APPENDIX D

RADIOCESIUM AND RADIOCOBALT INVENTORY AND TRANSPORT

This appendix discusses the releases of radiocesium (principally cesium-137) and radiocobalt (cobalt-60) to the Steel Creek system; describes the estimated distribution and inventory of these materials in the sediments, biota, and water of the creek, swamp, and Savannah River; examines their transport offsite; and predicts the concentrations in the Savannah River and downstream water treatment plants as a result of resumption of L-Reactor operation (reference case--direct discharge). This appendix is also the basis for discussions associated with the preferred cooling-water alternative (see Appendix L). TC

D.1 RELEASES OF RADIOCESIUM AND RADIOCOBALT

D.1.1 SRP releases

The principal sources of radiocesium and radiocobalt in the environment at SRP have been the reactor effluent discharges to onsite streams. These releases began in 1955, with the period of major reactor discharges occurring between 1955 and 1968.

From 1955 through 1980, about 560 curies of radiocesium have been discharged to onsite streams, approximately 284 curies of which were discharged to Steel Creek (Table D-1). These discharges resulted from leaching of reactor fuel elements with cladding failures which exposed the underlying fuel to water. The direct sources of these releases were heat exchanger cooling water, spent fuel storage and disassembly basin effluents, and process water from P- and L-Reactor areas (Figure D-1). A sharp decrease in the release of radiocesium (cesium-134 and cesium-137 in a ratio of 1:20, respectively; for ease of discussion, radiocesium will usually be referred to as cesium-137) occurred in the late 1960s and early 1970s when, (1) P-Reactor basin was fitted with sand filters and the basin water was demineralized before its release; and (2) the leaking fuel elements were removed to an environmentally safe storage area (L-Reactor is now equipped with a sand filter and ion exchange resin beds like those at P-Reactor).

A total of 66 curies of cobalt-60, formed by neutron activation of stainless steel in the reactors, has been discharged to SRP streams in the years following L-Reactor startup. An estimated 27 curies (15 from L-Reactor and 12 from P-Reactor) of this total was discharged to Steel Creek. Most of the cobalt-60 (half-life 5.26 years) has been eliminated through radioactive decay; however, an estimated 2.1 curies remain today either in Steel Creek or transported to the Savannah River system in a manner similar to radiocesium. This inventory is significantly less than the remaining cesium inventory in Steel Creek of 67 curies, 14 percent of which occurs above the L-Reactor outfall.

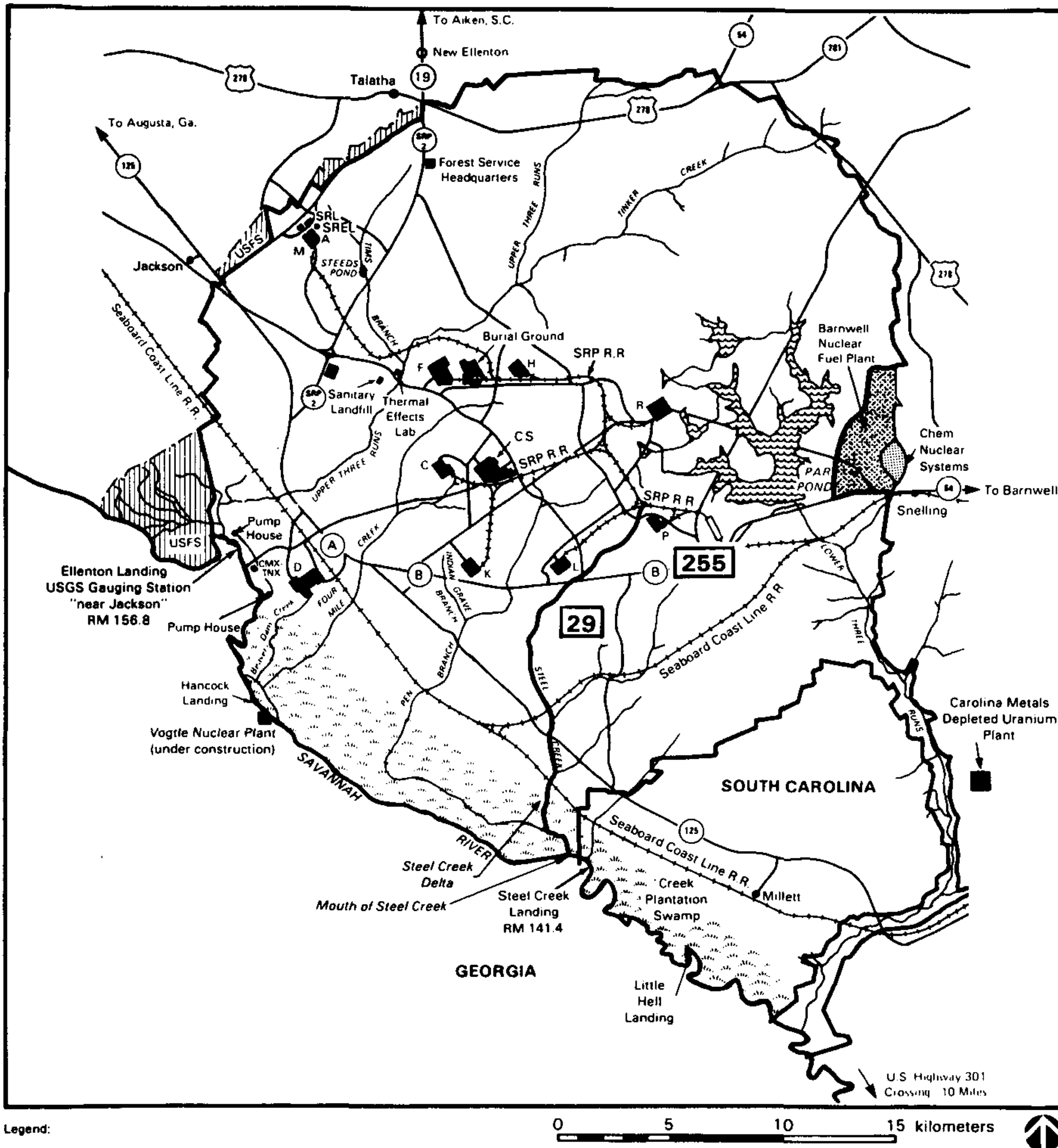
After their discharge to Steel Creek, the cesium-137 and cobalt-60 became primarily associated with the silts and clays in the Steel Creek system. The sediments and associated radionuclides have been subjected to continued resuspension, transport, and deposition according to the flow regime in the creek.

Table D-1. Cesium-137 release, transport, and accumulation in Steel Creek[a]

Year	Incremental releases P-Area (Ci/year)	Incremental releases L-Area (Ci/year)	Cumulative Cs-137 discharge corrected for decay (Ci)	Incremental Cs-137 transported past Road A in Steel Creek (Ci/year)
1955	0.2	0.2	0.4	--[b]
1956	0.4	0.3	1.1	--
1957	1.1	0.7	2.9	--
1958	0.5	0.6	3.9	--
1959	0.7	1.6	6.1	--
1960	4.8	5.2	16.0	4.5
1961	4.2	1.0	20.8	6.1
1962	13.7	1.3	35.3	11.8
1963	9.0	0.9	44.4	9.2
1964	45.6	7.7	96.7	23.0
1965	29.8	1.3	125.6	20.0
1966	35.7	0.9	159.4	25.2
1967	45.1	0.7	201.5	20.3
1968	40.9	0.2	238.0	22.2
1969	13.1	3.4	249.1	14.7
1970	7.7	3.2	254.4	9.2
1971	1.3	0	249.9	1.6
1972	0.2	0	244.4	0.8
1973	0.2	0	239.0	0.8
1974	0.07	0	233.6	0.6
1975	0.04	0	228.4	0.5
1976	0.07	0	223.2	0.8
1977	0.09	0	218.2	0.3
1978	0.02	0	213.3	0.3
1979	0.02	0	208.5	0.4
1980	0.02	0	203.7	0.7
Total	255	29		

[a]Adapted from Du Pont (1982a).

[b]Not measured; assumed to be 0 in calculating the inventory above Road A. However, assuming that the fraction of the total release transported over the 1960-1980 period is applicable to the earlier period, it is estimated that 3.9 curies were transported past Road A from 1955 to 1959.



Legend:

C, K, R, L, P Reactor Areas (C, P, K are operating)
F, H Separations Areas
M Fuel and Target Fabrication
D Heavy Water Production
A Savannah River Laboratory and Administration Area
CS Central Shop
RM River Mile

Road A = Highway 125

Note: See Table D-1 for listing of the annual releases to Steel Creek.

Figure D-1. Savannah River Plant site showing total radiocesium releases to Steel Creek from L- and and P-Areas.

D.1.2 Weapons test fallout

Atmospheric testing of nuclear weapons, mainly before the test ban treaty of 1963, caused 25,600,000 curies of cesium-137 to be deposited on the surface of the earth (United Nations, 1977; Miskel, 1973; Hayes, 1983c). The total resultant deposition was 2850 curies and 80 curies of cesium-137 in the 27,400 square kilometers of the Savannah River watershed and the 780 square kilometers of SRP, respectively. The deposited cesium-137 became attached to soil particles and has undergone only slow transport off the watershed. Results of routine monitoring by SRP indicate that since 1963 about 1 percent (about 32 curies) of the 2850 curies of cesium-137 deposited on the total Savannah River watershed has been transported down the river.

D.2 DISTRIBUTION OF RADIOCESIUM AND RADIOCOBALT

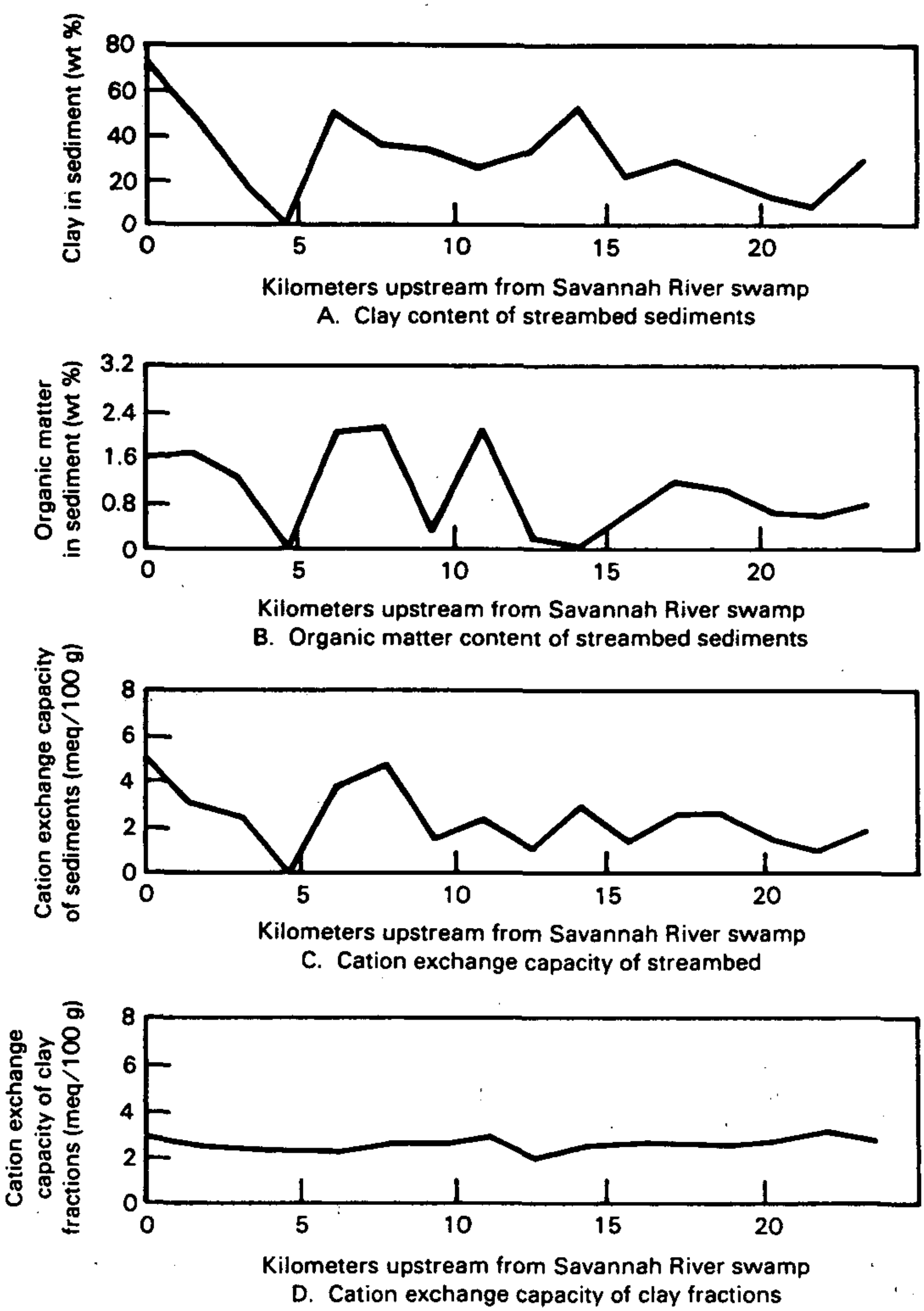
D.2.1 Sediments

D.2.1.1 Steel Creek sediments

Most of the cesium-137 that has been discharged to Steel Creek by SRP operations and weapons testing became associated with the silts and clays found in the streambed and suspended solids. The principal mechanisms for this association were (1) cation exchange with kaolinite and gibbsite clay minerals; (2) sorption on minerals; and (3) chelation with naturally occurring organic material. Figure D-2 shows the variation in ion-exchange capacity, clay content, and content of organic materials along the course of Steel Creek. A distribution coefficient of K_d = 3960, measured for sediments from Four Mile and Steel Creek (Kiser, 1979), and the work by Prout (1958), demonstrate the affinity of cesium-137 for the sediments and suspended solids in the Steel Creek system. Radiocobalt, because of its similar distribution coefficient, is expected to be associated with the sediment in the Steel Creek system in a manner similar to that of cesium-137.

