrations at all river locations have been generally indistinguishable and near or below the LLD since 1972.

The measurement data suggest that fish from R-8 and R-10 Savannah River locations were most impacted by Site releases from 1962 through 1972. The R-8 river location concentrations in fish may also represent the highest concentrations of radionuclides for routinely sampled Savannah River locations because Steel Creek has consistently shown the highest concentrations for any of the onsite streams. However, concentrations measured in fish collected at the mouth of Steel Creek from 1971 through 1981 indicate that the R-8 river location may not represent the highest concentrations in fish to which Savannah River fishermen may have been exposed. Concentrations in fish at the R-5 and R-9 river locations may also have been elevated relative to concentrations at the R-2 river location, but fish were not sampled from these locations after June 1961. However, concentrations in fish from Steel Creek have been higher than concentrations in fish from other onsite streams since 1960, and fish concentrations at the R-5 and R-9 river locations were not likely higher than concentrations at the R-8 river location. Concentrations measured in LTR were, however, generally higher than concentrations measured in Steel Creek before 1960.

Maximum Nonvolatile Beta, Cesium, and Strontium Concentrations

To estimate the maximum concentrations of radionuclides in fish to which members of the general public may have been exposed, it is necessary to examine the maximum yearly reported radionuclide concentrations in fish for the Savannah River. Table 14-5 shows maximum reported radionuclide concentrations since inception of the routine monitoring program in July 1957. Figures 14-17 and 14-18 show maximum radionuclide concentrations in flesh and bone, respectively, reported for Savannah River locations.

Table 14-5. Maximum Measured Radionuclide Concentrations for Savannah River, Steel Creek Mouth, and Onsite Locations.

	Radionuclide concentration in pCi g^{-1} (location, year)[a]			
	Nonvolatile beta activity		^{137}Cs	$^{89,90}Sr$
Location	(bone)	(flesh)	(flesh)	(bone)
Savannah River	640 (R-8, 1957)	40 (R-9, 1961)	78 (R-8, 1967)	151 (R-8, 1979)
Steel Creek mouth	nr[b]	nr	280 (1971)	140 (1971)
Onsite	4500 (LTR, 1958)	985 (LTR, 1959)	3500 (SC, 1969)	960 (SC, 1970)

[a] LTR = Lower Three Runs Creek, SC = Steel Creek.

[b] nr = not reported. Link to tabulated data.

The highest **average** reported Savannah River ^{137}Cs concentration (22 pCi g^{-1}) occurred during the first half of 1967 at a location just downriver from the mouth of Steel Creek (R-8). For dose reconstruction, using average measured concentrations is more realistic for estimating potential exposure to individuals who may have relied upon Savannah River fish for a significant portion of their diet (e.g., 19 kg y^{-1}).

On the other hand, the highest **average** reported onsite concentration (1900 pCi g^{-1}) occurred during 1969 and is about two orders of magnitude greater than the highest Savannah River **average** concentration. Although onsite locations have not been legally accessed by the general public, there is the possibility that some individuals (poacher exposure scenario) have illegally collected and consumed fish from onsite locations.

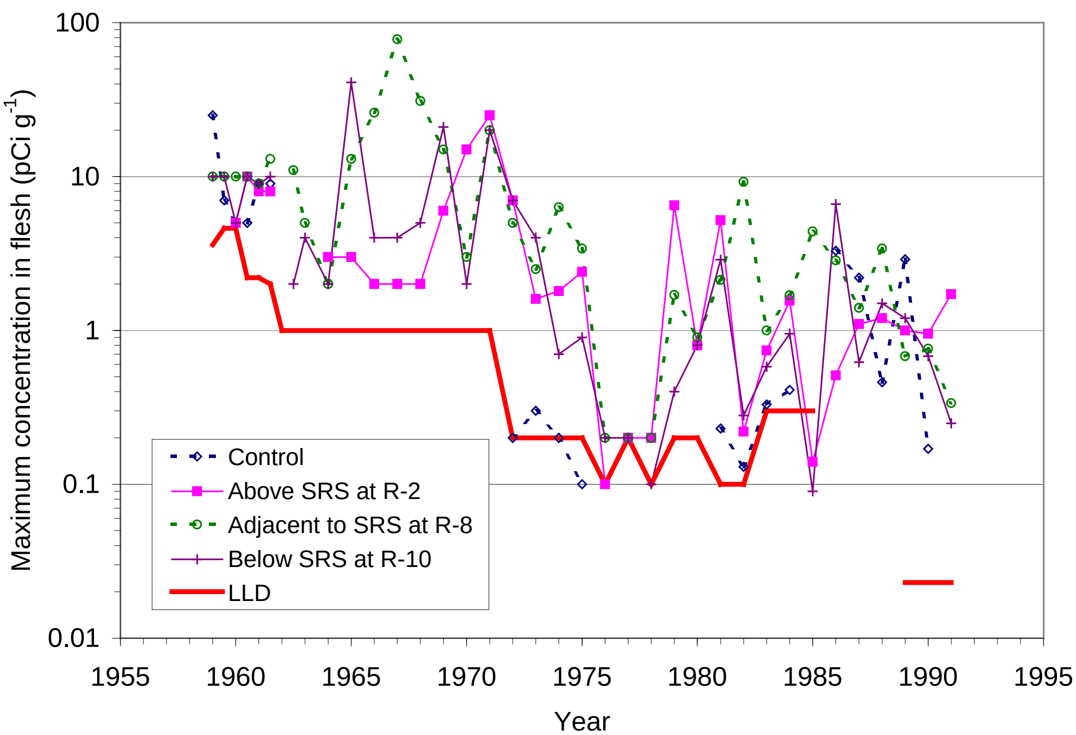

Figure 14-17. Maximum reported radionuclide concentrations in fish flesh collected from the Savannah River. Nonvolatile beta concentrations are shown before 1962 and ^{137}Cs concentrations are shown from 1962 through 1991. Link to tabulated figure data.

