APPENDIX D

RADIOCESIUM INVENTORY AND TRANSPORT AND ATMOSPHERIC TRITIUM RELEASES

This appendix discusses the existing releases of radionuclides, principally radiocesium, to the Beaver Dam Creek, Four Mile Creek, and Indian Grave Branch/ Pen Branch systems; describes the estimated distribution and inventory of radiocesium in the sediments, fish, and water of the creeks, swamp, and Savannah River; examines the transport of radiocesium offsite; and predicts the concentrations in the Savannah River and downstream water-treatment plants as a result of implementation of the alternative cooling water systems. This appendix also describes the atmospheric releases of tritium associated with the discharge of cooling water from existing and alternative cooling water systems.

D.1 RELEASES OF RADIOCESIUM

The principal sources of radiocesium in the environment at the Savannah River Plant have been reactor effluent discharges to onsite streams and releases from the chemical separations facilities in F- and H-Areas. From 1955 through 1980, about 560 curies of radiocesium were discharged to all onsite streams (DOE, 1984a).

From 1960 through 1980, approximately 21.9 and 16.2 (both decay corrected to 1980) curies of cesium-137 were discharged to Indian Grave Branch/Pen Branch and Four Mile Creek from K- and C-Reactors, respectively (Table D-1). These discharges resulted from leaching of reactor fuel elements with cladding failures that 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 K- and C-Reactor areas. In addition to these reactor effluent discharges, approximately 0.7 curies of cesium-137 (decay corrected to 1980) was released to Four Mile Creek from the chemical separations facilities in F- and H-Areas, and 21.9 curies (decay corrected to 1980) of cesium-137 was released to Four Mile Creek as a result of an overflow of high-level waste in 1967. Generally, the longer lived cesium-137 will be of greater interest than cesium-134. A cesium-134 to cesium-137 ratio of 1:20 is expected (DOE, 1984a) in creek sediments. Further, special low-level analyses of water samples from the Savannah River have not detected cesium-134 attributable to Plant releases since the program was initiated in March 1983 (Hayes, 1986). When the change in radionuclide transport due to operation of the alternative cooling water systems is considered, both forms of cesium are identified.

Through 1980, releases of radiocesium to Beaver Dam Creek amounted to only 0.004 curie (decay corrected). These small releases occurred from the D-Area heavy-water production facility (Du Pont, 1985a). A summary of releases through 1980 to Beaver Dam Creek is also presented in Table D-1.

Table D-1. Radiocesium Releases (Ci) 1960 Through 1980[a,b]

Creek	Radionuclide	Source	Total release	Total release, decay corrected to 1980
Indian Grave Branch/ Pen Branch	Cs-134	K	0.19	0.03
	Cs-137	K	24.442	16.2
			Total: 24.63	Total: 16.23
Beaver Dam Creek	Cs-134	D	-	-
	Cs-137	D	-	0.004
				Total: 0.004
Four Mile Creek	Cs-134	C	0.063	0.01
	Cs-137	C	31.092	21.9
	Cs-137	F	0.632	0.53
	Cs-137	H	0.206	0.18
	Cs-137	H[c]	41.160	30.8
			Total: 73.15	Total: 53.42

a. Du Pont, 1985a.
b. All releases are direct liquid releases to onsite streams.
c. In 1967, overflow of high-level waste to ground and nearby storm sewer occurred when flow from 242-H evaporator to Tank 9 was restricted by formation of crystals.

D.2 DISTRIBUTION OF RADIOCESIUM

D.2.1 SEDIMENTS

Most of the cesium-137 that has been discharged to onsite creeks by SRP operations and fallout from offsite 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 and sorption processes exchange with kaolinite and gibbsite clay minerals, and (2) chelation with naturally occurring organic material. Table D-2 shows the variation in sand, silt, and clay content; total carbon content; and ion exchange capacity in sediment depth increments of 0-5 and 5-10 centimeters in floodplain soils of the three creeks (Du Pont, 1985a). A distribution coefficient of K_d = 3960, measured for sediments from Four Mile Creek 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 creek systems.

As a result of these affinities, sedimentation and sorption processes control the distribution of cesium-137 within the creeks and deltas and the adjoining Savannah River swamp. The resuspension, transport, and deposition of sediment are governed by the hydraulic properties of the sediment and streambeds and by the creeks' flow regimes.

Table D-2. Results of Floodplain Sediment-Characterization Analysis for Beaver Dam Creek, Four Mile Creek, and Indian Grave Branch/Pen Branch[a]

Creek	Location/ depth increment	Composition (%) Sand	Silt	Clay	Total organic carbon (%C)	Cation-exchange capacity (meq/100g)
Indian Grave Branch/ Pen Branch	Road 3					
	0-5 cm	61	20	19	7.4	3.8
	5-10 cm	75	14	11	6.2	3.8
	Indian Grave Branch at Road B					
	0-5 cm	19	60	21	1.3	5.8
	5-10 cm	19	60	21	0.9	4.1
	Swamp between Four Mile Creek and Pen Branch					
	0-5 cm	23	43	34	7.1	13.4
	5-10 cm	17	37	46	5.0	11.9
	Delta					
	0-5 cm	15	48	37	4.7	13.2
	5-10 cm	49	28	23	3.3	9.7
	Stave Island					
	0-5 cm	72	6	22	24.1	17.3
	5-10 cm	68	11	21	18.0	15.6
Beaver Dam Creek	Downstream of D-Area effluent					
	0-5 cm	39	42	19	8.7	7.5
	5-10 cm	51	36	13	10.4	2.3
	Road A-12.2 South					
	0-5 cm	40	24	36	11.4	7.6
	5-10 cm	17	26	57	5.9	8.0
	Mouth					
	0-5 cm	17	53	30	2.1	11.7
	5-10 cm	41	32	27	1.2	7.7
Four Mile Creek	Road 3					
	0-5 cm	79	12	9	7.1	7.8
	5-10 cm	90	4	6	2.4	2.5