As a result of these affinities, sedimentation and sorption processes control the distribution of cesium-137 and cobalt-60 in Steel Creek, its delta, and the adjoining Savannah River swamp. The resuspension, transport, and deposition of sediment are governed by the hydraulic properties of the sediment and streambed and by the creek's flow regime. Studies of Steel Creek (Ruby et al., 1981) indicate (1) erosional conditions exist in the reach from P-Reactor to about 2.5 kilometers above Road A; (2) neutral conditions exist in the reach from 2.5 kilometers above Road A to about 1.8 kilometers below Road A; and (3) depositional conditions exist in the 4- to 5-kilometer reach from 1.8 kilometers below Road A across the delta to the creek's mouth at the breach in the Savannah River levee.

Almost all sediment redistribution occurred during the period of major reactor discharges, between 1955 and 1968. Since 1968, little change has occurred in the sedimentation patterns or in the channel-delta configuration of Steel Creek (Ruby et al., 1981).



Source: Hawkins (1971).

Figure D-2. Variation of clay content, organic matter, and cation exchange capacity in Steel Creek as a function of distance.

Soil cores collected in 1974 in lower Steel Creek (Table D-2; Figure D-3) showed that (1) 69 percent of the cesium-137 was in the upper 20 centimeters; (2) 86 percent in the upper 40 centimeters; and nearly all of it was confined to the upper 100 centimeters (Brisbin et al., 1974). More extensive coring conducted in 1981 within the Steel Creek corridor and delta areas (Figure D-3; Table D-3; Figure D-4) confirmed these results; about 61 percent of the cesium-137 was found in the upper 20 centimeters and 83 percent in the upper 40 centimeters (Smith et al., 1982). Sediment samples taken in 1981 from the center of Steel Creek had lower cesium-137 concentrations than sediments taken from either bank (Figure D-5) (Smith et al., 1981). In addition, the fine-grained (clay and silt) creekbed and floodplain sediments are usually associated with higher cesium-137 concentrations than the coarser-grained sediments (Tables D-4 and D-5).

Table D-2. Distribution of radiocesium (pCi/g dry weight) in Steel Creek soils[a]

Depth interval (cm)	Mean	Standard error	Range	Percentage of total Cs-137 inventory in interval
0-10	93.5	32.3	5.6-516.4	55
11-20	24.5	6.8	3.1-137.5	14
21-30	15.1	4.1	2.3-75.1	9
31-40	13.0	3.8	1.4-60.6	8
41-50	7.1	2.1	1.0-42.8	4
51-60	3.8	0.6	0.5-10.9	2
61-70	3.4	0.4	0.8-7.2	2
71-80	4.0	0.9	0.2-15.5	2
81-90	3.3	0.7	0.1-14.0	2
91-100	2.1	0.4	0.0-6.9	1
Total				100

[a]Adapted from Brisbin et al. (1974); see Figure D-3 for sampling locations.

EV-6 Studies between 1978 and 1981 showed concentrations of cobalt-60 in the Steel Creek floodplain sediments to be, on the average, about 15 times less than cesium-137 concentrations (Table D-6). No other man-made gamma activity radionuclides were detected above measurement sensitivities.

Gamma exposure measurements at one meter above ground level were conducted in Steel Creek along the 12 soil-sampling transects, and the results compared with radiocesium concentrations in one-meter-deep soil cores and vegetation

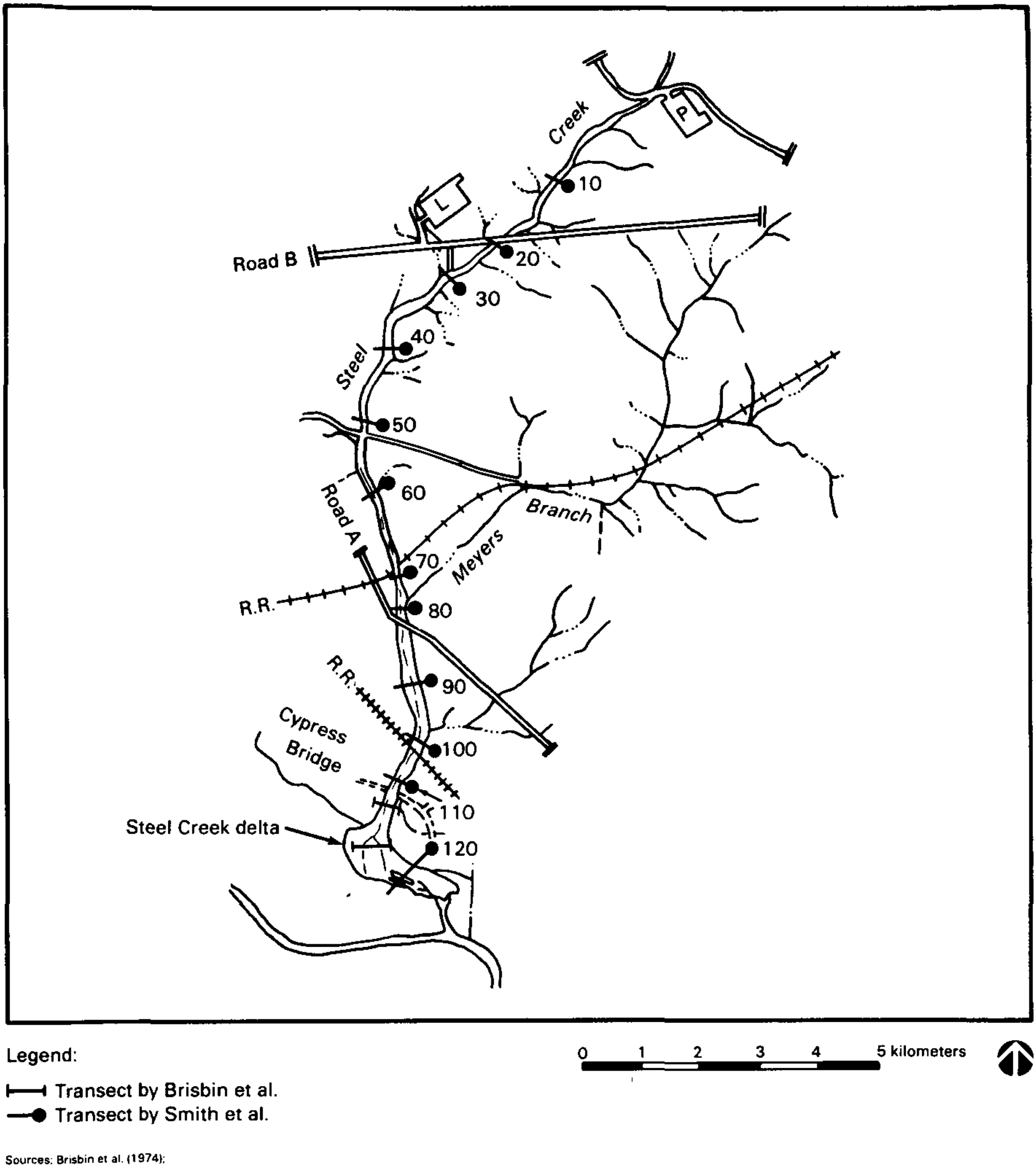


Figure D-3. Location of transects used for collection of soil cores, gamma dosimetry measurements, and vegetation samples in Steel Creek.

Table D-3. Estimated radiocesium concentrations at the sampled soil depths for the major Steel Creek sections and total Cs-137 for each section[a]

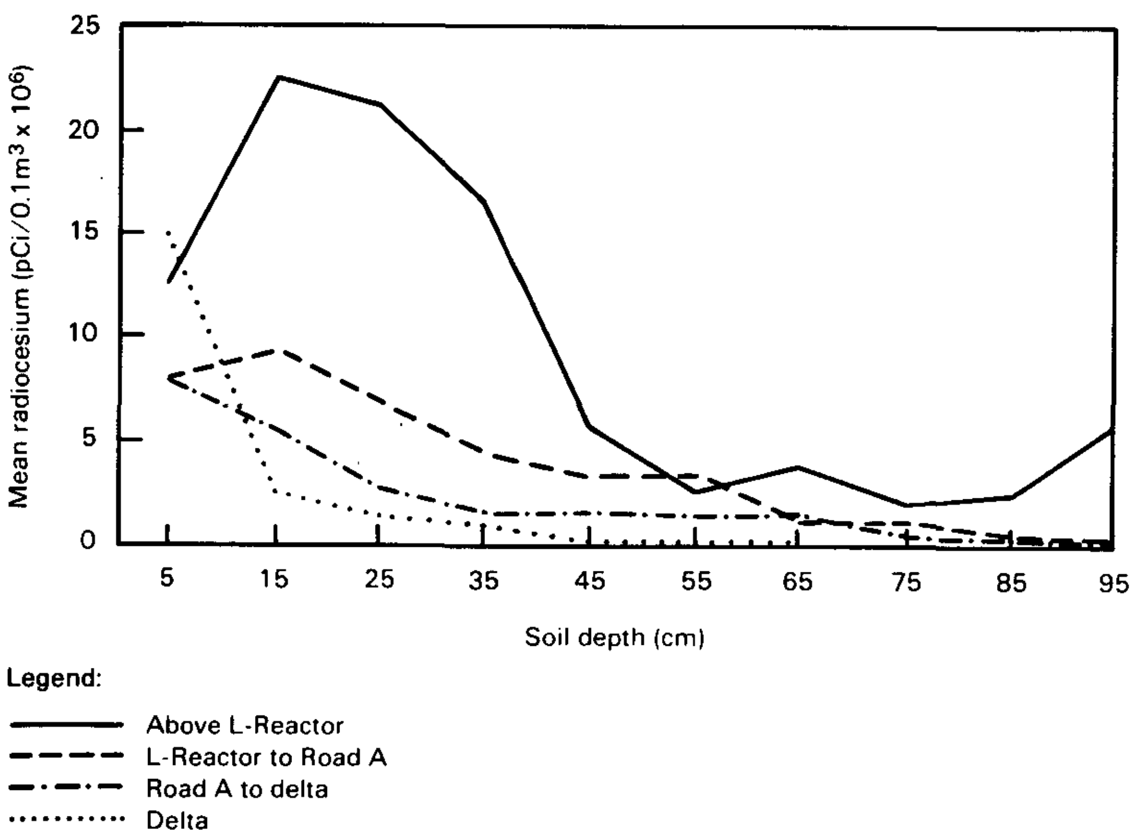
EV-4

Depth (cm)	Major sections of Steel Creek[b] P-Reactor to L-Reactor ($\mu Ci/m^2$)	L-Reactor to Road A ($\mu Ci/m^2$)	Road A to delta ($\mu Ci/m^2$)	Steel Creek delta ($\mu Ci/m^2$)	Total curies	Percent of total
0-10	12.51	8.13	8.10	15.02	27.27	41
10-20	22.21	9.45	5.35	2.63	13.70	20
20-30	21.27	6.29	2.48	1.03	8.44	13
30-40	16.80	4.67	1.56	0.85	6.33	9
40-50	5.91	3.47	1.65	0.24	3.84	6
50-60	2.41	3.45	1.31	0.15	3.23	5
60-70	2.66	0.85	1.33	0.22	1.67	2
70-80	1.88	0.93	0.56	0.17	1.23	2
80-90	2.48	0.37	0.28	--	.61	1
90-100	5.80	0.21	0.14	--	.76	1
Total	93.93	37.82	22.76	20.31		100
Area $m^2 \times 10^3$	97.48 (4%)	644.74 (28%)	458.02 (20%)	1138.71 (49%)	--	--
Curies	9.16 (14%)	24.38 (36%)	10.42 (15%)	23.13 (34%)	67.09	--

[a]Adapted from Smith et al., 1982; soil samples collected along transects shown in Figure D-3, as described in the reference.

[b]Figures D-1 and D-3 show the locations of these features.

samples (Gladden et al., 1982). Maximum exposure rates (Table D-7) were found at upstream transects near the sources of the contamination and downstream in the Steel Creek delta area. Mean exposure rates of 0.057 to 0.100 mR/hr were observed in the transects nearest P- and L-Reactors, and 0.092 mR/hr in the delta area. In general, the radiocesium content (pCi/0.1 m^3) in the surface soils was the most important variable for explaining variations in exposure rates. The relative importance of the other variables [plant concentration (pCi/g), soil concentration (pCi/g) as a function of depth, and soil texture] varied substantially along the length of Steel Creek (Gladden et al., 1982). Based on the gamma exposure rate data, radiocesium concentrations in the Steel Creek system can be characterized as nonuniformly distributed across the floodplain. Replicate transects within locations (any of the 12 transect locations) show little similarity in either the locations or magnitudes of the gamma exposure rates.



Source: Smith et al. (1982).

Figure D-4. Radiocesium concentrations in soil cores collected in Steel Creek (1981).