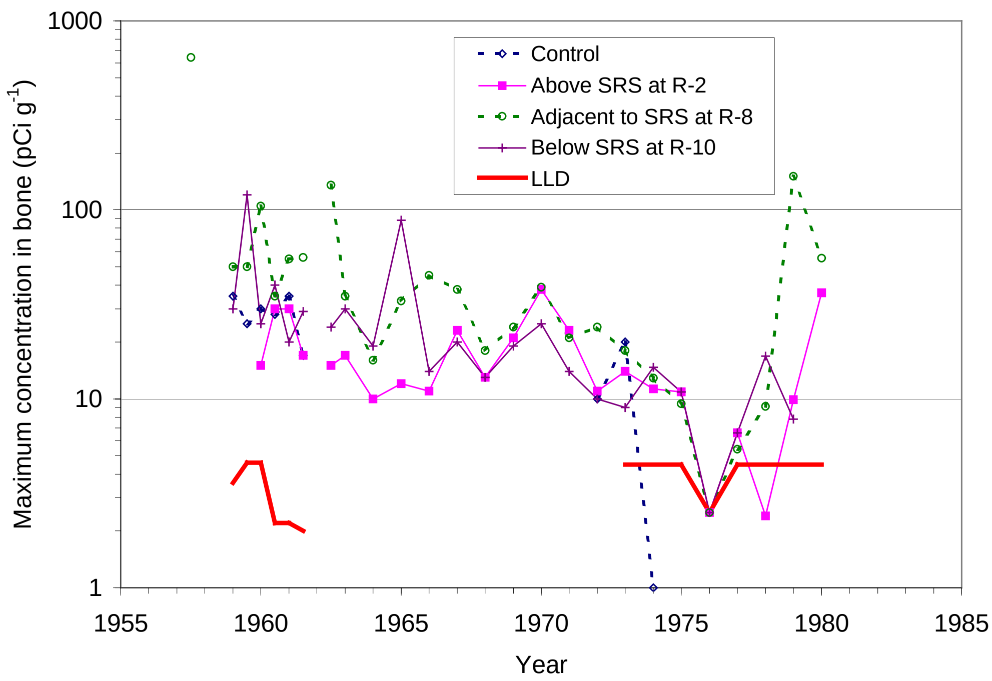

Figure 14-18. Maximum reported radionuclide concentrations in fish bone collected from the Savannah River. Nonvolatile beta concentrations are shown before 1962 and $^{89,90}Sr$ concentrations are shown from 1962 through 1980. Link to tabulated figure data.

Tritium

Mean and maximum tritium concentrations were reported for fish collected at locations above, adjacent-to, and below the Savannah River Site from 1970 through 1981 (Table 14-6). This beta-emitting radionuclide is incorporated into the water molecule; consequently it is present in all tissues. In general, average concentrations at adjacent-to and below-plant locations were higher than average above-plant concentrations. The maximum tritium concentration (54 pCi mL^{-1}) was measured in 1974 in a fish collected from the river location adjacent to the plant.

The reports have stated that the concentrations measured in fish reflect concentrations measured in Savannah River water. Examining annual average tritium concentrations measured in water collected at the above and below-plant Savannah River locations for the same years reveals higher concentrations at the R-10 river location. The median concentrations for fish and water are similar for the below-plant location, but median concentrations for fish and water are significantly different for the above-plant location. These results do not suggest that fish and water concentrations are not correlated, but it does not appear that they are linearly correlated with a slope near unity (at least at these relatively low concentrations). Tritium is generally not concentrated in biological tissues to levels greater than those found in water, but slightly higher levels in biological tissue may result from some degree of molecular organic binding (Whicker and Schultz 1982). This may account for the higher concentrations measured in fish at the R-2 river location.

Table 14-6. Mean and Maximum Tritium Concentrations (pCi mL^{-1}) Detected in Free Water Collected from Savannah River Fish from 1970 through 1981[a]

Year	Above plant (R-2)		Adjacent to plant (R-8)		Below plant (R-10)	
	Maximum	Mean	Maximum	Mean	Maximum	Mean
1970	6	4	8	5	11	5
1971	7	3	15	8	11	7
1972	9	4	16	7	17	8
1973	5	2	16	6	12	6
1974	8	4	54	12	12	8
1975	33	5	6	3	12	6
1976	9	5	10	5	16	8
1977	26	8	24	11	20	13
1978	1	1	4	4	7	7
1979	3	1	16	5	19	6
1980	7	3	17	5	8	4
1981	4	1	12	5	4	2
Median		3.5		5		6.5
Median[b]		0.47				5.3

[a] Data from Ashley and Zeigler (1984).
[b] Median value for river water, 1970–1981 (concentrations were not reported for the R-8 river location during this time period).

Other Radionuclides

Zinc-65 and ^{32}P were detected less frequently than ^{137}Cs (analysis frequencies were not specified), and bone tissue typically had higher concentrations than flesh. Zinc-65 is an activation product with a 245-day half-life and it is moderately assimilated in all body tissues (Whicker and Schultz 1982). Zinc-65 concentrations were reported from July 1961 through June 1970 in the Health Physics Regional Monitoring and Environmental Monitoring at the Savannah River Plant report series. The maximum reported concentrations in Savannah River fish flesh and bone, respectively, were 28 and 105 pCi g^{-1} during the second half of 1962 at the R-8 river location. In general, bone concentrations were higher than flesh concentrations. Since July 1963, concentrations in flesh and bone at all river locations have generally been less than the detection limit (1 pCi g^{-1}).

Phosphorus-32 is an activation product with a relatively short half-life of 14 days. It is rapidly assimilated primarily in bone tissue (Whicker and Schultz 1982). Maximum ^{32}P concentrations were reported from 1966 through 1968 in the Effect of the Savannah River Plant on Environmental Radioactivity report series. The maximum reported concentration in Savannah River fish flesh was 30 pCi g^{-1} during the first half of 1966 and in fish bone was 719 pCi g^{-1} during the first half of 1967.

Other gamma-emitting radionuclides, such as ^{103,106}Ru, ^{141,144}Ce, ^{60}Co, and ^{59}Fe, were rarely reported as detected in aquatic samples. However, mollusk (clam) and crustacean (crayfish and shrimp) tissues were occasionally analyzed for these radionuclides and were reported in the Health Physics Regional Monitoring report series in 1960 and 1961. Radiostrontium comprised the only reported activity in the shells of these animals, radiocesium comprised the only reported nonvolatile beta activity reported for crayfish and shrimp flesh, and radioisotopes of cesium, ruthenium, cerium, cobalt, and iron were all reported as detected in clam flesh.

Other Sources of Data

Data regarding radionuclide concentrations measured in fish were obtained from the Georgia Department of Natural Resources (GDNR) and the South Carolina Department of Health and Environmental Control (SCDHEC) (GDNR 1997; SCDHEC 1997). These data can potentially verify concentrations reported by the SRS. However, comparisons made between these data sets are of somewhat limited use because of differing objectives of the respective analytical laboratories. Historically, the SRS analyzed a large number of fish to evaluate environmental impacts. The methods of analysis were developed to provide averages for trend analysis and throughput of a large number of samples. The GDNR and SCDHEC programs, on the other hand, were designed to analyze smaller numbers of fish to evaluate health risks. In general, more sensitive analytical procedures were used by these agencies to better estimate absolute radionuclide concentrations. However, interlaboratory comparisons between the GDNR and the SRS have indicated that both laboratories provide accurate measurements (Hoel 1991). Additionally, different sampling locations have been maintained by the three organizations, which hinders complete data comparisons. The GDNR and SCDHEC data are available in the embedded Excel® workbook discussed later in this chapter.

Figure 14-19 shows ^{137}Cs concentrations in fish measured by the SRS, GDNR, and SCDHEC at the R-10 Savannah River location. In general, the concentrations are similar, but there is a significant amount of variability in the data. Concentrations measured by the SRS appear higher, in general, than concentrations measured by the other two agencies. This difference is likely the result of the less precise analytical procedures employed by the SRS (e.g., lower detection limits for the GDNR and SCDHEC).