Table D-2. Results of Floodplain Sediment-Characterization Analysis for Beaver Dam Creek, Four Mile Creek, and Indian Grave Branch/ Pen Branch[a] (continued)

Creek	Location/ depth increment	Composition (%)			Total organic carbon (%C)	Cation-exchange capacity (meq/100g)
		Sand	Silt	Clay		
Four Mile Creek (continued)	Road A					
	0-5 cm	33	42	25	0.1	10.1
	5-10 cm	33	29	38	0.3	11.2
	Delta					
	0-5 cm	34	42	24	5.5	10.9
	5-10 cm	46	28	26	2.6	6.2
	Mouth					
	0-5 cm	52	29	19	1.9	15.9
	5-10 cm	51	28	21	1.2	13.5

a. Du Pont (1985a).

Almost all sediment redistribution occurred between 1955 and 1968, the period of major reactor discharges. Since 1968, little change has occurred in the sedimentation patterns or in the channel-delta configurations (Ruby, Reinhart, and Reel, 1981).

D.2.1.1 Beaver Dam Creek Sediments

Concentrations of cesium-137 in Beaver Dam Creek sediments are presented in Table D-3. Cesium-137 concentrations ranged from 0.20 picocurie per gram at the south arm near Road A-12.2 to 1.13 picocurie at the mouth. These concentrations are very low compared to data from the other onsite streams.

D.2.1.2 Four Mile Creek Sediments

Cesium-137 has been monitored routinely in Four Mile Creek sediments since 1977. These data are presented in Table D-4 (Du Pont, 1985a,b). Sediment cesium-137 concentrations along Four Mile Creek ranged from 0.4 to 20.3 (mean = 8.6) picocuries per gram, dry weight, at the creek-swamp confluence and from 11 to 80.3 (mean = 35.3) picocuries per gram, dry weight, at Road A-7 upstream of thermal influence. In general, concentrations at both Four Mile Creek stations clearly reflected SRP releases, while Savannah River floodplain sediment concentrations downstream of Four Mile Creek were within ranges associated with global fallout as high as 1.0 picocurie per gram.

Table D-3. Concentrations of Cesium-137 (pCi/g, Dry Weight) in Beaver Dam Creek Sediments[a]

Core location	Concentration
Below 400-D	(b)
South Arm Road A-12.2	0.20
Mouth	1.13

a. Du Pont, 1985a.
b. Not detectable above background.

D.2.1.3 Pen Branch/Indian Grave Branch Sediments

Cesium-137 has been monitored routinely in Pen Branch/Indian Grave Branch sediments since 1977. Table D-5 presents these data (Du Pont, 1985a,b). Because the Pen Branch flow joins the flow of Steel Creek before its entry into the Savannah River, the routine floodplain sediment-monitoring stations at the Steel Creek mouth and in the Savannah River downstream of Little Hell Landing were used for data analysis for both the Pen Branch and Steel Creek systems (Du Pont, 1985a).

D.2.1.4 Swamp and Savannah River Sediments

Beginning in 1974, comprehensive radiological surveys were made of the Savannah River swamp, including the 1235-acre, uninhabited, privately owned Creek Plantation Swamp (Figure D-1), and of the soil and the vegetation. 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 were 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).

D.2.1.5 Savannah River Sediments

In 1974, riverbed sediments from downstream of the Savannah River Plant contained average radiocesium concentrations from about 2 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-6 summarizes more recent monitoring data for Savannah River sediments.

D.2.1.6 Beaufort-Jasper Water Treatment Plant Sediments

A radiological survey of the raw-water and backwash holding-pond sediments at the Beaufort-Jasper water treatment plant was performed in November 1982

Table D-4. Concentrations of Cesium-137 (pCi/g, Dry Weight) in Four Mile Creek Sediments

Source	Location (sampling year)	Concentrations
Du Pont, 1985a[a]	Road A-7 (1984)	70.6
	Road 3 (1984)	43.3
	C-Reactor effluent (1984)	0.26
	Road A (1984)	28.8
	Road A-12.21 (1984)	24.1
	Road A-12.2 (1984)	6.9
	Swamp entrance (1984)	10.5
	Swamp entrance (1984)	10.4
	Swamp entrance (1984)	10.3
	Swamp entrance (1984)	29.0
	Mouth (1984)	0.53
	Mouth (1984)	0.79
	Road A-7 (1977-1983)	35.2 ± 55.0[b]
	Four Mile Creek Swamp (1977-1983)	8.6 ± 15.9
	Savannah River downstream of Four Mile Creek (1977-1983)	0.4 ± 0.5
Du Pont, 1985b	Road A-7 (1984)	18 ± 0.18[c]
	A-7A, Beaver Pond (1984)	49 ± 0.60
	Discharge at swamp (1984)	0.5 ± 0.02

a. Du Pont, 1985a; these data are grouped into two categories. The first 12 entries are one-time samples, each 7.6 centimeters deep and 15.2 centimeters wide, collected in 1984. The last six entries are 7-year averages of floodplain sediment samples. These are 7.6-centimeter-deep multiple samples composited for analysis that were collected between 1977 and 1983.

b. Error term is 2 standard deviations of 7-year mean.

c. Error term is 2-sigma counting error.