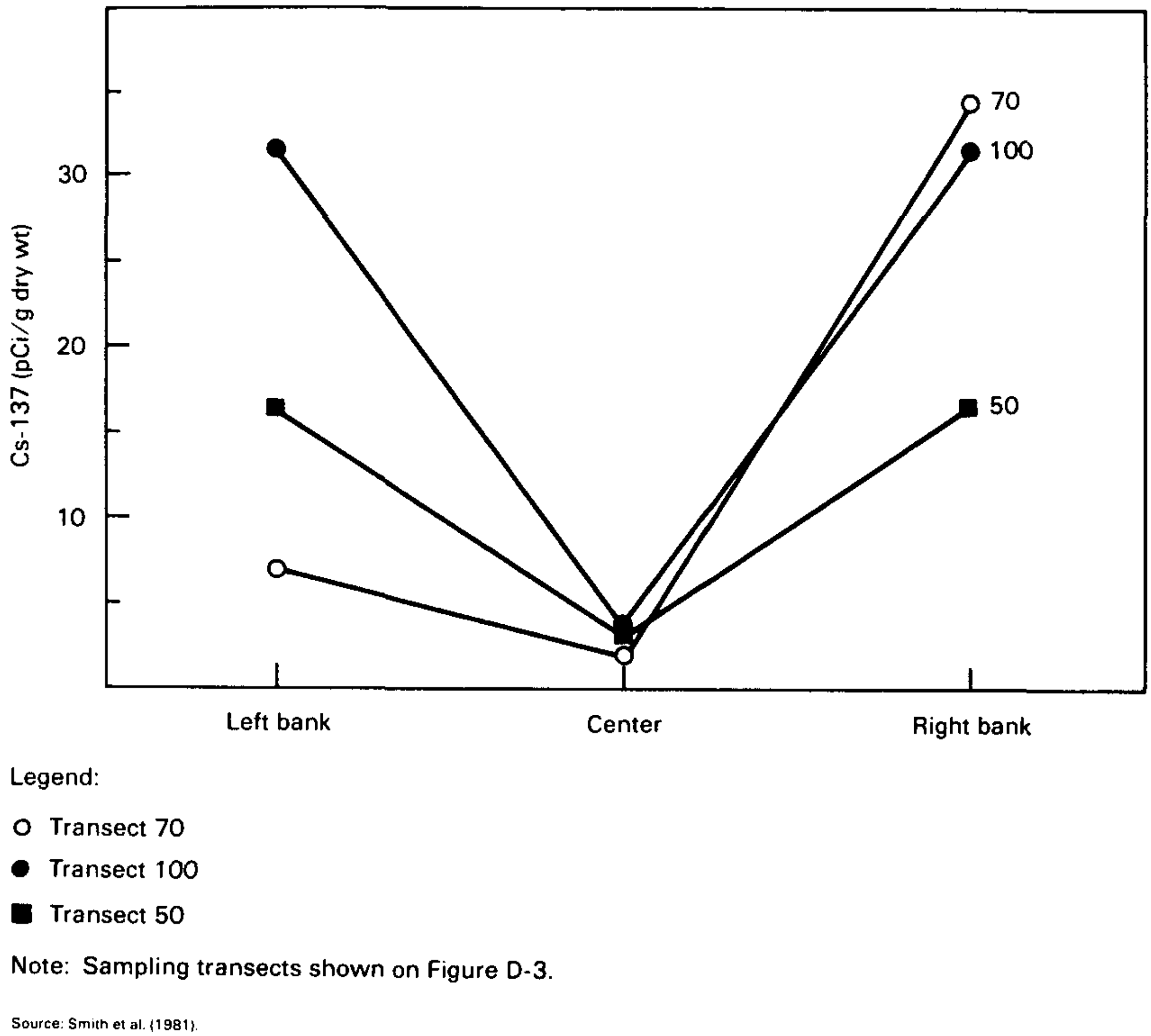


Figure D-5. Concentrations of radiocesium in midstream and stream bank sediment samples collected in Steel Creek (1981) at locations 50, 70, and 100.

Table D-4. Range of Cs-137 concentrations (pCi/g dry weight) of soil types in Steel Creek (1981)[a]

Soil type[b]	N[c]	% total	Mean	Standard error
1 (clay)	101	19.24	137.08	19.82
2	108	20.57	80.47	15.52
3	127	24.19	38.50	7.10
4	83	15.81	54.86	12.02
5 (sand)	106	20.19	17.23	2.99

[a]Adapted from Smith et al. (1981); data represent all soil samples collected along the 12 transects shown in Figure D-3.

[b]Soil samples were graded visually from 1 to 5, according to their "average" particle size; samples with the highest clay content are type 1 and those with the least clay and silt (i.e., predominantly sand) are type 5.

[c]N = Number of soil samples.

EV-11

Table D-5. Mean radiocesium concentration (pCi/g) in soil column by soil size category[a]

Location[c]	Soil type[b] 1(fine)	2	3	4	5(coarse)
Above L-Reactor	166	104	62	117	43
L-Reactor to Road A	171	112	38	36	8
Road A to delta	78	46	18	21	9
Delta	219	59	13	24	17

[a]Adapted from Smith et al., 1982.

[b]Soil samples were graded visually from 1 to 5, according to their "average" particle size; samples with the highest clay content are type 1 and those with the least clay and silt (i.e., predominantly sand) are type 5.

[c]Figures D-1 and D-3 show the locations of these features.

Table D-6. Co-60 and Cs-137 in Steel Creek sediments[a]

		Road B			Steel Creek at Swamp		
	Year	Co-60 pCi/g	Cs-137 pCi/g	Co-60 / Cs-137	Co-60 pCi/g	Cs-137 pCi/g	Co-60 / Cs-137
EV-8	1978	1.7	45	0.038	7.5	67	0.112
	1979	1.7	50	0.034	1.5	61	0.025
	1980	0.6	3.5	0.171	---	10	---
	1981	0.9	42	0.021	1.2	2	0.6[b]
EV-8			Rd B + at swamp average is 0.067 ± 0.061				

[a]Source: Hayes and Watts, 1983; locations of Road B and Swamp shown in Figure D-1.

[b]Outlier, not used to develop average ratio.

Table D-7. Mean and range of gamma exposure readings at sampling locations along Steel Creek[a]

	Transect location[b]	Number of observations	Mean (mR/hr)	Range
EV-13	10	60	0.057	0.010-0.500
	20	63	0.132	0.005-0.950
	30	86	0.091	0.015-0.350
	40	93	0.100	0.020-0.375
	50	122	0.039	0.010-0.129
	60	76	0.040	0.016-0.073
	70	97	0.053	0.015-0.400
	80	166	0.044	0.015-0.375
	90	160	0.054	0.013-0.375
	100	198	0.051	0.010-0.150
EV-13	110	138	0.033	0.014-0.129
	120	592	0.092	0.002-0.550
	10-120	1851	0.068	0.002-0.950

[a]Adapted from Gladden et al., 1982.

[b]Location of transects shown in Figure D-3.

D.2.1.2 Savannah River swamp sediments

Beginning in 1974, comprehensive radiological surveys were made in the Savannah River swamp, including the 1235-acre uninhabited, privately owned Creek Plantation Swamp (Figure D-6), and of the soil and the vegetation. Because no significant changes were observed in the mean concentration of cesium-137 in soil samples from 1976 (34.1 ± 50.3 picocuries per gram) to 1977 (39.9 ± 57.4 picocuries per gram), the 1978 survey included only thermoluminescent dosimeter (TLD) measurements. Provisions were made to conduct comprehensive surveys at 5-year intervals (Ashley and Zeigler, 1981). Soil cores collected in 1974 showed that about 70 percent of the cesium-137 was confined to the upper 6 to 7 centimeters, but that cesium was detectable at depths of 25 centimeters (Ashley and Zeigler, 1975). The 1982 values are appreciably less than those for 1974, but slightly lower on the average than those for 1977. Mean values at comparable locations averaged 33.3 (1982), 39.8 (1977), and 75.9 picocuries per gram (1974) (Du Pont, 1983b). In 1982, TLD measurements ranged from a minimum of 0.14 milliroentgen per day to maximum of 1.09 milliroentgen per day, both measured on Trail 1 (Figure D-6). The 1972-to-1980 average values ranged from 0.20 milliroentgen per day on Trail 9 to 1.46 milliroentgen per day on Trail 1 (Du Pont, 1983b).

EV-14

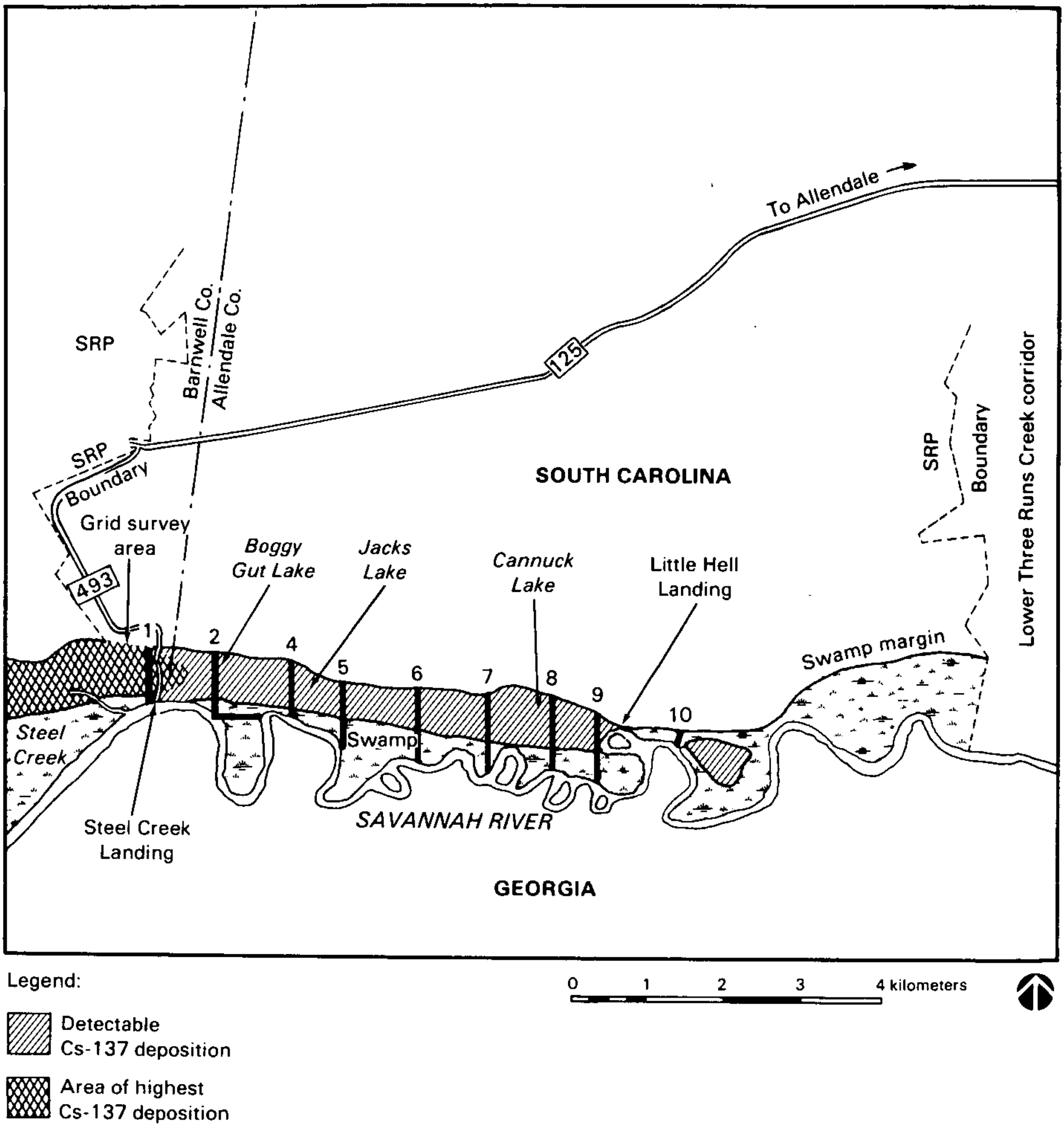
EV-14

D.2.1.3 Savannah River sediments

Turbulence in the Savannah River generally keeps the fine soils particles in suspension. These particles are deposited where the river velocity and turbulence are low, such as inside river bends and downstream from obstructions, Oxbow Lakes, and portions of the floodplain. Sediments from such locations upstream from the Savannah River Plant normally have about 1.0 picocurie per gram or less of radiocesium (Du Pont, 1982a). In 1974, riverbed sediments from downstream of the Savannah River Plant contained radiocesium concentrations from about 2.0 picocuries per gram at the U.S. Highway 301 bridge (River Mile 118.7 near Millhaven, Georgia) to 6.5 picocuries per gram at the Georgia Highway 119 bridge (River Mile 61.5, near Clyo, Georgia). Table D-8 summarizes more recent monitoring data for the Savannah River.

D.2.1.4 Holding pond sediment

A radiological survey of the raw water and backwash holding pond sediments at the Beaufort-Jasper water treatment plant was performed in November 1982. Cesium-137 concentrations in the sediment from the raw water holding pond are about one-tenth those from the backwash pond sediment, which is principally floc (Table D-9). Backwash floc from the North Augusta water treatment plant has cesium-137 and K-40 concentrations similar to those at the Beaufort-Jasper plant. These cesium-137 concentrations are low and within the concentration range of cesium-137 in sediments from other locations in South Carolina not influenced by SRP (Hayes, 1983d).



DR-4 Total contaminated offsite area is 940 acres

Source: Du Pont (1983b).

Figure D-6. Location of transects used for collection of soil cores and vegetation samples in Savannah River Swamp, including the 1235-acre Creek Plantation Swamp.

Table D-8. Cesium-137 concentration (pCi/g dry weight) in Savannah River sediments (8-cm depth)[a]

Location	River mile	Average 1975-1979	1980	1981	1982
Dernier's Landing[b]	160.5	0.5	0.2	0.07	0.03
Below Four Mile Creek	150.2	0.7	0.2	0.4	0.25
Above Little Hell Landing	136.6	0.8	0.2	0.7	0.7
Below Little Hell Landing	134.0	3.9	0.4	0.5	0.1
Above Lower Three Runs Creek	129.5	0.8	0.4	0.5	-
U.S. Highway 301 bridge	118.7	1.7	1.1	0.07	0.5
S.C. Highway 119 bridge	61.5	6.5[c]	-[d]	-	-

[a]Source: Ashley and Zeigler, 1976, 1978a, 1978b, 1981.
[b]Control above Plant.
[c]Based on 1975 data only.
[d]No analysis performed.

EV-16

Table D-9. *Gamma pulse height analyses of sediment core samples* Beaufort-Jasper and North Augusta water treatment plants, 11/8/82[a]

Location	Depth (cm)	Dry Weight gms	Cs-137 pCi/gm	K-40 pCi/gm
Beaufort-Jasper				
Raw Water Holding	0 - 2.4	504	0.08 ± 0.07	2.8 ± 0.9
Pond	2.4 - 4.7	164	0.05 ± 0.16	4.0 ± 2.3
Backwash Pond #1[b]	0 - 2.4	5	0.20 ± 5.2	5.4 ± 73
	2.4 - 4.7	10	.96 ± 2.5	0 ± 34
	4.7 - 7.1	57	.29 ± 0.44	1.6 ± 6.0
	7.1 - 9.4	39	.52 ± .64	0.3 ± 8.7
	9.4 -11.8	14	.71 ± 1.7	0 ± 23
Backwash Pond #2[b]	0 - 2.4	5	0.92 ± 4.5	0 ± 62
	2.4 - 4.7	12	.72 ± 2.0	2.3 ± 27
	4.7 - 7.1	20	.46 ± 1.2	0 ± 17
	7.1 - 9.4	24	.96 ± 1.0	0 ± 14
	9.4 -11.8	25	.92 ± 1.0	0 ± 14
	9.4 -14.2	54	.44 ± 0.5	4.2 ± 6.5
	14.2 -16.5	19	.79 ± 1.3	5.6 ± 18
	16.5 -18.9	8	1.1 ± 3.0	3.6 ± 42
Composite Backwash Ponds Ponds 1 & 2		291	0.48 ± 0.03	3.3 ± 0.5
North Augusta (Primarily Floc)		41	0.54 ± 0.12	2 ± 1.5

[a]Adapted from Du Pont (1983b).
[b]The backwash pond sediments contained primarily floc which when dried contained only small quantities of material.