Figure 14-20 shows average ^{137}Cs concentrations measured in fish by these three agencies at locations that historically were not considered to be impacted by SRS activities. These locations include the R-2 river location historically sampled by the SRS, a Silver Bluff location (above the SRS at river mile 147.4) sampled by the SCDHEC, and two locations sampled by the GDNR (one near Augusta and one 90 m downriver from the SRS). In general, concentrations measured by the three agencies are similar, although there is a large amount of variability in the data. These data provide additional support for the supposition that the R-2 Savannah River sampling location has adequately estimated background radionuclide concentrations in fish.

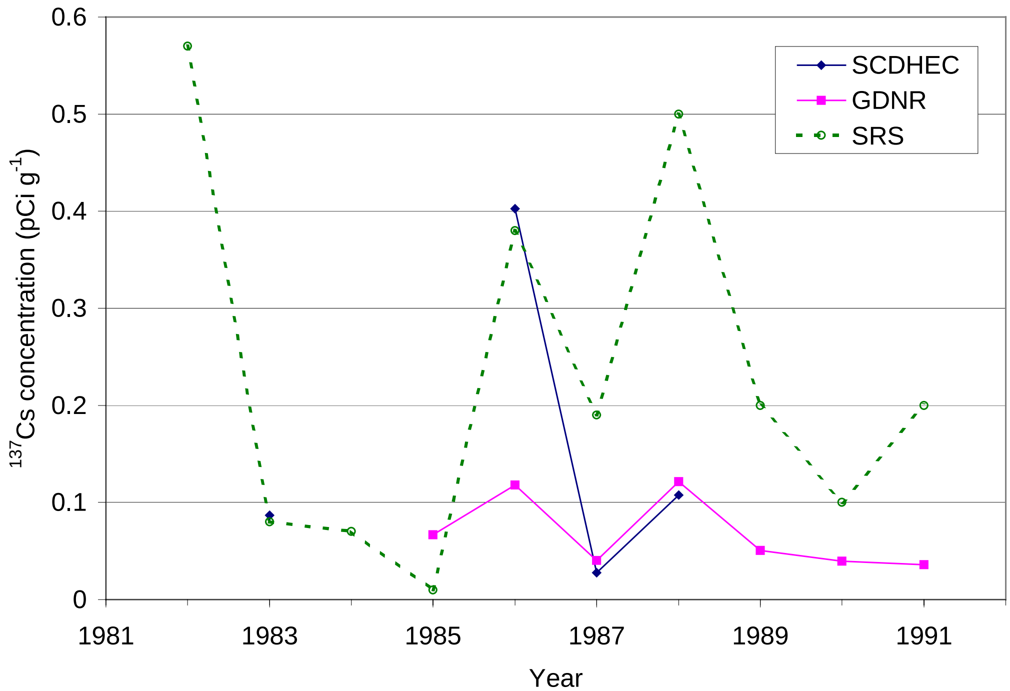

Figure 14-19. Average ^{137}Cs concentrations in fish from the R-10 Savannah River sampling location reported by the SRS, GDNR, and SCDHEC. Link to tabulated figure data.

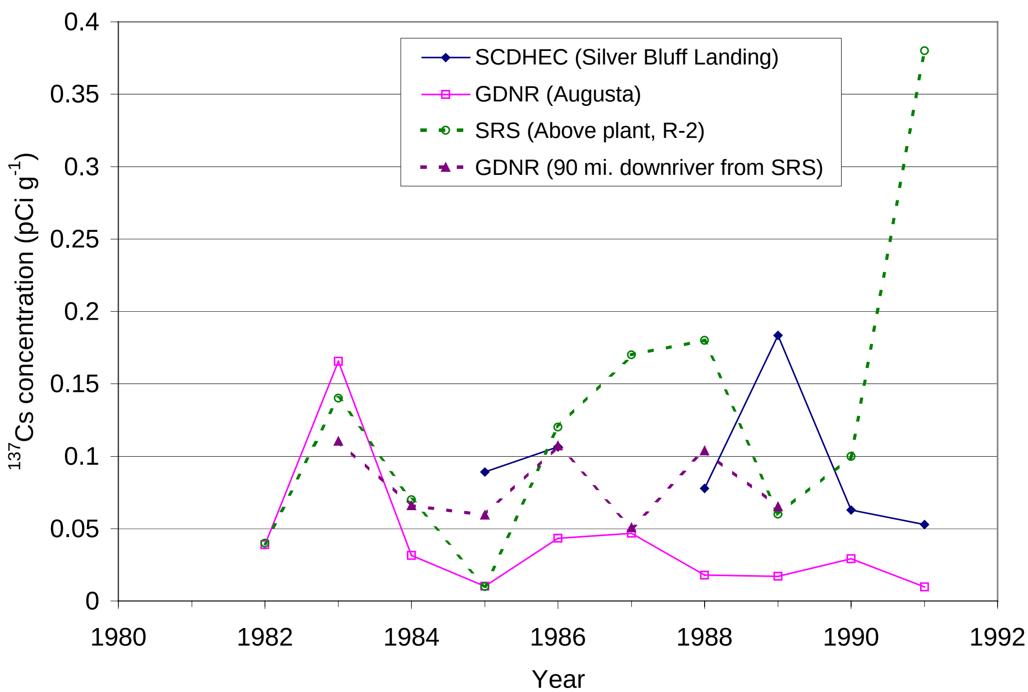

Figure 14-20. Average ^{137}Cs concentrations measured by the SRS, the GDNR, and the SCDHEC in fish collected from offsite locations not impacted by SRS activities. Link to tabulated figure data.

The GDNR has also measured tritium concentrations in free water obtained from fish tissues since 1985. At the R-10 Savannah River location, tritium concentrations reported by the GDNR from 1985 through 1986 range from 0.1 to 3.5 pCi ml^{-1} with a median of 1.7 pCi ml^{-1}. This is generally lower than concentrations reported by SRS from 1970 through 1981 (Table 14-6). A slight decrease in average concentration, however, is consistent with the decreases in release estimates of tritium to surface water after 1980 (Chapter 5).

Relative Contribution of Specific Radionuclides in Fish Tissue

To calculate a dose for a subsistence fisherman exposure pathway before 1962 (when only nonvolatile beta concentrations were reported), it may be necessary to estimate the fractional abundance of specific radionuclides in fish tissue. The median, maximum, and minimum ratios calculated as the concentration of cesium and strontium relative to the nonvolatile beta concentration for 1962 through 1969 are shown in Table 14-7 (based on data from Table 14-4). Ratios for flesh represent the relative concentration of cesium and ratios for bone represent the relative ratios for strontium. It appears that half or less of the radioactivity for both tissues can be attributed to cesium or strontium, based on median values for these years. It is clear that other radioisotopes were present in both flesh and bone tissue, particularly during the 1960s. It also appears that for a few years, measured ^{137}Cs concentrations were actually higher than measured nonvolatile beta concentrations (see Table 14-4).