(Du Pont, 1985a). 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. Backwash floc from the North Augusta water treatment plant, which is upriver from the Plant, has cesium-137 concentrations similar to those at the Beaufort-Jasper plant. These cesium-137 concentrations are low, generally less than 1 picocurie per gram, and within the concentration range of cesium-137 in sediments from other locations in South Carolina not influenced by the Savannah River Plant (Hayes, 1983a).

Table D-5. Concentrations of Cesium-137 (pCi/g, Dry Weight) in Indian Grave Branch/Pen Branch Sediments

Source	Location (sampling year)	Concentrations
Du Pont 1985a[a]	Road B-3 (1984)	0.10
	K effluent at Road B on Indian Grave Branch (1984)	0.6
	Road A-13.1 (1984)	7.7
	Road A-13.2 (1984)	0.10
	Swamp along Road A-13 (1984)	2.2
	Swamp along Road A-13 (1984)	5.0
	Swamp entrance (1984)	0.31
	Swamp entrance (1984)	0.57
	Swamp entrance (1984)	0.72
	Swamp entrance (1984)	0.31
	Swamp near Stave Island (1984)	1.3
	Swamp near Stave Island (1984)	0.43
	Pen Branch discharge at swamp (1977-1983)	4.2 ± 6.5[b]
	Steel Creek-Pen Branch Mouth (1977-1983)	14.4 ± 46.3
	Savannah River downstream of Little Hell Landing (1977-1983)	2.7 ± 7.9
Du Pont, 1985b	Pen Branch discharge at swamp (1984)	0.3 ± 0.02[c]

a. Du Pont, 1985a; these data are grouped into two categories. The first 12 entries are one-time samples, each 7.6 centimeters deep and 15.2 centimeters wide, collected in 1984. The last six entries are 7-year averages of floodplain sediment samples. These are 7.6-centimeter-deep multiple samples composited for analysis that were collected between 1977 and 1983.

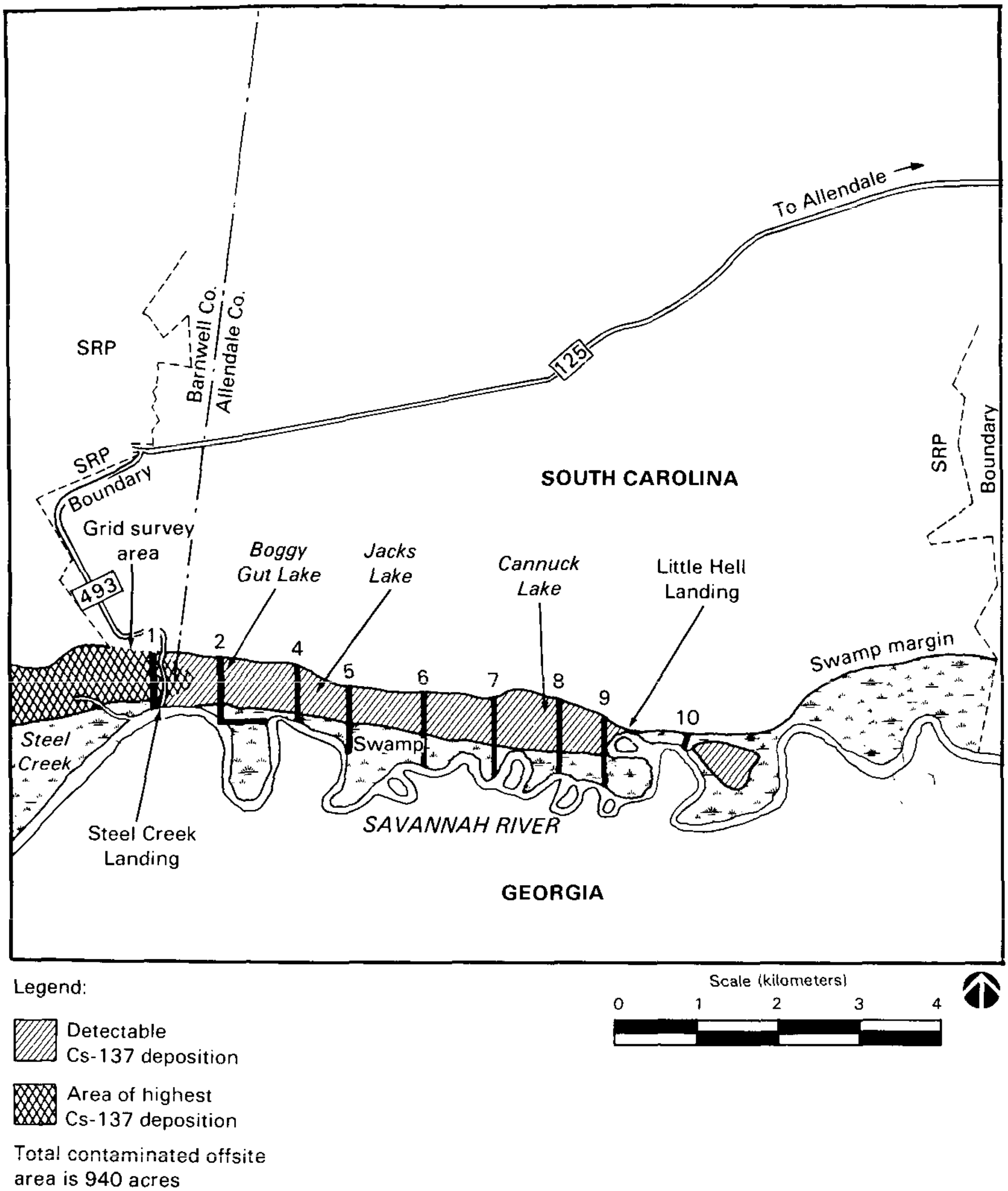
b. Error term is 2 standard deviations of 7-year mean.

c. Error term is 2-sigma counting error.