D.2.2 Biota

During the period of major reactor discharges of cesium-137, 1955 to 1968, Steel Creek was subjected to heated discharges as much as 20 times its normal unheated flow. There was pronounced vegetation mortality; most arboreal species on the Steel Creek floodplain and delta were lost. The vegetation kill zone projected well beyond the distal end of the Steel Creek delta and downstream in the Savannah River swamp (Smith et al., 1982). When the reactor discharges were discontinued, natural succession began to revegetate. This process is still active, but slow (Martin et al., 1977; Ruby et al., 1981).

Vegetation samples collected in Steel Creek (Figure D-7) from 1970 to 1979 show (Table D-10) annual reductions in cesium-137 concentrations from 1970 through 1973. Concentrations remained fairly constant from 1973 to 1976 (Ashley and Zeigler, 1981; Du Pont, 1982a). Du Pont (1982a) suggested that the high concentrations in 1977 were due to the uptake of cesium-137 desorbed and resuspended during the 1976 heated discharge to Steel Creek from P-Area (see Section
/-22 D.4). Results of additional vegetation samples collected (Figure D-3) in 1981 are presented in Smith et al. (1982), and summarized in Table D-11.

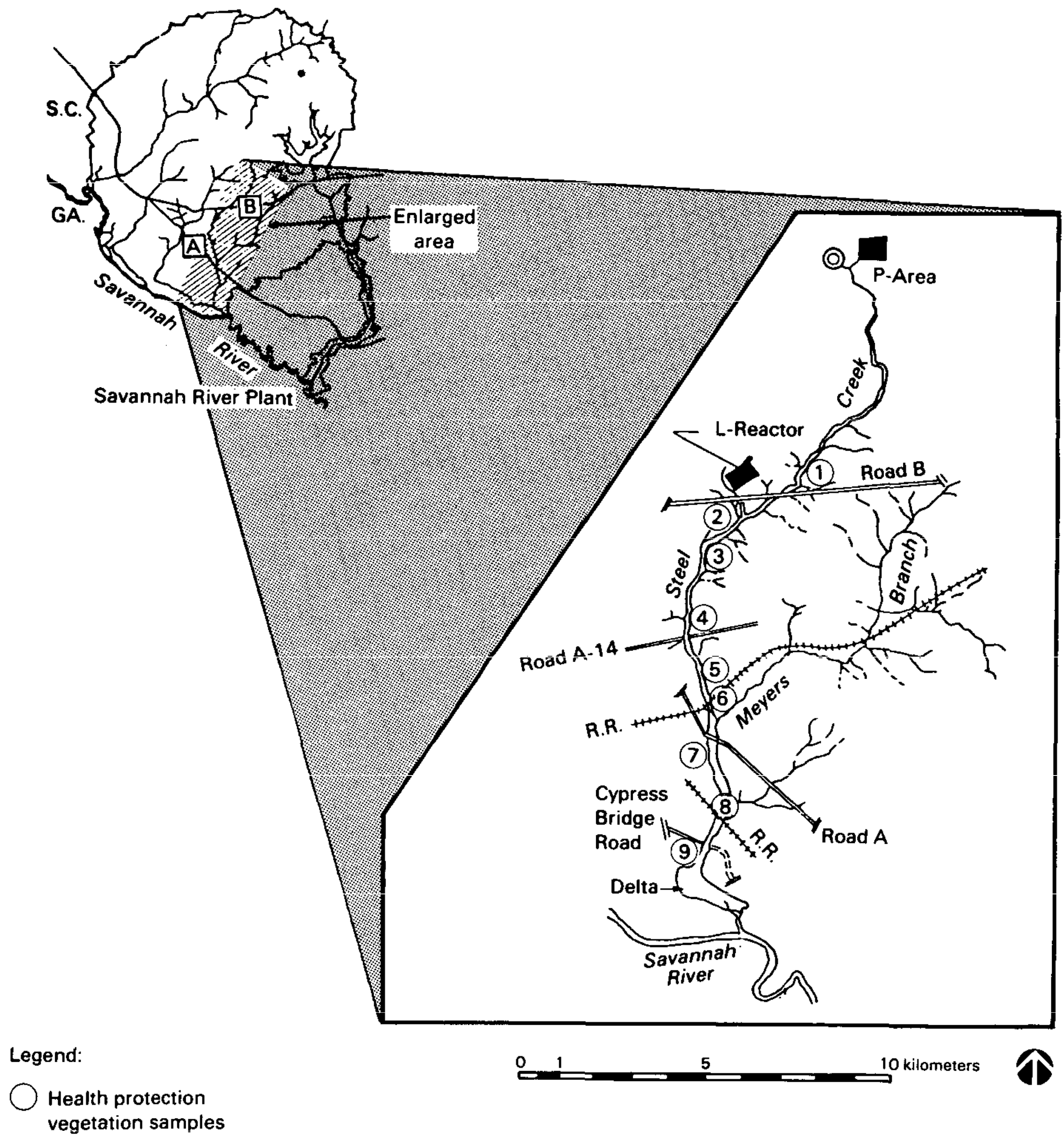
Table D-10. Average radiocesium concentrations in vegetation from Steel Creek[a]

Sample Point[b]	Average Cs-137 concentration (pCi/g dry weight)[c]									
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
0	600	310	150	210	380	240	420	1000	160	110
1	2200	360	20	340	280	220	250	1300	520	270
2	1000	890	150	120	160	240	400	1800	770	310
3	1300	660	450	360	210	380	360	420	270	250
4	220	1100	340	280	310	180	230	410	250	200
5	1960	510	360	210	210	200	100	420	220	200
6	1100	1100	770	220	260	160	390	220	150	130
7	1600	660	290	240	220	220	180	250	210	83
8	1100	570	460	190	130	110	170	220	160	110
9	260	160	380	210	190	190	190	210	170	140
Mean	1134	632	337	238	235	214	269	625	288	180
Standard deviation	664	320	208	71	74	70	114	553	201	77

[a]Adapted from Du Pont (1982a).

:V-18 [b]Location of transects are shown on Figure D-7; vegetation sampled was primarily cattails, duckweed, and knotweed.

[c]The period from 1962-1969 was associated with high release rates to Steel Creek, averaging 31.2 Ci/year; thereafter, the releases were substantially less, averaging 0.58 Ci/year (see Table D-1).



Source: DuPont (1982a).

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Figure D-7. Location of transects used for collection of vegetation samples in Steel Creek (1970 to 1979).

Table D-11. Cesium-137 concentration in vegetation samples (1981)

Vegetation type	Concentration (pCi/g dry wt) Herb. leaf	Herb. stem	Woody leaf	Woody stem
Mean	228.6	142.7	131.5	98.8
EV-22 Standard error	23.4	8.8	9.7	7.6
Sample size	145	145	123	122

Changes in the cesium-137 concentrations that have occurred in selected plants and insects from the Steel Creek watershed between 1971 and 1981 are listed in Table D-12.

From 1974 to 1977, annual surveys in the Savannah River swamp (Figure D-6) included soil, vegetation, and TLD measurements. Results of the 1982 comprehensive vegetation survey are compared in Du Pont (1983b) with those from 1977 and previous years. The average cesium-137 concentrations in vegetation from the Savannah River swamp are generally less than those in vegetation from Steel Creek (Ashley and Zeigler, 1981; Du Pont, 1983b). In 1983, the maximum con-
EV-23 centration in the swamp was 58 ± 16 picocuries per gram (dry weight), or about one-third the mean value listed in Table D-10 for the Steel Creek corridor.

Table D-12. Cesium-137 concentrations in selected plants and insects (picocurie per milligram dry wt)[a]

	1971 Floodplain			1971 Islands			1981		
	N	$\bar{X}$	(SE)	N	$\bar{X}$	(SE)	N	$\bar{X}$	(SE)
Plant genera									
<u>Alnus</u>	10	0.37	(0.06)	8	1.00	(0.28)	13	0.12	(0.01)
EV-22 <u>Myrica</u>	10	0.54	(0.28)	8	1.50	(0.78)	15	0.07	(0.008)
<u>Salix</u>	10	0.51	(0.28)	10	1.60	(0.59)	17	0.26	(0.04)
Arthropod orders									
Araneae	25	0.26	(0.07)	25	0.97	(0.17)	16	0.06	(0.002)
Coleoptera	25	0.44	(0.29)	24	0.99	(0.19)	13	0.02	(0.005)
Orthoptera	25	0.40	(0.08)	25	1.50	(0.28)	18	0.09	(0.01)

[a]Source: Brisbin et al., 1982.
Abbreviations: N = sample size
$\bar{X}$ = mean value
SE = standard error

Cesium-137 concentrations in the muscle tissue (edible parts) of deer and hogs killed by hunters at SRP are reported annually; concentrations in 1982
EV-25 averaged 13.8 pCi/g for deer and 5.8 pCi/g for hogs (Du Pont, 1983b). In a recent study, Watts et al. (1983) found that the cesium-137 distributions for

deer (from 1975 to 1979) at SRP and the South Carolina Coastal Plain are quantitatively described by a log normal distribution. For these five years, deer on the Coastal Plain exhibited concentrations that were higher statistically than those at SRP, at the 0.005 significance level for three years and at the 0.05 significance level for two years. EV-25

Domby et al. (1977) found that heron nestlings near Par Pond had body burdens ranging from less than 5 pCi/g wet weight to 27.4 pCi/g wet weight, depending on the species. Waterfowl have been shown to be effective vectors of radionuclide transport from systems and to display dramatic changes in body burden due to subtle migratory patterns (Brisbin et al., 1973; Hanson and Case, 1963). Differences in radiocesium body burdens of birds at the SRP is discussed by Staney et al. (1975) and shown to be related to season, diet, and location (see also Willard, 1960).

The Steel Creek delta and the Savannah River swamp provides roosting and feeding habitat for migratory ducks. Several areas in Steel Creek near Road A and Road B are wide and shallow, have slow-moving water, and are relatively unobstructed by trees. Wood ducks are known to nest in these areas, and the cesium concentration in flesh from these ducks reflects their cesium-contaminated environment, with average cesium-137 concentrations of 25 to 67 pCi/g in Steel Creek and somewhat lower in the swamp (Marter, 1974). Transient ducks from the Steel Creek Swamp have cesium-137 concentrations of 8 pCi/g, comparable to the concentrations in transient ducks obtained from Par Pond (Marter, 1974).

Concentration of cesium-137 in wildlife from Creek Plantation Swamp is reported to be less than 3.8 pCi/g wet weight (Du Pont, 1982a). Concentration of cesium-137 in muscle tissue and liver samples from furbearing animals captured near Steel Creek averaged 6 pCi/g and 5 pCi/g, respectively, comparable to concentrations found in similar animals captured near Upper Three Runs Creek (Marter, 1974).

Table D-13 lists the average values of cesium-137 in fish taken from Steel Creek and the Savannah River below the creek. In general, the concentrations of cesium-137 decrease with increasing distance from the contaminated creekbed sediments.

Concentrations in Savannah River fish are lower than those measured in fish from Steel Creek (Du Pont, 1982a). Whole-body bioaccumulation factors (cesium-137 concentrations in fish/cesium-137 concentrations in water) for fish taken from the river at the U.S. Highway 301 bridge from 1965 to 1970 average about 2300 (Table D-14). The mean bioaccumulation factor for 20 species of fish (527 specimens) from Steel Creek was found to be 2019 (whole-body) and 3029 (flesh) (Smith et al., 1982; Ribble and Smith, 1983). In contrast, largemouth bass from Par Pond exhibit bioaccumulation factors (flesh) that average about 1200 (Harvey, 1964). Whole-body bioaccumulation factors determined for fish from Lower Three Runs Creek are reported in Table D-15. A fish flesh bioaccumulation factor of 3000, 1.5 times the value recommended in the NRC LADTAP-II computer code (Simpson and McGill, 1980), was chosen for dose assessment analyses in this document.

Table D-13. Measured annual mean radiocesium concentration in fish from Steel Creek, swamp, and the Savannah River[a]

Year	Species	N[b]	Mean radiocesium content, pCi/g wet weight: Steel Creek, Road A	Steel Creek, Mouth	Steel Creek, Swamp	Savannah River, Steel Creek to Hwy 301 bridge[c]
1962	--[d]	--[d]	--[d]	--[d]	10	2[e]
1963	--	--	--	--	10	2[e]
1964	--	--	--	--	13	1[e]
1965	--	--	--	--	66	5-8[f]
1966	--	--	--	--	27	8-3[f]
1967	--	--	--	--	40	17-3.5[f]
1968	--	--	1250	--	43	7-2.5[f]
1969	--	--	1500	--	64	4-4[f]
1970	--	--	590	--	44	2-1.5[f]
1977	Bream	1	3.9	--	--	--
1977	Bream	5	--	0.4	--	--
1977	Catfish	1	2.8	--	--	--
1978	Bream	8	20	--	--	--
1978	Bream	4		2	--	--
1978	Bass	4		1	--	--
1981	Largemouth bass	53	20.1	--	--	--
1981	Blackband darter	36	15.0	--	--	--
1981	American eel	44	10.0	--	--	--
1981	Shiners	57	9.5	--	--	--
1981	Pirate perch	48	8.2	--	--	--
1981	Creek chubsucker	41	8.5	--	--	--
1981	Spotted sunfish	49	8.0	--	--	--
1981	Redbreasted sunfish	45	7.5	--	--	--
1981	Savannah darter	31	3.4	--	--	--
1981	Mean fish (20 species)	527	10.7	--	--	--
1981	Bream	31	--	--	--	0.09
1981	Bass	3	--	--	--	0.12
1981	Catfish	13	--	--	--	0.10
1981	Carp	2	--	--	--	1.45
1981	Eel	1	--	--	--	0.06
1981	Other species	18	--	--	--	0.05

7-25 [a]Adapted from Marter, 1970a; Du Pont, 1982a,b; Ribble and Smith, 1983.