Table 14-7. Ratios of Cesium and Strontium Concentrations Relative to Nonvolatile Beta Concentrations for 1962 through 1969 for Fish Collected from Three Savannah River Locations

Ratios	Above SRS		Adjacent to SRS		Below SRS	
	Flesh (Cs)	Bone (Sr)	Flesh (Cs)	Bone (Sr)	Flesh (Cs)	Bone (Sr)
Median	0.25	0.41	0.38	0.43	0.44	0.50
Maximum	0.33	0.82	3.14	1.14	1.50	0.76
Minimum	0.20	0.20	0.20	0.26	0.17	0.34

The Health Physics Regional Monitoring report series (1957 through 1962) stated that ^{137}Cs and ^{65}Zn comprised the majority of radioactivity in fish flesh and ^{89,90}Sr comprised the majority of nonvolatile beta activity in fish bone. The authors indicated that the dominance and magnitude of specific radionuclides varied significantly between different locations. The Environmental Monitoring at the Savannah River Plant report series (1965 through 1971) also reported that ^{137}Cs and ^{65}Zn comprised the majority of radioactivity in fish flesh and ^{89,90}Sr comprised the majority of nonvolatile beta activity in fish bone. Zinc-65 concentrations in fish were highest in Steel Creek and decreased through the 1960s. Zinc-65 was present in measurable concentrations in bone only by 1970, after which radiozinc concentrations were no longer reported. The Effect of the Savannah River Plant on Environmental Radioactivity report series (1962 through 1969) also reported that ^{137}Cs and ^{65}Zn comprised the majority of radioactivity in fish flesh, and ^{89,90}Sr comprised the majority of nonvolatile beta activity in fish bone. In 1962, radioactivity in Savannah River fish was attributed primarily to ^{40}K (Du Pont 1962a). Zinc-65 and ^{32}P were also detected in fish tissues but less frequently. The median ratio values reported in Table 14-7 indicate that radiostrontium and radiocesium comprise less than half of the nonvolatile beta activity for bone and flesh, respectively. There also appears to be significant variability in these data. It is likely that other radioisotopes, such as ^{65}Zn, ^{32}P, and naturally occurring ^{40}K, also accounted for some portion of the nonvolatile beta radioactivity measured in both flesh and bone. Data from the SCDHEC (1997) indicate an average ^{40}K concentration in Savannah River fish of 2.3 pCi g^{-1}. This is consistent with ^{40}K concentrations of 2.6 pCi g^{-1} measured in Par Pond and L Lake in 1992 (Hinton 1997).

Figure 14-21 shows the ratio of radiocesium to radiozinc activity measured in the flesh of fish collected from Par Pond and Steel Creek. Zinc-65 has a significantly shorter half-life than does ^{137}Cs (245 days compared to 30 years) and is not as persistent in the environment. It appears that ^{65}Zn comprised a significant portion of the gamma activity detected in fish flesh through the mid-1960s. Concentrations of specific isotopes were not reported before July 1961, but ^{65}Zn likely comprised a significant portion of the radioactivity in fish flesh during the 1950s.

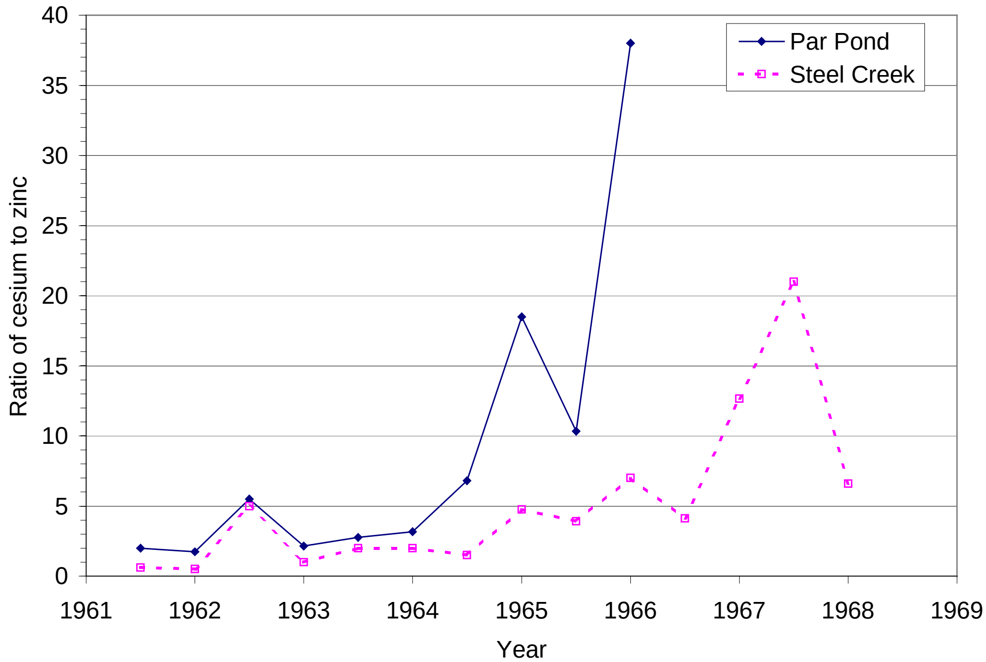

Figure 14-21. Ratio of ^{137}Cs activity relative to ^{65}Zn activity measured in the flesh of fish collected from Par Pond and Steel Creek. Link to tabulated figure data.

Harvey (1963) reported relative concentrations of various radionuclides in fish collected from Par Pond during 1962. Only $^{134,137}Cs$, ^{65}Zn, and $^{89,90}Sr$ were selectively concentrated in fish from an environment that also contained detectable concentrations of $^{141,144}Ce$, ^{51}Cr, $^{103,106}Ru$, $^{95}Zr/Nb$, ^{54}Mn, $^{59}Fe/^{60}Co$, and $^{140}Ba/La$ (^{32}P and ^{40}K concentrations were not reported in this study). Relative concentrations of $^{134,137}Cs$, ^{65}Zn, and $^{89,90}Sr$, in bluegill, catfish, and bass measured in this study are shown in Table 14-8. Radiozinc and radiocesium comprised all of the activity in flesh tissue, but radiozinc dominated in bluegill while radiocesium dominated in both catfish and bass. All three radioisotopes were present in bone tissue, with radiozinc dominating in all three species. It appears likely that the relative dominance and magnitude of specific radionuclides may vary significantly between locations as well as between species.