D.2.2 BIOTA

When K- and C-Reactors are not operating, the Pen Branch and Four Mile Creek delta areas provide roosting and feeding habitat for migratory ducks. The cesium-137 concentration in flesh from these ducks is expected to reflect their cesium-contaminated environment (Marter, 1974; Fendley, 1978).

Whole-body bioaccumulation factors for fish taken from the river at the U.S. Highway 301 bridge from 1965 to 1970 average about 2903 picocuries per gram



Source: Du Pont, 1983a

Figure D-1. Locations of Transects Used for Collecting Soil Cores and Vegetation Samples in Savannah River Swamp, Including 1235-acre Creek Plantation Swamp

Table D-6. Cesium-137 Concentrations (pCi/g, Dry Weight) in Savannah River Sediments (0-8cm depth)[a]

Location	River mile	Average, 1975-1979	1980	1981	1982	1983	1984
Demier's Landing[b]	160.5	0.5	0.2	0.07	0.03	0.13	0.21
Downriver of Four Mile Creek	150.2	0.7	0.2	0.4	0.25	0.20	(d)
Upriver of Little Hell Landing	136.6	0.8	0.2	0.7	0.7	0.25	0.34
Downriver of Little Hell Landing	134.0	3.9	0.4	0.5	0.1	0.39	0.37
Upriver of Lower Three Runs Creek	129.5	0.8	0.4	0.5	(d)	0.32	0.76
U.S. Highway 301 bridge	118.7	1.7	1.1	0.07	0.5	0.50	(d)
GA Highway 119 bridge	61.5	6.5[c]	(d)	(d)	(d)	(d)	(d)

a. Sources: Ashley and Zeigler, 1976, 1978a,b, 1981; DOE, 1984a.
b. Control above plant.
c. Based on 1975 data only.
d. No analysis performed.

(Table D-7). 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, Sharitz, and Gladden, 1982a,b; Ribble and Smith, 1983). 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.

D.2.3 WATER

D.2.3.1 Beaver Dam Creek

Based on the low concentration of cesium-137 in Beaver Dam Creek sediment and the nature of operations in D-Area, which do not involve cesium-137, the concentration in water is expected to be negligible.

D.2.3.2 Four Mile Creek

Annual mean cesium-134 and cesium-137 concentrations in Four Mile Creek water (nominally based on 12 measurements per year at Road A) are presented in Table D-8. From 1978 to 1986 the annual mean concentrations remained low, ranging from 0.45 to 2.4 picocuries per liter and from 0.30 to 1.6 picocuries per liter for cesium-134 and cesium-137, respectively. However, the individual measurements exhibit considerable variability, with standard deviations typically ranging from about 1 to 2 times their respective annual mean value. In addition, the 95 percent confidence limit for the counting error was usually several times the reported value. BC-22

Table D-7. Radiocesium Whole-Body Bioaccumulation Factors for Fish from Steel Creek and Savannah River[a]

Year	Steel Creek (Road A) Maximum	Steel Creek (Road A) Average	Savannah River[b] Downriver of Steel Creek	Savannah River[b] Hwy 301 bridge
1965	--[c]	--	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[d]	2019[e]	--	--
Arithmetic mean		1842	3191	2903
Geometric mean		1802	2700	2295

a. Adapted from Marter, 1970a,b; Du Pont, 1982; and Smith, Sharitz, and Gladden, 1982a,b.
b. Values are averages.
c. Data not available.
d. Mean of 53 specimens of largemouth bass, for which maximum whole-body bioaccumulation factors were measured in 1981. Maximum bioaccumulation factor measured for largemouth bass was 4780. One specimen of American eel had a bioaccumulation factor of 8300.
e. Mean of 527 specimens representing 20 species.

The cesium-134 data are suspect because the reported concentrations of cesium-134 are greater than the cesium-137 concentrations. A cesium-134 to cesium-137 ratio of 1:20 is expected (DOE, 1984a). Further, special low-level analyses of water samples from the Savannah River have not detected cesium-134 attributable to Plant releases since the program was initiated in March 1983 (Hayes, 1986).

BC-22

D.2.3.3 Pen Branch/Indian Grave Branch

Table D-8 also lists the cesium-134 and cesium-137 concentrations for Pen Branch/Indian Grave Branch. Ranges similar to those for Four Mile Creek were observed. From 1978 to 1986, annual mean concentrations ranged from 1.0 to 2.0 picocuries per liter and from 0.12 to 1.6 picocuries per liter for cesium-134 and cesium-137, respectively. As noted in Section D.2.3.2, the data exhibit considerable variability and the 95-percent confidence limits for the counting error were typically several times the measured values. The cesium-134 data are suspect for the reasons stated in Section D.2.3.2.

Table D-8. Annual Mean Concentrations of Cesium-134 and Cesium-137 (pCi/liter) in Water of Four Mile Creek and Indian Grave Branch/Pen Branch[a]

		Annual Mean Concentration (pCi/L)[b]								
Creek	Location	1978	1979	1980	1981	1982	1983	1984	1985	1986
Pen Branch	Road A									
Cesium-134		1.4	(c)	(c)	1.2	1.0	2.0	1.4	1.7	(c)
Cesium-137		0.26	(c)	(c)	0.40	0.53	1.6	0.12	0.42	(d)
Four Mile Creek	Road A									
Cesium-134		0.78	(c)	(c)	0.77	0.45	1.3	1.4	2.4	(c)
Cesium-137		0.48	(c)	(c)	0.58	0.30	1.6	0.65	0.43	(d)

BC-22

a. Sources: Ashley et al., 1982; Zeigler, Culp, and Smith, 1983; Ashley, Padezanin, and Zeigler, 1984a; Du Pont, 1985b; Ashley and Zeigler, 1981, 1984; Zeigler, Lawrimore, and Heath, 1986; Zeigler, et al., 1987.
b. Mean values were below the minimum detectable concentration for cesium, using standard techniques.
c. No value reported.
d. Not detected.