[b]N is the number of specimens analyzed.

[c]At U.S. Highway 301 bridge (near Millhaven, Georgia) unless otherwise noted.

[d]Data not available or not provided.

[e]Below mouth of Steel Creek.

[f]Value for below mouth of Steel Creek is listed first followed by the value for Hwy 301 bridge.

Table D-14. Radiocesium whole body bioaccumulation factors for fish from Steel Creek and the Savannah River[a]

Year	Steel Creek Road A Maximum	Steel Creek Road A Average	Savannah River Below Steel Creek Average	Savannah River Hwy 301 bridge Average
1965			1626	3902
1966			1975	1111
1967			5528	1707
1968	2385	1355	4058	2174
1969	5490	2353	4848	7273
1970	3958	1639	1111	1250
1981	3792[b]	2019[c]	--	--
Arithmetic mean	--	1842	3191	2903
Geometric mean	--	1802	2700	2295

EV-28

Weighted average of arithmetic means[d] = 2565

Weighted average of geometric means[d] = 2188

TC

[a]Adapted from Marter, 1970a,b; Du Pont, 1982a; Smith et al., 1982.

[b]Mean of 53 specimens of largemouth bass; this species had the maximum whole-body bioaccumulation factors measured in 1981. The maximum bioaccumulation factor measured for largemouth bass was 4780. One specimen of American eel had a bioaccumulation factor of 8300.

[c]Mean of 527 specimens representing 20 species.

[d]Steel Creek data are weighted by a factor of 2 because the fish lived in an environment more highly contaminated by cesium-137 than the Savannah River.

TC

Table D-15. Radiocesium whole-body bioaccumulation factors for fish from Lower Three Runs Creek[a]

Species	Mean bioaccumulation factor (1971-1974)	Number of individuals
Dollar sunfish	691	5
Pike/pickerel	908	6
Redbreast sunfish	1334	3
Bass	2803	4

[a]Adapted from Shure and Gottschalk, 1976.

D.2.3 Water

D.2.3.1 Steel Creek

During 1982, the concentration of cesium-137 in Steel Creek at the Cypress Bridge monitoring station averaged about 3 pCi/l. This concentration is about the same as during the previous 5 years.

In November and December 1981, seven water samples from Steel Creek between Road A and the delta were analyzed for their cesium-137 content (Ribble and Smith, 1983). The concentrations ranged from 3.9 to 7.9 pCi/l and had a mean
V-30 value of 5.3 ± 1.81 picocuries per liter (with a mean potassium concentration of 0.99 mg/l). About 84 percent of this value was associated with the dissolved fraction and 16 percent with the suspended solid fraction. Shure and Gottschalk (1976) similarly found that about 20 percent or less of the cesium-137 in water samples from Lower Three Runs Creek was associated with the suspended solid fraction.

It is estimated that November and December 1981 concentrations of cobalt-60 averaged about 0.3 picocurie per liter. This estimate is based on cesium-137 and cobalt-60 measurements made during testing of the L-Reactor secondary cooling-water system conducted in the spring of 1982 (Hayes and Watts, 1983).

More recently, Hayes (1983e) reported the results of cesium-137 measurements in Steel Creek made from April through August 1983. During this period, the average transport of cesium-137 was 3.2 ± 1.5 microcuries per week at Cypress Bridge, just upstream from the delta (Figure D-3). On this basis, the annual transport would be about 0.17 ± 0.08 curie per year. These measurements indicate that about half the cesium-137 transported was due to remobilization from the creek floodplain system above L-Reactor.

In addition, Hayes (1983e) reported that the water that enters Steel Creek from L-Area and Meyers Branch (the principal tributary of Steel Creek) and as local rainfall contained concentrations of cesium-137 of less than 1 picocurie
IV-47 per liter. However, the measured cesium-137 concentrations at Cypress Bridge averaged about 3.7 ± 0.6 picocuries per liter during the April through August 1983 study period. Hayes contends that a reequilibration process between the water and the cesium in the creekbed and floodplain sediments governs the cesium-137 concentrations, because he could find no correlation during this period between cesium concentration and creek flow rate, or such other variables as suspended solid or tritium concentrations in Steel Creek water or rainfall in the area. Hayes concluded that the creekbed and floodplain sediments could support cesium concentrations as high as about 11 picocuries per liter at equilibrium, and that the lower concentrations (3.7 picocuries per liter) were probably due to insufficient time for the process to reach equilibrium between the water and the cesium-laden sediments. The travel time for water from L-Area to Cypress Bridge is less than 1 day.

D.2.3.2 Savannah River

The concentrations of cesium-137 in the Savannah River have been monitored since 1960. The highest concentrations were measured in the early 1960s as a result of SRP releases and nuclear weapons test fallout (Figure D-8). Since 1972, concentrations of cesium-137 in the Savannah River have been below the routine detection limit of about 1 picocurie per liter. Recently, special measurements made with high water volume sampling techniques and low level counters show that the 1979-1982 average concentration in the Savannah River was about 0.08 picocurie per liter below SRP and near the limit of detection above SRP (Section 3.7.2). It is estimated that the cobalt-60 concentration in river water during the 1979 to 1982 period averaged about 0.002 picocurie per liter (based on measurements in Steel Creek performed by Hayes and Watts, 1983). |TC

Radiocesium and radiocobalt concentrations will be diluted as the flow of the Savannah River increases downstream from SRP, and as these radionuclides are deposited in the river channel and floodplain. Based on river flow records for 1960 to 1969, an increase in flow of 11 percent can be expected between the U.S. Highway 301 bridge (River Mile 118.7) near Millhaven, Georgia, and the Georgia Highway 119 bridge (River Mile 61.5) near Clyo, Georgia. Ratios of drainage areas suggest that river flow will increase by 18 percent between River Mile 118.7 and River Mile 39.2, the location of the intake structure for the Cherokee Hill water treatment plant. Using tritium as a tracer, Hayes (1983a) measured an average 1976-1981 increase in flow of about 20 percent between these two locations. An additional 28 percent reduction in the concentrations of cesium-137 and cobalt-60 can be expected to occur through deposition, sorption and reequilibration of the radionuclides with river channel and floodplain sediments (Hayes and Boni, 1983).

D.2.3.3 Water treatment plants

The North Augusta, South Carolina water treatment plant is about 20 river miles above the SRP. However, there are no known individuals who consume Savannah River water for a distance of about 120 river miles downstream of the SRP. At this distance (River Mile 39.2) and beyond (River Mile 29.0) are the Beaufort-Jasper and Cherokee Hill water treatment plants, respectively. The Beaufort-Jasper water treatment plant pumps water from the river through a 2.4 kilometer long inlet canal that connects to an open canal. This open unlined canal flows 29 kilometers to the water treatment plant (Du Pont, 1983a). The Cherokee Hill water treatment plant pumps from the Savannah River above the U.S. Interstate Highway 95 bridge, and the water is piped about 11 kilometers to the plant (Du Pont, 1983a).

Recent measurement (April through June, 1983) of finished (potable) water indicates that cesium-137 concentrations (from SRP, weapons test fallout, and upstream nuclear reactors) averaged 0.028 picocurie per liter at Beaufort-Jasper and 0.033 picocurie per liter at Cherokee Hill (Kantelo and Milham, 1983). During this monitoring period, the cesium-137 concentrations in the finished water were found to vary inversely with river flow (Kantelo and Milham, 1983). The concentrations of cesium-137 at Beaufort-Jasper are slightly less than those at Cherokee Hill (Hayes and Boni, 1983). The slightly lower concentrations at Beaufort-Jasper result from inflow of local fresh water and deposition, sorption, and reequilibration of cesium-137 with the sediments of the open canal leading to the treatment plant (Hayes and Boni, 1983).

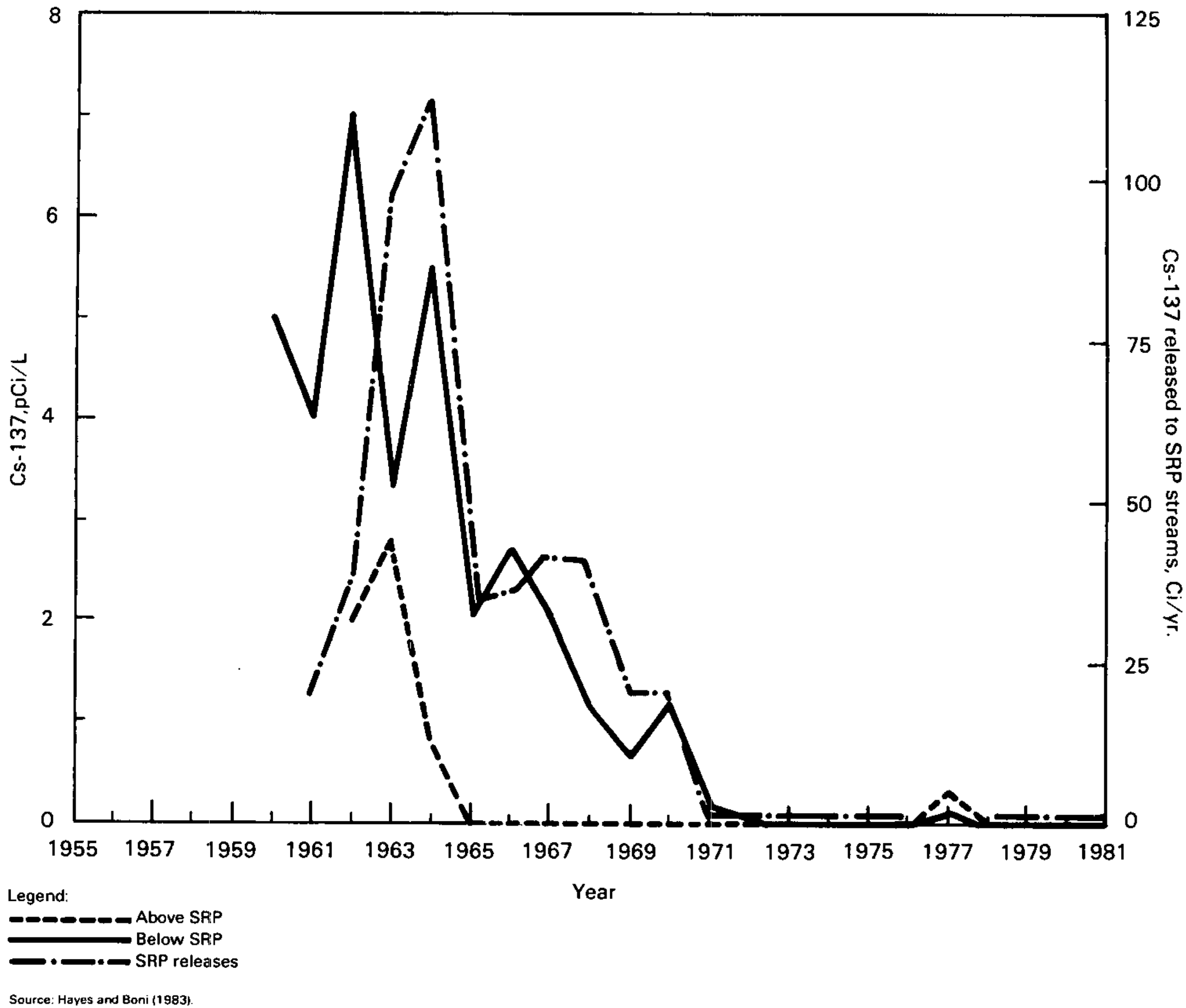

Figure D-8. Cesium-137 concentrations in the Savannah River, 1960-1980.

At North Augusta the concentration of cesium-137 in the finished water averaged 0.006 picocurie per liter, about 5 times less than comparable concentrations in Beaufort-Jasper and Cherokee Hill finished water. Upstream nuclear reactors and nuclear weapons test fallout account for the cesium-137 in the North Augusta finished water (Kantelo and Milham, 1983).

Studies of cobalt-60 in the finished water in these water treatment plants indicate that the concentrations are less than the detection limit of about 0.003 picocurie per liter (Kantelo and Milham, 1983).

Studies made in 1965, when the cesium-137 concentration in river water at the U.S. Highway 301 bridge was 1.47 picocuries per liter, suggest that a concentration reduction of about 48 percent by dilution and by association with river channel and floodplain sediments occurs by the time the water reaches the downstream water supply intakes. The Cherokee Hill water treatment plant removes another 32 percent. Dilution and association with sediments along the open canal and the treatment process at Beaufort-Jasper removes about 50 percent of the cesium-137 from the raw water. Thus, as summarized in Table D-16, the concentration of cesium-137 in the finished water from the water treatment plants is a small fraction of the concentration at the U.S. Highway 301 bridge (Hayes and Boni, 1983).

Table D-16. Cesium-137 concentrations and reduction ratio in the Savannah River and water treatment plants[a]

Location	Cs-137 (pCi/ℓ)	Reduction (percent)
North Augusta[b]	0.03	
Highway 301[c]	1.47	
Highway 17[c]	0.77	47.6
Cherokee Hill[b]	0.29	80.3
Beaufort-Jasper[b]	0.04	97.3[b]

[a]Measurements made in 1965; adapted from Hayes and Boni (1983).

[b]Concentration in finished (potable) water.

[c]"Raw" Savannah River water. Approximate river flow rates of 200 cubic meters per second at Highway 301, and 225 cubic meters per second at Highway 17 at time of cesium-137 sampling.

[d]By the year 2000, the expected reduction factor for Beaufort-Jasper will be 79.3 percent because of planned changes in the intake canal.

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D.3 RADIOCESIUM AND RADIOCOBALT INVENTORY IN STEEL CREEK AND SAVANNAH RIVER SWAMP

A number of different methods were used to calculate the inventory of cesium-137 and cobalt-60 in the Steel Creek system. These inventory estimates are discussed below.