Table 14-8. Relative Concentrations of $^{134,137}Cs$, ^{65}Zn, and $^{89,90}Sr$ in Bluegill, Catfish, and Bass Collected from Par Pond in 1962[a]

	Bluegill		Catfish		Bass	
Radionuclide	Flesh	Bone	Flesh	Bone	Flesh	Bone
$^{134,137}Cs$	0.40	0.07	0.68	0.16	0.73	0.17
^{65}Zn	0.60	0.77	0.32	0.54	0.27	0.49
$^{89,90}Sr$		0.16		0.30		0.34

[a] Data from Harvey (1963)

During a June 19, 1991 meeting, the SRS and GDNR discussed elevated ^{90}Sr concentrations in fish flesh collected from the Savannah River (Hoel 1991). In particular, concentrations measured in bass and suckers collected from two locations in the river were evaluated. Both the GDNR and SRS laboratories analyzed composite samples. Although the SRS measured values were about a factor of 2 lower than the GDNR measured values, both laboratories measured concentrations of ^{90}Sr in flesh that were somewhat higher than would be expected for muscle tissue. Examining data supplied by the GDNR (GDNR 1997) reveals an average ratio of ^{90}Sr in edible tissue to that in nonedible tissue of 0.37. This number is based on concentrations measured in five composite samples collected on October 30 and 31, 1990, from three different Savannah River locations and includes the bass and sucker composites discussed at the GDNR and SRS meeting. If this ratio is an accurate measure of the relative concentrations of ^{90}Sr in edible (muscle) and nonedible (bones, scales, viscera) tissues, it calls into question the assumption that ^{137}Cs is the dominant radionuclide in the edible portion of fish (i.e., muscle tissue).

Evaluating data provided by the GDNR for 20 composite samples collected in 1995 and 1996 reveals an average ratio of 0.04. This ratio is approximately an order of magnitude less than the ratio calculated for the 1990 data, and is likely an overestimate of the true ratio because many ^{90}Sr concentrations reported for edible tissue were less-than values. Harvey (1963) reported $^{89,90}Sr$ concentrations for bone and flesh from bluegill, bass, and catfish collected from Par Pond in 1962. The ratio of $^{89,90}Sr$ in flesh to that in bone was less than 0.03. Whicker et al. (1990) reported ^{90}Sr levels in soft tissue to be 30 to 100 times lower than in bone tissue. Because strontium is a chemical analog of calcium, the relative distributions between bone and soft tissue for calcium are similar to those measured for strontium (Whicker et al. 1990). These data suggest that the elevated radiostrontium concentrations measured in fish flesh by the GDNR in 1990 were atypical, and it seems unlikely that radiostrontium would normally be present in significant concentrations in fish flesh. It is possible that the method of sample preparation by the GDNR in 1990 may not have adequately separated edible and nonedible portions of fish tissue.

Effect of Sample Preparation on Measured ^{137}Cs Concentration

Beginning in 1971, individual whole fish rather than dissected flesh tissue were analyzed for ^{137}Cs content. It is likely that this resulted in the reporting of concentrations that underestimated the true concentrations in flesh. Radiocesium concentrations are typically highest in muscle tissues, and analysis of additional tissues with lower ^{137}Cs concentrations (e.g., bone) would result in lower measured concentrations than analysis of muscle tissue only.

The GDNR calculated ratios of ^{137}Cs concentrations measured in edible tissue to those measured in whole fish (Hoel 1991). Ratios ranged from 1.20 to 1.49 with an average ratio of 1.4.

Concentration factors reported for whole body and muscle tissue by Gladden (1982) suggest a similar ratio of 1.5. It may be necessary to modify ^{137}Cs concentrations measured since 1971 by a factor (e.g., 1.5) to account for a reduction in measured concentrations because of a change in sample preparation procedures.

Estimating Radionuclide Concentrations in Fish at the Mouths of Onsite Streams

It is likely that the routine adjacent to SRS Savannah River fish sampling location (R-8) did not represent the maximum radionuclide concentrations in fish to which members of the public may have had legal access. Cesium-137 concentrations measured in fish from 1971 through 1981 at the mouth of Steel Creek were consistently higher than concentrations measured in fish at the R-8 river location just downstream from the mouth (Figure 14-22). The median ratio of concentrations measured in fish at the Steel Creek mouth (collected by SRS from 1971 through 1981 and by GDNR from 1982 through 1991) relative to concentrations measured in fish at the R-8 river location from 1971 through 1991 is 4. Comparing data compiled by the GDNR from 1982 through 1991 at the mouths of Steel Creek, Lower Three Runs Creek and, to a slightly lesser extent, Four Mile Creek also suggest elevated concentrations relative to those measured by the SRS at the R-8 river location (Figure 14-23).

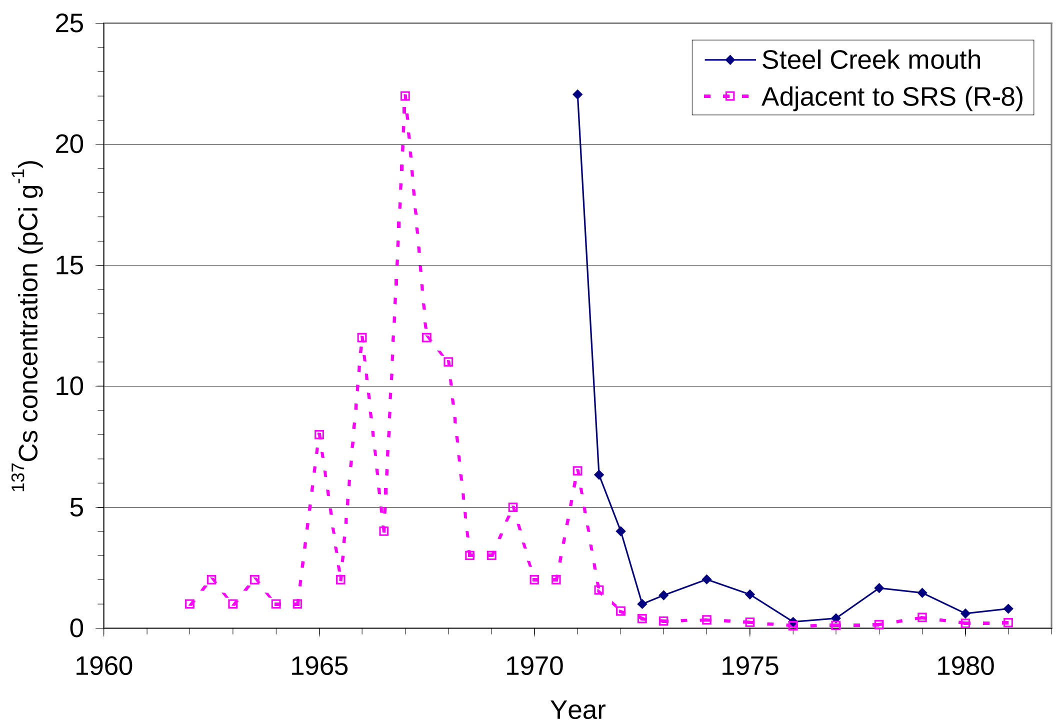

Figure 14-22. Comparison of average ^{137}Cs concentrations measured in fish collected by the SRS at the mouth of Steel Creek and at the R-8 Savannah River location. Link to tabulated figure data.