D.2.3.4 Savannah River

The concentrations of cesium-137 in the Savannah River have been monitored routinely since 1960. The highest concentrations were measured in the early 1960s as a result of SRP releases and nuclear weapons test fallout (Figure D-2). Radiocesium concentrations are diluted as the flow of the Savannah River increases downriver from the Savannah River Plant, and as these radionuclides are deposited in the river channel and floodplain (Hayes and Boni, 1983).

Results of recent special low-level cesium-137 measurements of Savannah River water samples are presented in Table D-9. In 1983, prior to the restart of L-Reactor, the concentration of cesium-137 in the river attributable to the Savannah River Plant was 0.046 picocurie per liter (difference between upriver and downriver average values). With a total river flow at the Highway 301 Bridge (the downriver monitoring station) of 1.189 x 10^{13} liters during 1983 (Du Pont, 1984a), the annual release of cesium-137 to the river from the Plant was calculated to be about 0.55 curie. In 1984 the releases totaled about 0.57 curie, following the same calculation methodology (Table D-9 and Du Pont, 1985b). BC-22

D.2.3.5 Water-Treatment Plants

The North Augusta, South Carolina, water-treatment plant is about 20 River Miles above the Savannah River Plant. There are no known individuals who consume Savannah River water for a distance of about 120 River Miles downriver of

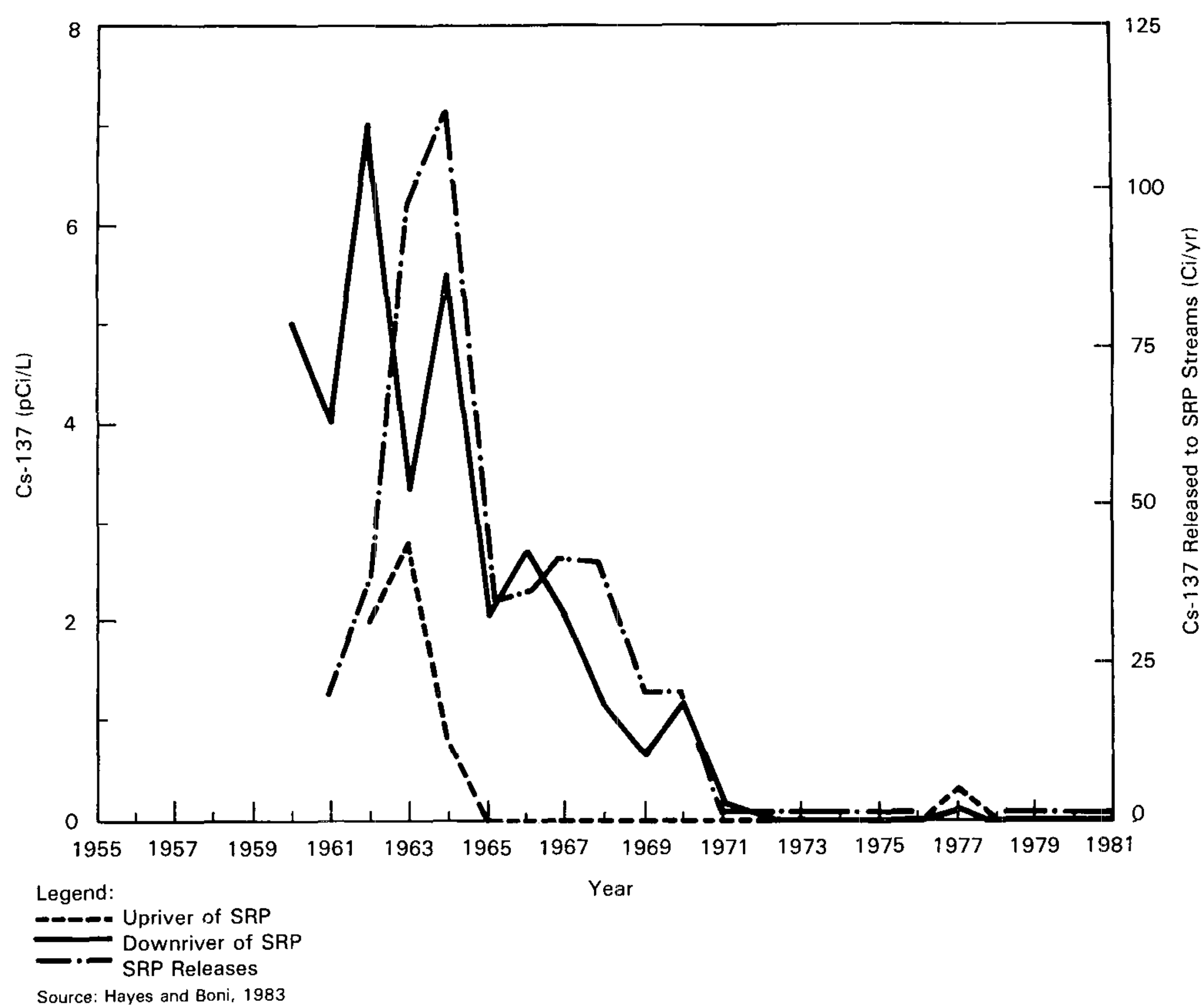


Figure D-2. Cesium-137 Concentrations in the Savannah River, 1960-1980

Table D-9. Special Low-Level Cesium-137 Measurements in Water[a]