D.3.1 Aerial radiological surveys

Aerial radiological surveys of the Savannah River Plant and the surrounding areas were performed in 1974 and 1979 to determine the surface terrestrial distribution of cesium-137 (Boyns, 1975; Boyns and Smith, 1981). A comparison of the position of the cesium-137 gamma exposure-rate isopleths from these surveys shows that the areas of activity are in the same general locations. Gamma exposure rates in 1979 were lower than those in 1974, which can be explained by the masking effect of higher creek and swamp water levels in 1979 and to a lesser extent by radioactive decay. When adjusted to a common water level, these surveys suggest little or no radiocesium transport (radiocesium associated with the streambed sediments) occurred during the 5-year interval.

Smith et al. (1982) used the 1974 aerial radiological survey data to estimate the mean cesium-137 gamma exposure rates in Steel Creek (Figure D-3). The aerially determined exposure rates were corrected to surface-level rates and to account for the cesium-137 distribution in the soil column. Based on the corrected data, the estimated cesium-137 inventory in Steel Creek (decay corrected to 1981) is 58.1 curies, which may be proportioned approximately as follows (Smith et al., 1981):

Location	Inventory (Ci)
Above Road A	18.4
Below Road A	39.7
Total	58.1

D.3.2 Ground radiological surveys

Smith et al. (1982) performed a ground radiological survey in Steel Creek (Figure D-3) using sodium iodide scintillation counters and stratified random sampling procedures. The cesium-137 gamma exposure rate data were corrected to account for the cesium-137 distribution in the soil column. Based on the corrected data, the estimated cesium-137 inventory (decay corrected to 1981) is

56.9 curies for the Steel Creek floodplain to a depth of 1.0 meter. The approximate portions of this inventory lying above and below Road A are listed below (extrapolated from Smith et al., 1981):

Location	Inventory (Ci)
Above Road A	18.0
Below Road A	38.9
Total	56.9

D.3.3 Soil surveys

Studies of cesium-137 in Steel Creek based on core samples up to 1 meter in length and categorized by soil type, sample depth interval, and creek section (Table D-3, Figure D-3), identified 67.1 curies decay corrected to 1981 between the area above L-Reactor and the delta (Smith et al., 1982). The approximate portions of this inventory lying above and below Road A are listed below:

Location	Inventory (Ci)
Above L-Reactor	9.2
L-Reactor to Road A	24.4
Total Above Road A	33.6

Location	Inventory (Ci)
Road A to Delta	10.4
Delta Area	23.1
Total Below Road A	33.5
Total Steel Creek	67.1

An estimated 8.9 curies is believed to lie onsite in the Savannah River swamp between the Steel Creek delta and the SRP boundary.

Results of soil samples collected in the swamp southeast of Steel Creek in 1974 (Figure D-6) estimated that the radiocesium inventory in the swamp was 25 curies (Marter, 1974); this could have decayed to 21 curies by 1981, assuming no net transport of cesium from the swamp.

D.3.4 Radiocesium inventory by a contaminated area method

Du Pont (1982a) also estimated the cesium-137 inventory in Steel Creek with a contaminated area method, which uses radiological measurements of concentrations in sediments and vegetation, which are integrated over the area and depth. The results of this method yield an inventory estimate of about 75 curies which would have decayed to about 61 curies by 1981. This estimate, detailed below, agrees with the estimates presented in Sections D.3.1, D.3.2, and D.3.3:

Location	Inventory (Ci)
Road A to SCL Bridge	18.0
SCL Bridge to delta	16.2
Delta	26.6
Total	60.8

D.3.5 Radiocesium inventory in vegetation

The cesium-137 inventory in the Steel Creek biotic community is very small. The inventory was made using floodplain areas integrated from USGS floodplain maps, estimates of the biomass inventory (304 grams per square meter; Martin et al., 1977), and analyses of cesium-137 concentrations in vegetation from various stream reaches. Approximately 0.4 curie of the cesium-137 is in the plant community (Du Pont, 1982a). The inventory in the animal community is insignificant (much lower biomass) compared to the plant community.

D.3.6 Radiocesium inventory in water

The amount of cesium-137 in the water of the Steel Creek system at any one time is small, less than 0.001 curie. This estimate is based on the assumption that the water stored in the system is equal to about 1 day's flow. The travel time of water from P-Area to the Cypress Bridge (Figure D-3) is about 0.5 day (Hayes, 1981) and the cesium-137 concentration averages about 4 pCi/l (Ashley and Zeigler, 1978b) (also see Section D.2.3.1).

D.3.7 Summary for cesium-137

Smith et al. (1982) estimated the cesium-137 inventory in Steel creek using gamma exposure rates obtained from aerial and ground surveys and cesium-137 concentrations obtained from soil core measurements. These results are in agreement with the inventory developed by the contaminated area method (Du Pont, 1982a). The inventory of about 67 curies determined from soil core measurements is considered the best estimate. As shown in Figure D-9, this cesium-137 inventory estimate for Steel Creek leaves about 55 curies unexplained.

This unaccounted for cesium-137 is within the error limits of the estimated inventory. The unexplained cesium-137 might be caused by:

Less radiocesium released than indicated in Table D-1.

A cesium-134-to-cesium-137 ratio greater than 1:20.

Cesium-137 deposited in the Savannah River between the mouth of Steel Creek and the U.S. Highway 301 bridge.

More cesium-137 from Steel Creek transported past the U.S. Highway 301 bridge than indicated by the measurements.

More cesium-137 below depths of 1 meter than indicated by Figure D-4.

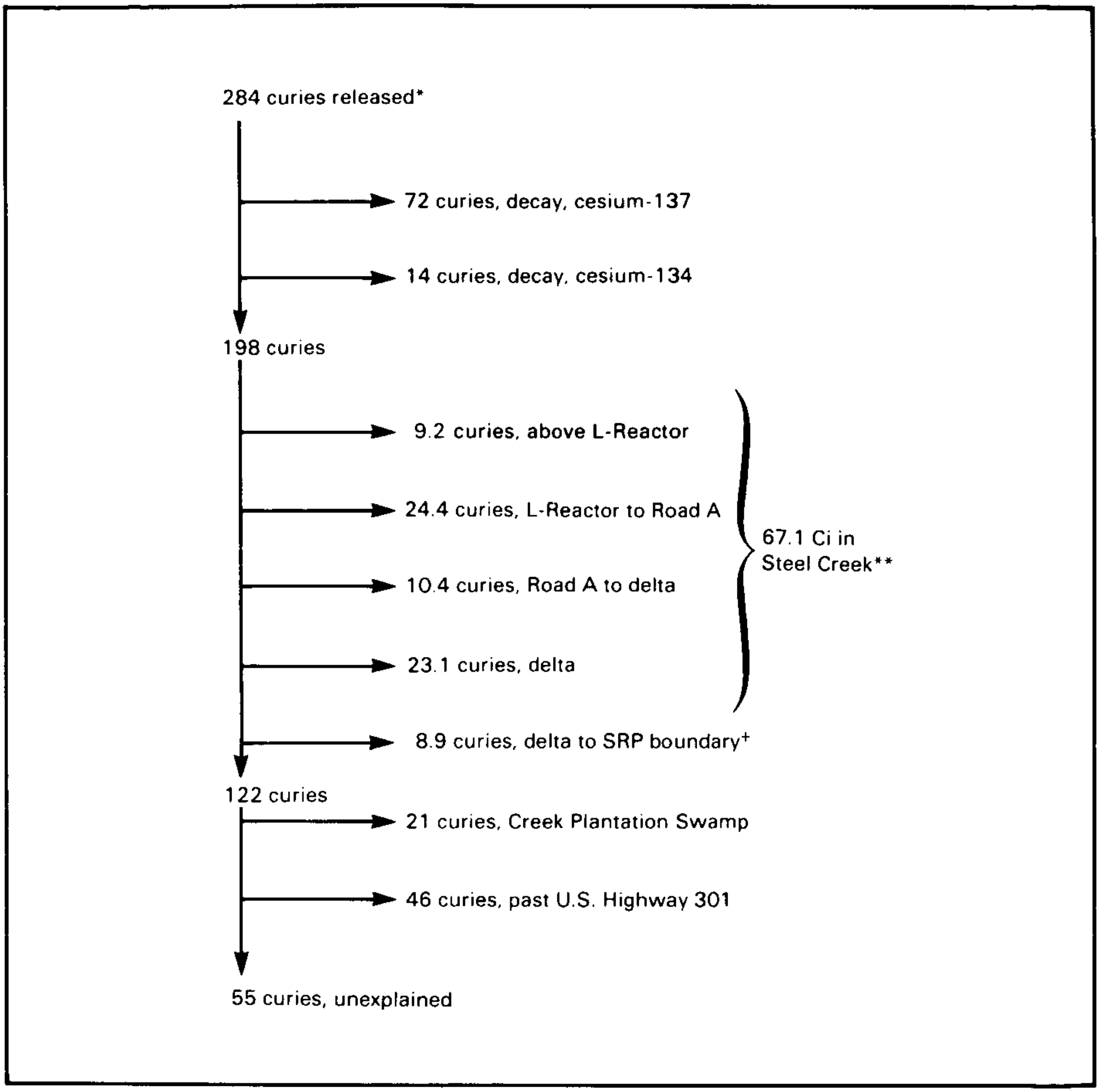
D.3.8 Radiocobalt inventory

The current radiocobalt inventory in Steel Creek has been bounded by two values, 2.1 and 4.6 curies, and calculated according to the following methods, respectively, (1) assuming no transport of cobalt from the creek system and decay correcting to 1981, and by (2) conservatively assuming that cobalt behaves in a manner similar to cesium such that the inventory is reduced by a factor of .068, the ratio of cobalt-60 to cesium-137 in the sediments of the Steel Creek system.

D.4 REMOBILIZATION OF RADIOCESIUM AND RADIOCOBALT

A portion of the cesium-137 and cobalt-60 inventory that is currently in the Steel Creek channel and floodplain (Figure D-9) will be remobilized and transported off the plant site when the direct discharge of thermal effluents to Steel Creek is resumed after the restart of L-Reactor at temperatures as high as 75°C near the outfall canal and at discharge rates of about 11 cubic meters per second (reference case). This remobilization of cesium-137 and cobalt-60 will augment the small amount that is currently being transported from the creek.

Using the reference case, the quantities of cesium-137 (and cobalt-60) transported from Steel Creek to the Savannah River and to offsite portions of the swamp (Creek Plantation Swamp) as the result of L-Reactor operations are reestimated below, using 1976 monitoring data, a new set of data for 1982 on radionuclide transport in Steel Creek, and the historic flooding record for the swamp (Du Pont, 1982a, 1983a; Langley and Marter, 1973). Section 4.4.2 contains estimates of cesium-137 remobilization and transport for each alternative cooling-water system (also see Section D.4.4). TC



*Released to Steel Creek during 1955-1980.

**Based on soil core measurements.

+Estimated

Figure D-9. Cesium-137 mass balance in Steel Creek in 1981 based on soil core and river measurements and decay.

The following field measurements in Steel Creek provided data that were used in the transport analyses:

- In June 1976, a study was performed to observe the effect of a month-long diversion from P-Reactor Area (to permit inspection of Par Pond dam) of about 2.5 cubic meters per second of hot water (about 70°C at the discharge point) on desorption of cesium-137 from the sediments. The cesium-137 transport near Road A peaked at about 3.2 mCi/day within 2 weeks and returned exponentially to normal levels in about 3 months (Du Pont, 1982a). These data were supplemented by laboratory hot water desorption experiments (Du Pont, 1982a).

- In the spring of 1982, a study was performed to observe the transport of cesium-137 and cobalt-60 during testing of the L-Reactor secondary cooling-water system using Savannah River water that was discharged at near-ambient temperatures and at flow rates up to about 6 cubic meters per second. Measurement of creek flow and concentration of cesium-137 in water samples during these tests were used to reestimate the sediment-water transport values presented in Du Pont (1982a). Similar measurements were used to predict the sediment-water transport of cobalt-60 that is likely to occur when L-Reactor cooling-water discharges are resumed (Hayes, 1983b; Hayes and Watts, 1983).