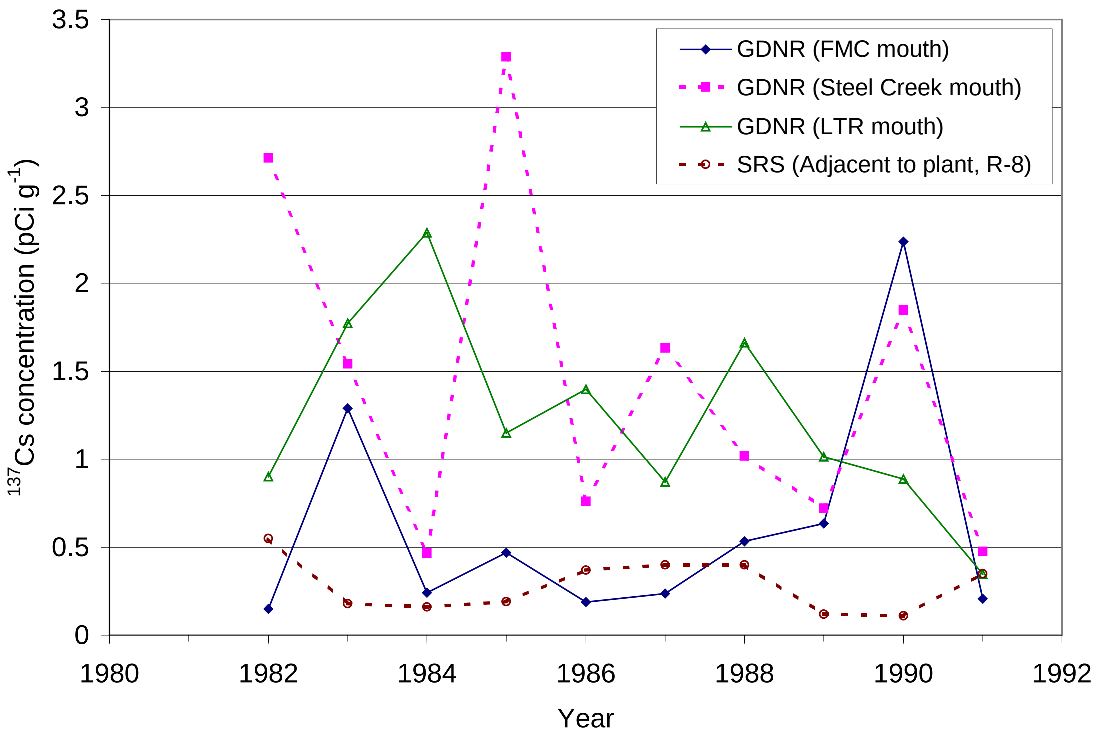

Figure 14-23. Average ^{137}Cs concentrations measured in fish collected by the GDNR at the mouths of FMC, Steel Creek, and LTR shown with concentrations measured in fish collected by the SRS at the R-8 Savannah River location. Link to tabulated figure data.

The ratio of concentrations measured in fish at the mouth of Steel Creek to concentrations measured at the R-8 river location (median ration = 4) can be used to estimate ^{137}Cs concentrations for time periods during which no concentrations were reported (i.e., before 1971). Figure 14-24 illustrates estimated concentrations at the mouth of Steel Creek from July 1958 through 1970 and measured concentrations at the same location from 1971 through 1991 that may have resulted from SRS activities. Average concentrations measured in fish at the R-8 Savannah River location between July 1958 and 1970 were used for the following calculations.

Estimated ^{137}Cs concentrations in fish for periods before 1962 were calculated from the measured nonvolatile beta concentrations in fish reported for that time and the median ratio of ^{137}Cs activity relative to nonvolatile beta activity for the R-8 river location described in Table 14-7 (median ratio = 0.38). Concentrations reported since 1971 were adjusted by an edible tissue to whole fish ratio of 1.5. These concentrations were then multiplied by a factor of four to estimate concentrations that might have been measured in fish at the mouth of Steel Creek. Finally, background concentrations (those measured at the R-2 Savannah River location) were subtracted from the estimated and measured Steel Creek mouth concentrations.

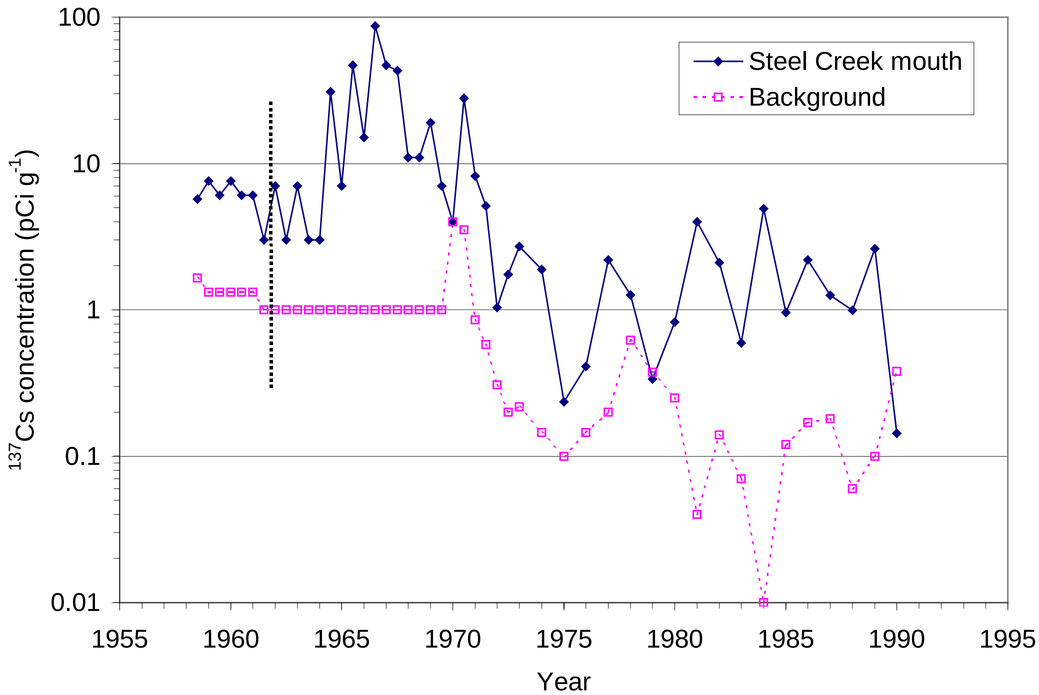

Figure 14-24. Estimated excess ^{137}Cs burdens in fish at the mouth of Steel Creek because of SRS operations shown with background concentrations measured at the R-2 Savannah River location. Values shown before the dashed vertical line were derived from reported nonvolatile beta concentrations and the median ratio of ^{137}Cs/nonvolatile beta activity for the R-8 location. Link to tabulated figure data.