			Concentration, pCi/L		
Location	Year	No. of Analyses[b]	Maximum[c]	Minimum[c]	Average[d]
Savannah River					
Shell Bluff (Upriver)	1983	11	0.024 ± 0.005	0.012 ± 0.006	0.017 ± 0.008
	1984	37	0.029 ± 0.003	0.004 ± 0.001	0.012 ± 0.011
	1985	28	0.032 ± 0.004	0.007 ± 0.002	0.015 ± 0.007
	1986	23	0.035 ± 0.002	0.007 ± 0.001	0.021 ± 0.007
Highway 301 (Downriver)	1983	13	0.113 ± 0.016	0.035 ± 0.010	0.063 ± 0.042
	1984	51	0.106 ± 0.007	0.031 ± 0.002	0.065 ± 0.037
	1985	28	0.211 ± 0.010[e]	0.023 ± 0.006	0.071 ± 0.038
	1986	46	0.213 ± 0.004	0.057 ± 0.002	0.114 ± 0.038
Water Treatment Facility					
Port Wentworth, GA Raw	1983	21	0.057 ± 0.008	0.023 ± 0.006	0.045 ± 0.017
	1984	28	0.037 ± 0.005	0.022 ± 0.004	0.032 ± 0.010
	1985	15	0.069 ± 0.003	0.016 ± 0.003	0.049 ± 0.031
	1986	19	0.098 ± 0.003	0.022 ± 0.002	0.064 ± 0.016
Port Wentworth, GA Finished	1983	33	0.048 ± 0.009	0.020 ± 0.004	0.036 ± 0.019
	1984	31	0.035 ± 0.006	0.017 ± 0.020	0.026 ± 0.011
	1985	18	0.060 ± 0.003	0.013 ± 0.005	0.036 ± 0.022
	1986	23	0.089 ± 0.006	0.023 ± 0.002	0.051 ± 0.015
Beaufort-Jasper, SC Raw	1983	19	0.066 ± 0.014	0.019 ± 0.007	0.042 ± 0.027
	1984	31	0.052 ± 0.001	0.020 ± 0.004	0.031 ± 0.022
	1985	14	0.144 ± 0.025[f]	0.018 ± 0.005	0.043 ± 0.063
	1986	22	0.080 ± 0.003	0.040 ± 0.005	0.063 ± 0.011
Beaufort-Jasper, SC Finished	1983	33	0.039 ± 0.006	0.013 ± 0.005	0.024 ± 0.015
	1984	28	0.024 ± 0.006	0.009 ± 0.002	0.016 ± 0.010
	1985	15	0.022 ± 0.002	0.008 ± 0.002	0.013 ± 0.009
	1986	21	0.044 ± 0.004	0.006 ± 0.002	0.020 ± 0.010

a. Adapted from DOE 1987.
b. Represents number of times analyses were performed on samples obtained from continuous samplers.
c. ± value is the 2 sigma counting uncertainty.
d. ± value is the 2 sigma standard deviation about the mean.
e. These slightly higher Cs-137 concentrations occurred the first month after L-Reactor restart on October 31, 1985.
f. Occurred in April during construction activities in the canal between the river and water treatment plant.

BC-22

the Plant. 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 water from the Savannah River above the U.S. Interstate Highway 95 bridge; the water is piped about 11 kilometers to the plant (Du Pont, 1983a).

BC-22 A special program was initiated in March 1983 to measure the effect of L-Reactor restart on the cesium-137 and cobalt-60 concentrations in the raw and finished water in the downriver water treatment plants (Beaufort-Jasper and Cherokee Hill). The concentrations of these two radionuclides are so low in the raw and finished water that samples of 300-400 liters were required. A special resin was used to concentrate the radionuclides. Analysis was performed in an ultra low-level counting facility; counting was performed for about 16 hours (Hayes, 1987). Results of these studies for cesium-137 are presented in Table D-9.

D.3 INVENTORY OF CESIUM-137

The decay-corrected inventory of cesium-137 releases to onsite streams from 1960 through 1980 totaled 414.18 curies (Du Pont, 1985a). Most cesium-137 releases to onsite streams during this period originated from L- and P-Reactor areas (to Steel Creek) and R-Reactor area (to Lower Three Runs Creek). Two methods (Table D-10) were used to estimate the inventory of cesium-137 remaining in the onsite streams. The first method (Method 1, Table D-10) is based on the extensive sampling of Steel Creek. 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 identified 67.1 curies (decay corrected to 1981) between the area above L-Reactor and the delta (Smith, Sharitz, and Gladden, 1982a,b). This value is about 33 percent of the amount of cesium-137 released to Steel Creek (201.23 curies). To calculate the estimated inventory of cesium-137 remaining in the other streams, the release values were multiplied by 0.33, assuming that the Steel Creek ratio of remaining cesium-137 to the total amount released is the same for all streams. The second method (Method 2, Table D-10), from the Comprehensive Cooling Water Study (Du Pont, 1985a), uses a mass-balance approach. Using this approach, the amount of cesium-137 (decay corrected to 1980) remaining in an onsite stream was calculated by multiplying the total cesium-137 released to the stream between 1960 and 1980 by about 76 percent, or the ratio of total cesium-137 released to all SRP streams (about 414 curies, decay corrected to 1980) minus the total cesium-137 in transport (about 100 curies, decay corrected to 1980) to the total cesium-137 released to all SRP streams.

The three creeks of concern - Four Mile Creek, Beaver Dam Creek, and Pen Branch/Indian Grave Branch - contain only about 17 percent of the total cesium-137 remaining onsite. This amounts to 23.22 curies if Method 1 is used to derive the estimate.