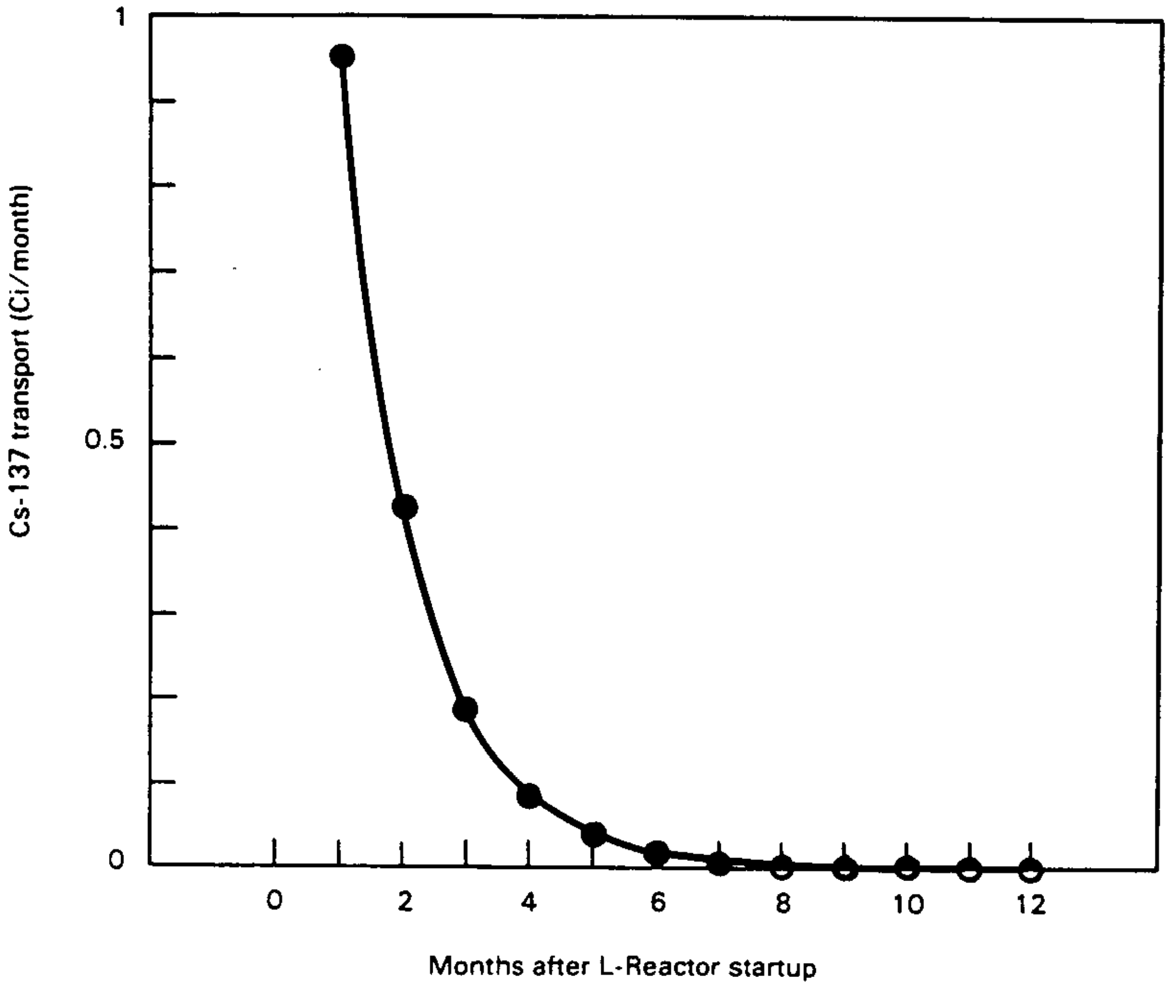
D.4.1 Desorptive transport

For the reference case, hot-water desorption of cesium-137 and cobalt-60 from the sediments in the Steel Creek system will occur following the resumption of L-Reactor operation. From early June 1976 until the end of that month, about 2.5 cubic meters per second of heated water, discharged at approximately 70°C, was diverted to Steel Creek from P-Reactor. The cesium-137 concentration at Cypress Bridge (Figure D-3) peaked within 2 weeks after the start of the diversion and decreased exponentially to a background level in about 3 months (Du Pont, 1982a). To estimate the heated water cesium-137 transport, the Cypress Bridge data (Figure D-10) were fitted with an exponential function and integrated to give monthly transport values.

A correlation coefficient of 0.94 was calculated using an exponential representation of the data. A laboratory experiment (Du Pont, 1982a) with sediments from Steel Creek confirmed that higher water temperatures extract more cesium-137 than water at ambient temperatures.

These analyses indicate that the transport in the first year for the reference case would be about 1.7 curies due to cesium-137 being desorbed from the sediments.

Hot water desorption experiments conducted in the laboratory to determine the desorption of cesium-137 from sediments also showed the desorption of small amounts of cobalt-60 (Table D-17) (Du Pont, 1982a; Hayes and Watts, 1983). The cobalt-60 to cesium-137 ratio of desorbed activity averaged 0.056. An estimate of the amount of cobalt-60 that will be desorbed during the first year of L-Reactor operation for the reference case was made by multiplying the 1.7



Source: Du Pont (1982a).

Figure D-10. Transport of cesium-137 from hot-water desorption of cesium-137 from Steel Creek sediments.

curies of cesium-137 that is expected to be desorbed by the laboratory-determined cobalt-60/cesium-137 ratio, 0.056. This calculation indicates that about 95.2 mCi/yr or 0.26 mCi/day of the cobalt-60 is expected to be desorbed from the sediments in the first year. No additional desorption is expected the second year.

Table D-17. Cs-137 and Co-60 desorption from sediments during a laboratory experiment[a]

Water Temperature (°C)	Activity Desorbed (pCi/ℓ) Co-60	Cs-137	Co-60/Cs-137
72	20.4	458	0.045
52	25.4	288	0.088
42	14.2	384	0.037
22	16.5	314	0.053
	Average ratio = 0.056 ± 0.023		

[a]Adapted from Du Pont, 1982a, Appendix I.

D.4.2 Transport in biota

SRP routinely monitors vegetation in the Steel Creek corridor for radionuclides. Even though cesium-137 is routinely detected in the vegetation, cobalt-60 is not. The limit of detection for cobalt-60 is about 5 pCi/g.

About 0.4 ± 0.2 curie of cesium-137 is tied up in the biota on the Steel Creek floodplain. The reference-case discharge, principally the result of high flow rates and fluctuating water levels (related to reactor operation about 65 percent of the year), would be expected to kill this biota in the first year of L-Reactor operation and to transport the isotope off the site. TC

D.4.3 Sediment-water transport

D.4.3.1 Cesium-137

The initial (1981) estimates of the expected cesium-137 transport in Steel Creek following L-Reactor restart using the direct discharge of cooling water to Steel Creek (reference case) are presented in Du Pont (1982a). The cesium-137 transport process was divided into three elements: coupled suspended sediment-water (7.7 ± 4.4 curies first year, 7.2 curies second year), hot water desorption (1.7 ± 0.2 curies; Section D.4.1, above), and biota loss (0.4 ± 0.2 curies; Section D.4.2, above). In this manner, total cesium-137 transport was estimated at 9.8 curies for the first year and 7.2 curies for the second year, with a 20-percent-per-year decrease thereafter. To improve these estimates of cesium-137 remobilization in the Steel Creek system, cesium-137 transport studies were made during secondary cooling-water system tests using ambient river water from February to April 1982. These tests included flows as high as about 6 cubic meters per second, about one-half of full reactor cooling-water flow (Hayes, 1983b; Du Pont, 1983a).

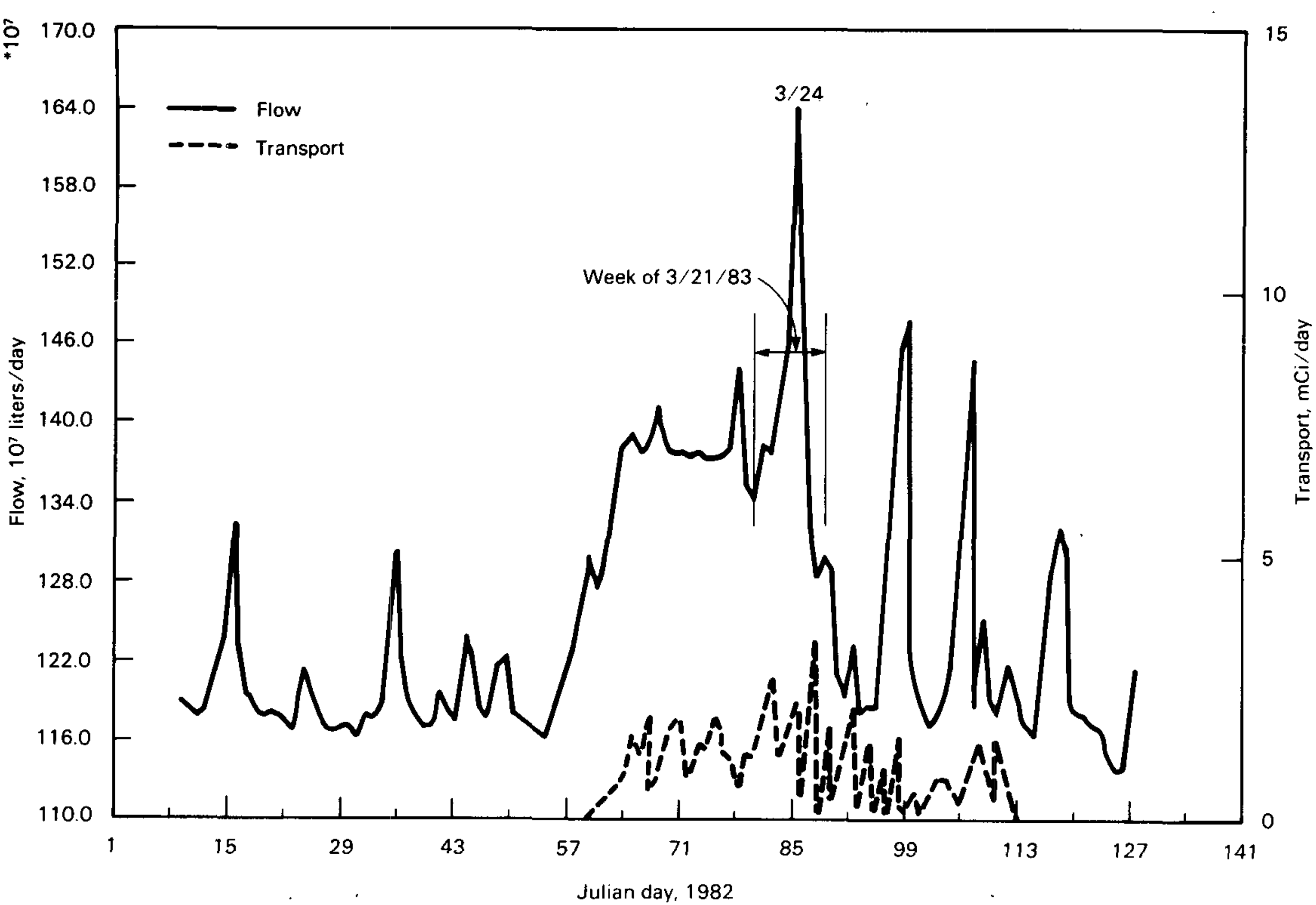
Average flow rates required to estimate total cesium-137 transport (flow rate times concentration) were obtained by calculating noon-to-noon average flow using data sampled every 15 minutes from the U.S. Geologic Survey-maintained gaging station at the Cypress Bridge upstream of the creek mouth (Figure D-3). Composite water samples were also obtained on a noon-to-noon schedule; however, they were collected at the mouth of Steel Creek. Because Pen Branch combines with Steel Creek in the swamp before discharging to the Savannah River, the creek flow values measured at Cypress Bridge were increased by 12.7 cubic meters per second to obtain the correct flow at the mouth of Steel Creek. Flow rates in Steel Creek varied during the test period, depending on the specific test of the secondary cooling water system being conducted (see Figure D-11).

As shown in Figure D-11 and Table D-18, the test period most similar to the reference case conditions expected during resumed L-Reactor operation occurred during the week of March 21, 1982 (Julian day 80). During this week (on March 24, 1982), the average daily flow reached 6.2 cubic meters per second and averaged 3.5 cubic meters per second for the week. This average weekly flow exceeded any previous weekly discharge of cooling water flow since L-Reactor was shut down in 1968, although flows of this magnitude have occurred as the result of heavy rainstorms (see Section 3.4.1).

Increases in total cesium-137 concentrations (with suspended solids and in solution) at the mouth of Steel Creek lagged the increase in pump test flow (Table D-18). The highest cesium-137 concentration, 2.7 pCi/l, occurred on March 28, 1982, about 3 days after the flow decreased to about 2.1 cubic meters per second from the peak flow of 6.2 cubic meters per second. This concentration is probably the result of water draining off the back areas of the floodplain and into the creek. Water in the back areas would have longer residence times and the sediments have higher concentrations of cesium-137 (Figure D-5); thus, the water draining from these areas could accumulate higher cesium-137 concentrations.

The average daily cesium-137 transport during the period of highest flow, March 21-28, 1982, was 1.96 $\pm$ 1.53 mCi and at an average flow of 3.5 cubic meters per second (flow measured at Cypress Bridge). Hayes (1983b) used this data to reestimate the transport of cesium-137 from the mouth of Steel Creek. His new estimate for the sediment-water transport during the first and second years of resumed reactor operation is 2.3 $\pm$ 1.8 curies per year (1.96×10^{-3} curies per day x [11 cms/3.5 cms] x 365.25 days/year = 2.3 Ci/yr).

EV-47 This transport estimate is supported by more recent measurements (Hayes, 1983e). Hayes believes that the concentrations of cesium-137 in Steel Creek water are governed by a reequilibration process between the water and the cesium in the creekbed and floodplain sediments (see Section D.2.3.1). During the April through August 1983 study period, the cesium-137 concentration at Cypress Bridge averaged 3.7 picocuries per liter on a weekly basis. From this value and a cooling-water discharge from the heat exchangers of about 11 cubic meters per second, the estimated sediment-water transport during the first and second years



Note: See Table D-16 for data listing.

Source: Hayes (1983b).

Figure D-11. Daily average discharge and cesium-137 transport at Steel Creek mouth from January 8 to May 6, 1982.