For this example, average concentrations across all species have been used, but it may be necessary to account for potential differences in concentrations that may occur for different species of fish. These differences (previously discussed) and the relative percentage of bass, bream, and catfish collected at the R-8 Savannah River location (Table 14-1) may be used to estimate the concentrations that might have been measured in bass only, the species of fish that likely represents the maximum potential ^{137}Cs concentrations.

The data depicted in Figure 14-24 serve as a potential method for estimating maximum annual average radionuclide concentrations to which members of the public may have been exposed. It may eventually be necessary to evaluate concentrations at the mouths of other onsite streams using a similar approach.

It may also be possible to estimate radionuclide concentrations in fish at locations not included in the SRS routine monitoring program based on radionuclide concentrations measured in water. Figure 14-25 shows ^{137}Cs concentrations measured in water and fish collected from Steel Creek at Road A and from Lower Three Runs Creek at Patterson Mill Road. Fish and water concentrations appear well correlated.

Concentration ratios (or factors) are calculated here as the radionuclide concentration measured in fish (pCi g^{-1} wet weight) divided by the concentration measured in water (pCi mL^{-1}). The data depicted in Figure 14-19 can be used to calculate such a ratio. Table 14-9 shows the concentration ratios calculated for these data as well as concentration ratios reported by other researchers (Harvey 1963; Gladden 1982). Concentration ratios appear to be significantly lower in Lower Three Runs Creek and Par Pond than in Steel Creek. This may be related to different water chemistry for the two locations, as different concentrations of nutrients such as potassium can markedly affect concentration ratios (Whicker et al. 1990), and concentrations may also vary as a function of water concentration. Whicker et al. (1990) reported concentration ratios for Pond B that were more than two times greater than those shown for Steel Creek in Table 14-8.

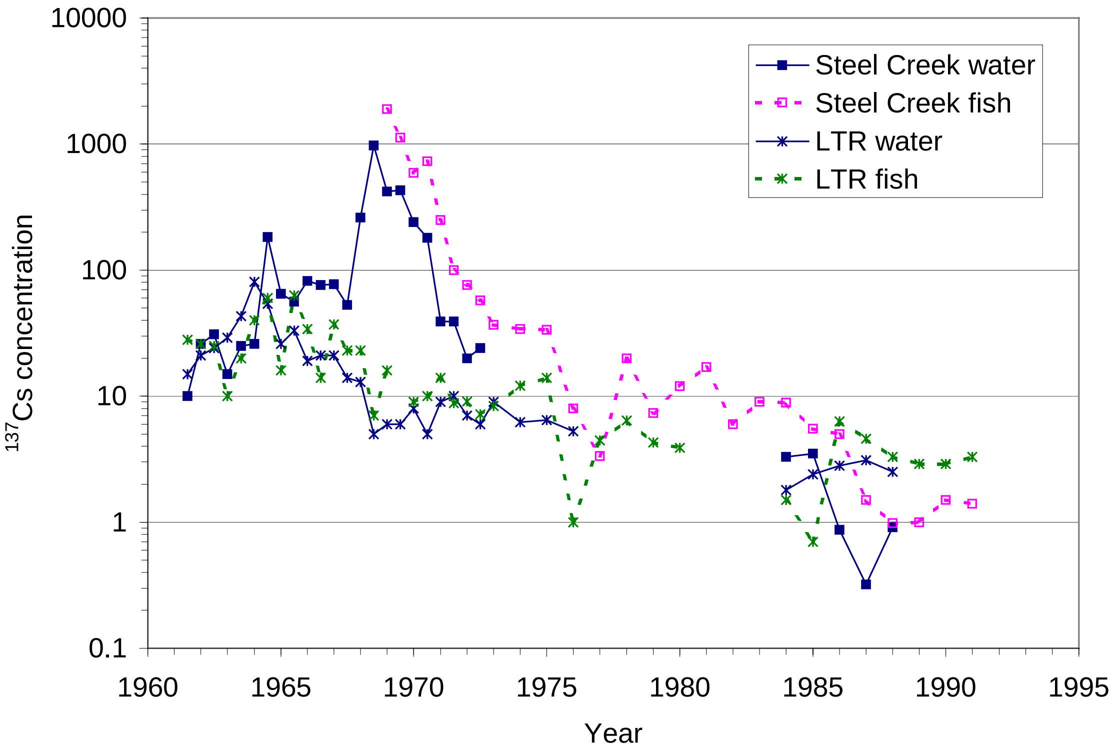

Figure 14-25. Annual average ^{137}Cs concentrations measured in fish (pCi g^{-1}) and water (pCi mL^{-1}) collected from Steel Creek at Road A and from LTR at Patterson Mill Road. Link to tabulated figure data.

Table 14-9. Mean Concentration Ratios Calculated for ^{137}Cs in Fish from Par Pond, Lower Three Runs Creek, and Steel Creek

Location	Concentration ratio (fish/water)
Lower Three Runs[a]	1258
Par Pond[b]	1100
Steel Creek[a]	3426
Steel Creek[c]	3029

[a] Ratio calculated based on data depicted in Figure 14-25.
[b] Ratio reported by Harvey (1963).
[c] Ratio reported by Gladden (1982).

Different species of fish may also exhibit significantly different concentration ratios. Gladden (1982) reported a mean concentration ratio (3029) for 527 fish collected from Steel Creek. Concentration ratios ranged from a maximum of 5688 for largemouth bass to a minimum of 963 for Savannah darters. Table 14-10 shows concentration ratios for ^{137}Cs, ^{65}Zn, and ^{90}Sr reported for Par Pond and Pond B for bass, catfish, and bluegill. It is clear that concentration ratios vary not only as a function of location, but also as a function of species and tissue type. It may be possible to estimate radionuclide concentrations in fish based on concentrations in water. However, site- and species-specific concentration ratios are clearly necessary because these ratios can vary substantially with species and, in particular, with location.

Table 14-10. Concentration Ratios for Fish Collected from Par Pond[a] and Pond B[b]

		^{137}Cs		^{90}Sr		^{65}Zn
Species	Tissue	Par Pond	Pond B	Par Pond	Pond B	Par Pond
Bass	Bone	500	nm[c]	1700	20,160	1400
	Flesh	1200	8600	<48	1088	1600
Catfish	Bone	800	nm	2100	18,240	3000
	Flesh	1200	6400	<48	20	600
Bluegill	Bone	600	nm	2400	nm	8200
	Flesh	900	5500	<48	nm	800

[a] Data from Harvey (1963).
[b] Data from Whicker et al. (1990).
[c] nm = not measured.

ELECTRONICALLY COMPILED FISH DATA

The various data summarized in this chapter are electronically compiled in two Microsoft Excel® workbooks. One workbook (Ch14-Figure_data.xls) contains the figures depicted in this chapter as well as the tabulated data that were used to produce the figures. In this workbook, there is a separate worksheet for each figure and one worksheet that contains the tabulated data for all of the figures. The second workbook (Ch14-All_data.xls) contains the data that have been tabulated from various environmental monitoring reports and aperture card printouts. The workbook contains several named worksheets that include brief summary of the compiled data.