Table D-10. Cesium-137 Inventory Remaining in Onsite Streams as Estimated by Two Methods[a]

Stream	Total release 1960 through 1980[b] (Ci)	Percent of total release[c]	Method 1 (using Steel Creek sampling data)[d] (Ci)	Method 2 (mass balance approach)[e] (Ci)
Four Mile Creek	53.42	12.9	17.81	40.59
Beaver Dam Creek	0.0	0.0	0.0	0.0
Indian Grave/ Pen Branch	16.23	3.9	5.41	12.27
Total of all SRP streams	414.18	100	138.10	314.65

a. Sources: DOE, 1984a; Du Pont, 1985a.
b. Sum of cesium-134 and cesium-137 activities (Du Pont, 1985a). All values decay corrected to 1980.
c. *Total decay-corrected (to 1980) cesium-137 releases from 1960 through 1980.*
d. L-Reactor EIS (DOE, 1984a) uses 67.1 curies as the estimate of cesium-137 remaining in Steel Creek. This value is about 33 percent of amount of cesium-137 released to Steel Creek (201.23 curies). Values for other streams were calculated by multiplying release value by 0.33, assuming that the ratio of remaining cesium-137 to the total released for Steel Creek is the same for the other onsite creeks. All values decay corrected to 1980.
e. Values calculated by multiplying percentage of total releases by 314.65 (414.18 - 99.53) curies. All values decay corrected to 1980.

D.4 REMOBILIZATION OF RADIOCESIUM

The amount of cesium-137 transported from onsite streams to the Savannah River resulting from the implementation of the alternative cooling water systems for K- and C-Reactors was estimated on the basis of data from routine monitoring in Four Mile Creek and Pen Branch (Sections D.2.3.2 and D.2.3.3) and detailed monitoring in Steel Creek (Hayes, 1983c; DOE, 1984a; Zeigler et al., 1987). Special low-level monitoring techniques have shown that the Plant is not releasing cesium-134 to the Savannah River. Therefore, the remobilization of cesium-134 is not considered here.

Measurements in Steel Creek at stream flows of about 3.5 cubic meters per second showed that concentrations of cesium-137 in Steel Creek water appeared to be governed by a reequilibriation process between the water and the cesium in the creekbed and floodplain sediments. Hence, transport was found to be proportional to creek flow (Hayes, 1983c).

BC-22 To estimate the remobilization of cesium-137 from Four Mile Creek, Pen Branch, Steel Creek, and Lower Three Runs Creek as the result of the existing cooling water systems, the annual flow volume from each creek was multiplied by the appropriate mean concentration of cesium-137. Because these cesium-137 concentrations were determined by standard techniques and are less than the limits of detection, the cesium transported by the individual creeks and assumed to reach the Savannah River was adjusted so the sum of the creek contributions matched the total contribution from the Plant, as estimated in Section D.2.3.4. As indicated in Table D-11, the transport from the Plant creeks in 1983, based on standard counting techniques, is calculated to total 1.25 curies, with 0.54 curie from Four Mile Creek. However, the total Plant contribution to the River, based on special low-level counting methods, is estimated to be 0.55 curie. Thus, the contribution from Four Mile Creek was reduced to 44 percent [(0.55/1.25) x 100 = 44 percent) of the calculated value of 1.25 curies, or 0.24 curie of cesium-137.

As indicated in Table D-11, the average total stream flows below Road A for Pen Branch and Four Mile Creek are about equal, approximately 3.0×10^{11} liters per year, or 9.75 cubic meters per second. This flow for the existing cooling water systems for K- and C-Reactors is assumed to be the same as that for the once-through cooling-tower alternatives. The recirculating cooling-tower alternatives would have substantially less flow, 1.08 and 1.35 cubic meters per second for K- and C-Reactors, respectively. Thus, cesium-137 remobilization under these alternatives would be approximately 13.8 and 11.1 percent, respectively, of the "full-flow" alternatives.

For K-Reactor, the recirculating cooling-tower alternative would result in a decrease in the release of cesium-137 of about 0.12 curie per year. For C-Reactor, it would result in a decrease in the release of approximately 0.21 curie per year.

BC-22 Table D-12 lists the estimated amounts of cesium-137 remobilized for each alternative cooling water system, calculated as outlined above.

Table D-11. Parameter Values for Cesium-137 Remobilization Estimates[a]

Condition	Year	Four Mile Creek[b]	Pen Branch[b]	Steel Creek[b]	Lower Three Runs Creek[b]	Total Calculated releases	Savannah River[c]	Adjustment factor
Total flow (10^{11} liters)	1983	3.34	2.43	0.57	0.59		118.900	
Annual mean Cs-137 (pCi/l)		1.60	1.60	3.00	2.50		0.046	
Calculated transport (curies Cs-137)		0.54	0.39	0.17	0.15	1.25	0.550	0.44
Adjusted transport (curies Cs-137)		0.24	0.17	0.07	0.07	0.55		
Total flow (10^{11} liters)	1984	3.31	3.41	0.73	0.70		107.100	
Annual mean Cs-137 (pCi/l)		0.65	0.12	1.40	1.10		0.053	
Calculated transport (curies Cs-137)		0.22	0.04	0.10	0.08	0.44	0.570	1.30
Adjusted transport (curies Cs-137)		0.29	0.05	0.13	0.10	0.57		
Total flow (10^{11} liters)	1985	2.59	3.19	0.41	0.56		80.220	
Annual mean Cs-137 (pCi/l)		0.43	0.42	0.28	0.56		0.056	
Calculated transport (curies Cs-137)		0.11	0.13	0.01	0.03	0.28	0.450	1.61
Adjusted transport (curies Cs-137)		0.18	0.21	0.02	0.05	0.46		
Estimated releases to SR, existing system (curies Cs-137)	Mean 1983-1985	0.24	0.14					
Annual total flow (10^{11} liters)		3.08	3.01					

a. Annual flow (below Road A) and cesium-137 concentration data from Ashley, Padezanin, and Zeigler (1984b); Bennett et al. (1983, 1984, and 1985); Du Pont (1985b); Zeigler, Lawrimore, and Heath (1986); and Zeigler et al. (1987).

b. Cesium-137 concentrations in SRP streams measured by standard techniques; reported values less than the limits of detection.

c. Cesium-137 concentrations in Savannah River measured by special low-level techniques; annual average concentrations attributable to SRP operations determined by subtracting downriver average from the upriver average (see Table D-9).