Table D-18. Daily Cs-137 concentrations, transport and creek flow at mouth of Steel Creek[a]

Calendar date	Julian date	Cs-137 (pCi/ℓ)	Cs-137 (mCi/day)	Flow (m^3/day)
03/01/82	60	0.1	0.129	1,293,600
03/05/82	64	0.6	0.826	1,376,900
03/06/82	65	1.2	1.661	1,384,250
03/07/82	66	0.9	1.270	1,411,200
03/08/82	67	1.4	1.935	1,381,800
03/09/82	68	0.6	0.826	1,376,900
03/10/82	69	1.1	1.517	1,379,350
03/11/82	70	1.4	1.924	1,374,450
03/12/82	71	1.4	1.931	1,379,350
03/13/82	72	0.6	0.825	1,374,450
03/14/82	73	1.1	1.512	1,374,450
03/15/82	74	1.0	1.377	1,376,900
03/16/82	75	1.4	1.931	1,379,350
03/17/82	76	1.2	1.729	1,440,600
03/18/82	77	0.9	1.217	1,352,400
03/19/82	78	0.5	0.671	1,342,600
03/20/82	79	1.0	1.384	1,384,250
03/21/82	80	0.9	1.249	1,376,900
03/22/82	81	1.5	2.124	1,416,100
03/23/82	82	1.9	2.774	1,460,200
03/24/82	83	0.9	1.473	1,636,600
03/25/82	84	1.0	1.428	1,428,350
03/26/82	85	1.6	2.120	1,325,450
03/27/82	86	0.8	1.027	1,283,800
03/28/28	87	2.7	3.513	1,300,950
03/29/82	88	0.3	0.387	1,291,150
03/30/82	89	1.4	1.701	1,215,200
03/31/82	90	0.4	0.477	1,193,150
04/01/82	91	1.1	1.358	1,234,800
04/02/82	92	1.8	2.130	1,183,350
04/03/82	93	0.6	0.712	1,188,250
04/04/82	94	1.1	1.304	1,185,800
04/05/82	95	0.4	0.517	1,293,600
04/06/82	96	0.8	1.162	1,452,850
04/08/82	98	1.1	1.350	1,227,450
04/09/82	99	0.1	0.120	1,195,600
04/10/82	100	0.5	0.589	1,178,450
04/11/82	101	0.1	0.117	1,173,550
04/13/82	103	0.7	0.852	1,217,650
04/14/82	104	0.6	0.808	1,347,500
04/16/82	106	0.4	0.476	1,190,700
04/18/82	108	1.2	1.438	1,198,050
04/20/82	110	1.3	1.586	1,220,100
04/22/82	112	0.2	0.236	1,178,450

[a]Adapted from Hayes, 1983b. Cesium-137 values are the sum of the suspended solid fraction and the dissolved fraction. See Figure D-11.

of resumed reactor operation (under the reference case) is 1.3 curies per year (11 cubic meters per second x 1000 liters per cubic meter x 86,400 seconds per day x 365.25 days per year x 3.7 x 10^{-12} curies per liter = 1.3 curies per year. If the upper equilibrium limit of 11 picocuries per liter (Hayes, 1983e) is used, the transport estimate becomes 3.8 curies per year, which is within the estimate of 2.3 ± 1.8 curies per year (Hayes, 1983b) described in the preceding paragraph. The travel time from the L-Reactor outfall to the Steel Creek delta, about 1 day, is apparently too short to develop the upper concentration equilibrium limit. EV-47

D.4.3.2 Cobalt-60

Radiocobalt was detected in only four of the suspended sediment samples obtained during the flow tests of the secondary cooling-water system. In contrast, cesium-137 was detected in nearly all of the 250 samples. Because of the limited number of positive samples from the flow test, the expected cobalt-60 sediment-water transport was conservatively estimated by assuming that the cobalt-60 in the sediments would be transported in a manner similar to cesium-137. The ratio of cobalt-60 to cesium-137 in the sediments of the Steel Creek system is about 0.068 (Table D-6).

On the basis of the flow test data, a weekly maximum of about 0.56 mCi/day-m^3/sec of cesium-137 was remobilized from Steel Creek. Thus, the expected cobalt-60 transport from sediment sources in Steel Creek, as determined by Hayes and Watts (1983) is 0.43 mCi/day or 0.16 curie per year (0.56 x 10^{-3} Ci/day-m^3/sec x 0.068 x 11 cms x 365.25 days/year = 0.16 Ci/yr).

D.4.4 <u>Summary of remobilization estimates</u>

For the reference case, the total amount of cesium-137 estimated to be remobilized and transported from Steel Creek during the first year of resumed L-Reactor operation is 4.4 ± 2.2 curies. This value is the sum of three transport estimates: 1.7 ± 0.2 by desorptive transport, 0.4 ± 0.2 curie transport in biota, and 2.3 ± 1.8 curies suspended sediment-water transport. In the second year it is anticipated that this value will be reduced to 2.3 ± 1.8 curies. Thereafter, a 20 percent reduction in transport per year is assumed. Thus, after 10 years of resumed operation, approximately 14.4 curies of cesium-137 will have been transported to the Savannah River swamp system (Hayes, 1983b).

The 2.1 curie decrease from the first to the second year is based on the assumption that the hot cooling water will no longer desorb cesium-137 from the creekbed and floodplain sediments and that there is no more vegetation to contribute cesium-137. It is also noted that the sediment-water transport estimate presented here is substantially less than initially estimated (Du Pont, 1982a); however, the original estimates of transport resulting from hot water desorption and from cesium-137 in the vegetation remain unchanged (see Section D.4.3.1).

The amount of cesium-137 remobilized and transported to the Savannah River on an annual basis was estimated for each alternative cooling-water systems involving flowing streams (see Section 4.4.2) by applying the following equation:

$$Cs_{out} = 2.3F + 0.4F + 1.7(T/75°C), \text{ in curies per year}$$

TC where F is the cooling-water flow normalized to the flow from the reference case, and T is the temperature (°C) of the water discharged from the cooling-water system to Steel Creek during periods of severe summer meteorological conditions. This equation accounts for the three major aspects of cesium-137 remobilization and transport--the first term accounts for sediment-water transport, the second term is for biota (principally vegetation), and the third term is for hot-water desorption. For the reference case, F = 1 and T = 75°C, and CS_{out} = 4.4 curies per year. This equation is believed to provide conservative results because, when the summer ambient conditions (0.62 cubic meter per second creek flow at L-Reactor with a water temperature of 28°C) are used as input parameters, the calculated cesium-137 transport is 0.65 curie per year, about three times the measured value.

The total amount of cobalt-60 estimated to be remobilized and transported from Steel Creek during the first year of resumed L-Reactor operation is estimated to be at most 0.25 ± 0.13 curie. This total is composed of a 0.16 curie per year fraction associated with sediment-water transport and a 0.09 curie per year fraction associated with desorptive transport. During the second year, up to 0.14 ± 0.10 curie will be transported in association with the suspended sediments (0.16 Ci/yr x 0.876 decay factor = 0.14 Ci/yr; Hayes and Watts, 1983). Approximately 0.6 curie of cobalt-60 will be transported to the Savannah River swamp system during the first 10 years of resumed L-Reactor operation.

Tables D-19 and D-20 compare the current cesium-137 and cobalt-60 transport values with the estimated values for the first, second, and tenth years after resumption of L-Reactor operation. Maximum concentrations of cesium-137 and cobalt-60 1.5 river miles below Steel Creek, the point of complete mixing of Steel Creek and river water, are predicted to be 1/425 and 1/3300 of the EPA drinking-water standard, respectively. Concentrations in finished water from the Beaufort-Jasper and Cherokee Hill water treatment plants are predicted to be very small fractions of these drinking-water standards.

D.4.5 Accumulation of cesium-137 in Creek Plantation Swamp

The flooding of the SRP and Creek Plantation swamps at river stages above 27.7 meters above mean sea level (about 440 cubic meters per second) will cause the flow from Steel Creek to be diverted from the Savannah River into the swamp paralleling the river. In the past, this diversion has caused cesium-137 to be deposited in Creek Plantation Swamp (Figure D-6) and other areas. Radiological surveys showed that the cesium-137 was in a relatively narrow band on the bankside edge of the Creek Plantation floodplain. Using sediment measurements, about 21 curies of cesium-137 are currently estimated to be present in the Creek Plantation Swamp.

Table D-19. Estimated cesium-137 remobilization from Steel Creek compared with current transport values[a]

Location	River Mile	Inventory transported (Ci/yr)				Concentration in water (pCi/ℓ)			
			After restart				After restart		
		Current values	1st year	2nd year	10th year	Current values	1st year	2nd year	10th year
Steel Creek mouth	141.6	0.25	4.4	2.3	0.4	5.3	11.15	5.80	1.01
Savannah River at 1.5 river miles below Steel Creek	140.1	0.41[b]	4.4	2.3	0.4	0.04[b]	0.47	0.25	0.04
Hwy 301 bridge	118.7	0.39[b]	4.3	2.2	0.4	0.04[b]	0.44	0.23	0.04
Hwy 17 bridge	21.4	0.20[b]	2.7	1.4	0.2	0.02[b]	0.23	0.12	0.02
WATER TREATMENT PLANTS									
Finished water									
Beaufort-Jasper	39.2	--	--	--	--	0.028	0.01	<0.01	<<0.01
Cherokee Hill	29.0	--	--	--	--	0.033	0.09	0.05	<0.01
EPA interim primary drinking water standard	--	--	--	--	--	200	200	200	200

[a]Based on mean transportation estimates made by Hayes (1983b) and Hayes and Watts (1983), and data presented in Table D-16, and average flow rates in the Savannah River at locations indicated. Estimates of concentration and transport for 1st, 2nd and 10th year only represent the contribution resulting from the remobilization of cesium-137 in Steel Creek by resumed operation of L-Reactor (reference case). No alterations of existing water treatment plant systems were assumed.

[b]1979-1982 average concentration measured at the Hwy. 301 bridge was 0.04 picocurie per liter; other values derived using appropriate flow rates and reduction factors.

Table D-20. Estimated cobalt-60 remobilization from Steel Creek compared with current transport values[a]

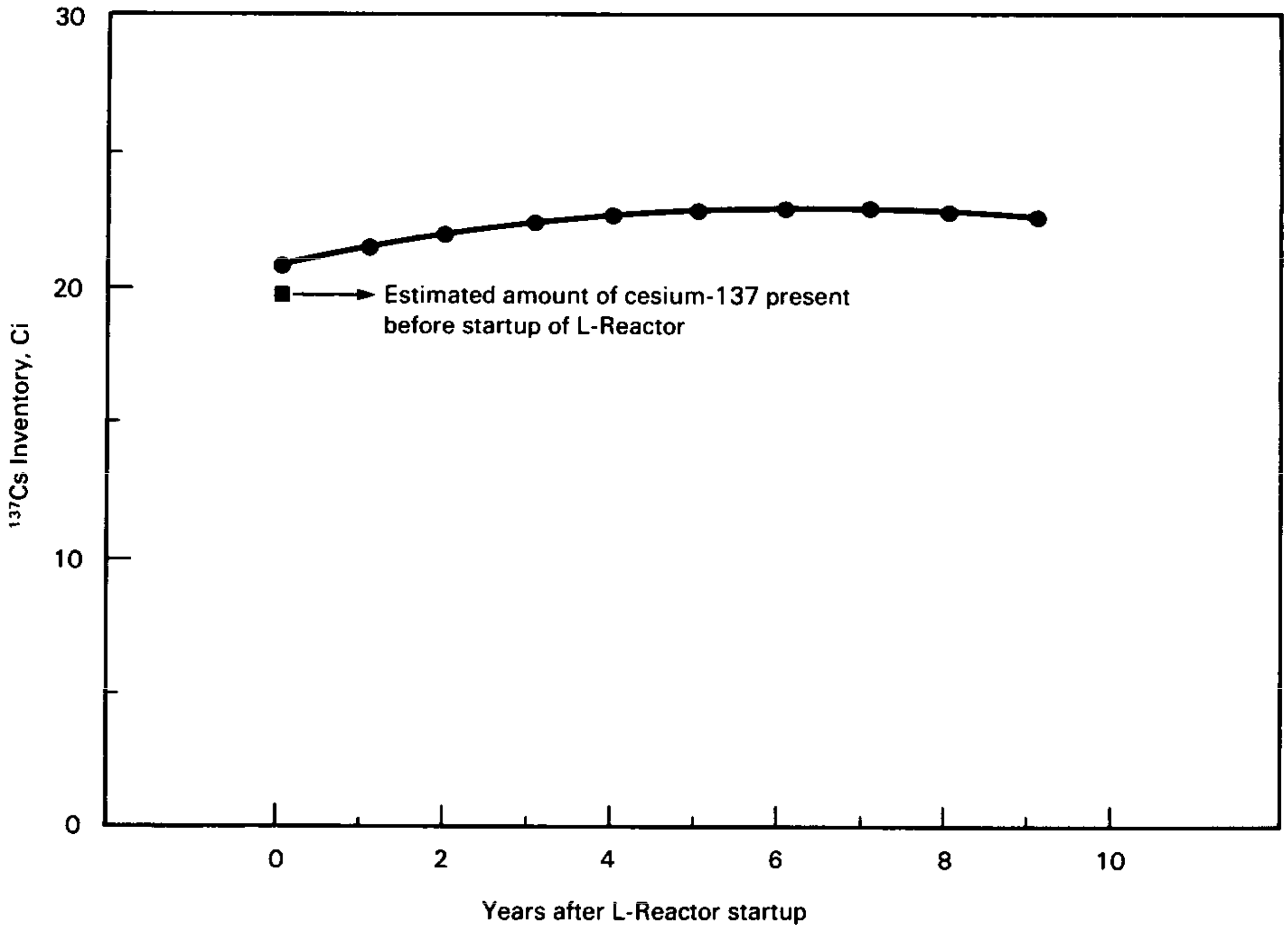
Location	River Mile	Inventory transported (Ci/yr)				Concentration in water (pCi/ℓ)			
			After restart				After restart		
		Current values	1st year	2nd year	10th year	Current values	1st year	2nd year	10th year
Steel Creek mouth	141.6	0.02[b]	0.25	0.14	<0.01	0.3[b]	0.63	0.35	0.02
Savannah River at 1.5 river miles below Steel Creek	140.1	0.02[b]	0.25	0.14	<0.01	<<0.01[b]	0.03	0.02	<<0.01
Hwy 301 bridge	118.7	0.02[b]	0.24	0.14	<0.01	<<0.01[b]	0.03	0.02	<<0.01
Hwy 17 bridge	21.4	0.01[b]	0.15	0.09	<<0.01	<<0.01[b]	0.02	<0.02	<<0.01
WATER TREATMENT PLANTS									
Finished water									
Beaufort-Jasper	39.2	--	--	--	--	<0.003[c]	0.02	<0.02	<<0.001
Cherokee Hill	29.0	--	--	--	--	<0.003[c]	0.02	<0.02	<<0.001
EPA interim primary drinking water standard	--	--	--	--	--	100	100	100	100

[a]Based on mean transportation estimates made by Hayes (1983b) and Hayes and Watts (1983), and average flow rates in the Savannah River at locations indicated. Estimates of concentration and transport for 1st, 2nd and 10th year only represent the contribution resulting from the remobilization of cobalt-60 in Steel Creek by resumed operation of L-Reactor (reference case). No credit is taken for removal of cobalt-60 by the water treatment process.

[b]Estimated on the basis of 0.06 times the value for cesium-137.

[c]Based on Kantelo and Milham (1983).

Cesium-137 is expected to be deposited again in Creek Plantation Swamp during the first 10 years of operation of L-Reactor (reference case) as a result of river flooding and the transport of cesium-137 from Steel Creek. The maximum inventory estimate, corrected for radioactive decay, will be about 23 curies about 6 years after resumed L-Reactor operation (Figure D-12).



Adapted from Du Pont (1982a).

Figure D-12. Increase in cesium-137 on the Creek Plantation Swamp.

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