Table 14-11 summarizes the data that have been electronically compiled for fish collected as part of the routine environmental monitoring program maintained by the SRS. Additionally, the names of the individual spreadsheets in which these data are compiled (including a brief description of the data) are provided.

Table 14-11. Description of Data Electronically Compiled for Fish

Workbook name	Worksheet name	Brief description of data
Ch14-Figure data.xls	Figures 14-1 through 14-25	Each worksheet contains a separate figure depicted in this chapter
	Data for figures	This worksheet contains the tabulated data for each of the figures
Ch14-All data.xls	Nonvolatile beta	Nonvolatile beta concentrations
	Zn-65	Zinc-65 concentrations
	Sr-89,90	Sr-89,90 concentrations
	Species %	Number and type of fish sampled, 1971–1991
	Cs-137	Cesium-137 concentrations, July 1961–1980
	Cs-137(2)	Cesium-137 concentrations, 1980–1991
	SCDHEC-Fish	Data provided by the South Carolina Department of Health and Environmental Control
	Locations	Description of sampling locations used by SCDHEC
	GDNR-Fish	Data provided by the Georgia Department of Natural Resources

USEFULNESS AND LIMITATIONS OF FISH DATA FOR DOSE RECONSTRUCTION

There are a number of factors that impact how the fish data may be used during subsequent phases of the dose reconstruction project. These factors include the availability of sufficient original monitoring data sets to verify reported summary data and evaluate spatial and temporal trends, as well as the ability to distinguish between Site releases of contaminants and other sources of the same contaminants in the environment (i.e., establish appropriate background concentrations).

In general, the aperture card printouts provided consistent verification of the summary values reported in the routine environmental monitoring reports. Information obtained from the GDNR and SCDHEC also provided general verification of the concentrations reported by SRS for fish collected from the Savannah River from 1982 through 1991.

Arithmetic mean concentrations have been historically reported by the SRS, and many of the trends and comparisons made in this chapter are based on these reported concentrations. Radiocesium concentrations, however, often fail to show a normal frequency distribution in environmental samples. This was evident for concentrations of ^{137}Cs measured in both fish and deer tissue (see Chapter 11). Medians, percentiles, and ranges are often more appropriate descriptors of these types of data. However, arithmetic mean concentrations likely err on the conservative side (i.e., provide an overestimate) of the central tendency for cesium concentrations in fish because the distributions are generally skewed to the right (e.g., log-normal).

The R-8 river location has been historically used by the Savannah River Site to represent the highest measured concentrations for fish collected from the routinely sampled Savannah River locations. However, concentrations measured at the mouth of Steel Creek from 1971 through

1981 were consistently higher than concentrations measured at the R-8 river location, just downstream from the mouth of Steel Creek. In addition, an examination of GDNR data indicates that ^{137}Cs concentrations in fish at the mouth of Four Mile Creek, Steel Creek, and Lower Three Runs Creek were elevated relative to the R-8 river location used by the SRS. Because Savannah River fishermen can potentially access fish at the mouth of Steel Creek, it may be necessary to consider concentrations measured at the R-8 river location as an underestimate of maximum concentrations to which Savannah River fishermen may have been exposed.

Concentrations for the Clark Hill and Stoke's Bluff control locations were sporadically reported. However, the concentrations reported for the Savannah River location 1 mi above the mouth of Four Mile Creek (R-2) are similar to concentrations reported for Clark Hill and Stoke's Bluff. Additionally, concentrations reported for this location are within the range of concentrations measured by the GDNR and SCDHEC at locations that would not be expected to have been impacted by SRS operations. This location appears to be adequate for establishing appropriate background concentrations.

Information is somewhat limited for the 1950s and early 1960s because of the lack of radionuclide-specific data. Therefore, it may be necessary to estimate ^{137}Cs and other radionuclide concentrations based on nonvolatile beta concentrations reported before 1962. Additionally, very little information at all is available before July 1958.

The section in this chapter entitled "Estimating Radionuclide Concentrations in Fish at the Mouths of Onsite Streams" provides a possible methodology for estimating maximum excess ^{137}Cs concentrations resulting from SRS operations in fish potentially accessible to members of the public. This methodology takes into account the fact that the R-8 location may not have represented the highest Savannah River fish concentrations, considers possible background concentrations, and estimates ^{137}Cs concentrations based on measured nonvolatile beta concentrations during time periods when ^{137}Cs concentrations were not measured.

Fish flesh was analyzed before 1971, and whole fish have been analyzed since then. It is possible that this would result in lower measured concentrations because tissues other than muscle (e.g., bone) typically do not accumulate as much cesium. However, a significant decrease in concentrations at this time is not apparent at any location, and Savannah River location concentrations have generally been near the LLD since 1971. However, for dose reconstruction, it may be necessary to modify concentrations reported since 1971 by an edible tissue to whole fish adjustment factor. Fish were also not analyzed by species until 1971, but this does not appear to be a significant limitation.

Variations in radionuclide uptake in fish can also vary as a function of location as demonstrated with the concentration ratios shown in Tables 14-8 and 14-9. This should be considered when comparing concentrations measured in fish collected from different locations. It is clear that site-specific factors (e.g., potassium and calcium concentrations) may influence the degree to which various radionuclides are assimilated in fish tissues.

It is difficult to determine the range of movement of fish living in onsite streams. However, based on the reported concentrations, the range of movement appears limited and has not resulted in significant numbers of highly contaminated fish entering the Savannah River. There is little question that some fish living in onsite streams have accumulated significant ^{137}Cs burdens, and that reactor effluent has also contributed to slightly elevated concentrations measured in fish collected from the Savannah River adjacent to and below the SRS. Significantly elevated ^{137}Cs concentrations have also been reported for fish collected from Par Pond and Pond B, but fish living in these reservoirs have been isolated from onsite streams that drain into the Savannah River.

In summary, although mean concentrations may not be the best descriptors of the data, the available data are potentially quite useful for estimating exposure to the general public resulting from regular consumption of fish. Concentrations were not reported in the documents that have been reviewed for some onsite locations from 1977 through 1983, but concentrations have consistently been reported for Savannah River locations, which are most important for determining exposure to the general public. Very few fish were collected at any location from 1976 through 1978, but ^{137}Cs concentrations for those fish that were collected from the Savannah River were near the LLD at this time. Average ^{137}Cs concentrations in Savannah River fish appear to have decreased by more than an order of magnitude between 1963 and 1991, and nonvolatile beta concentrations before 1963 appear similar to those recorded in 1951 and 1952, before plant startup.

The fish data may also be useful to some extent for source term verification and model validation. These efforts will likely be undertaken during the next phase of the dose reconstruction and will require appropriate dispersion models and associated site-specific parameters.

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