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Table D-12. Estimated Cesium-137 Releases to Savannah River from C- and K-Reactors in First Year for Each Cooling Water Alternative

Alternative	Reactor	Release to River (Ci)	Change in release (Ci)
Recirculating cooling towers	K[a]	0.02	-0.12
Once-through cooling tower,[b] existing system to Indian Grave Branch	K	0.14	0.0
Recirculating cooling tower	C[c]	0.03	-0.21
Once-through cooling tower,[b] existing system to Four Mile Creek	C	0.24	0.0

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a. Discharges from K-Reactor flow into Indian Grave Branch/Pen Branch.
b. Either a mechanical- or a natural-draft once-through cooling-tower that receives its water by pumping or gravity feed.
c. Discharges from C-Reactor flow into Four Mile Creek.

D.5 TRITIUM AND OTHER RADIONUCLIDE RELEASES

D.5.1 TRITIUM RELEASES AND INVENTORY

Tritium accounts for more than 99 percent of the radioactivity in the Savannah River. From 1960 through 1978, about 1.4×10^6 curies of tritium of SRP origin were in transport in the Savannah River. The peak tritium concentration in river water downstream of the Plant was 14 picocuries per milliliter, recorded in 1961 and 1963. A summary of tritium concentration data appears in Table D-13.

The sources of tritium in liquid effluents include direct release from SRP facilities (42 percent) and migration of tritium from the burial ground, F- and H-Area seepage basins, and the K-Area containment basin (58 percent) (Du Pont, 1984a). Migration occurs when tritium that has been released to the basin in previous years reaches SRP streams via groundwater that outcrops into the streams. Tritium migrating from the C-Area seepage basins has not been detected.

Table D-14 presents the tritium releases through 1980 for individual streams. Tritium monitoring data indicate that essentially all tritium released from the Plant in liquid effluents moves down SRP streams to the Savannah River (Du Pont, 1984a, 1985b).

Table D-13. Average Tritium Concentrations (pCi/ml) in Four Mile Creek, Beaver Dam Creek, Indian Grave Branch/Pen Branch, and Savannah River[a]

Location	Concentration								
	1953-1981	1978	1979	1980	1981	1982	1983	1984	Average
Beaver Dam Creek									
effluent		47	28	34	38	73	69	50	48.4
Four Mile Creek									
Road A		200	96	80	61	61	58	61	88.1
Indian Grave Branch/ Pen Branch									
K effluent		2.1	23	7.1	3.6	7.8	19	7.6	10.0
Road A		38	46	31	35	32	29	32	34.7
Savannah River									
Above Plant	1.04	0.39	0.38	0.39	0.21	0.36	0.31	0.33	0.34
Above Four Mile Creek	(b)	1.9	1.6	1.4	2.9	3.2	2.5	2.5	2.3
Highway 301	7.55	3.9	3.1	3.2	4.1	4.3	3.3	3.3	3.6

a. Sources: Ashley and Zeigler, 1981; Zeigler, Culp, and Smith, 1983; Ashley, Padezanin, and Zeigler, 1984a,b; Du Pont, 1985a,b; Ashley et al., 1982.
b. Not analyzed.

Table D-14. Tritium Releases to Four Mile Creek, Beaver Dam Creek, and Indian Grave Branch/Pen Branch Through 1980[a]

Creek	Source[b]		Release (Ci)
Four Mile Creek	C		249,380
	F		260
	F sbm		39,324
	H		1,172
	H sbm		98,432
		Total	388,568
Beaver Dam Creek	D[c]		124,090
Indian Grave Branch/ Pen Branch	K		212,180
	K sbm		145,390
		Total	357,570

a. Du Pont, 1985a.
b. sbm = seepage basin migration. Entries not so labeled represent areas of direct liquid releases.
c. Releases were from D-Area heavy-water production facility.

Tritium releases to the Savannah River have decreased significantly since the early 1960s when the maximum tritium releases occurred (Du Pont, 1985a,b). The following process control improvements have caused the reduction:

- The elimination of a continuous purge from the reactor-area disassembly basins in the late 1960s, which allowed longer holdup time for tritium decay (the half-life of tritium is 12 years) and some evaporation.

- The development of equipment and techniques to flush and contain the tritium-bearing moderator present on fuel and target housings during disassembly-basin discharge.

- The diversion of disassembly-basin purges from streams to seepage basins in P- and C-Areas in 1978, which allowed a longer holdup time for radioactive decay before migration to streams via groundwater.

In addition, total tritium releases were reduced by the shutdown of R-Reactor in June 1964 and of L-Reactor from February 1968 until October 1985.

D.5.2 EFFECTS OF ALTERNATIVE COOLING WATER SYSTEMS ON TRITIUM RELEASES

Source terms used to calculate the current cumulative impact from liquid releases to the Savannah River are presented in Table D-15. Changes in releases of tritium as a result of alternative cooling water systems are presented in Table D-16.

Table D-15. Tritium and other Radionuclide Releases Used for Calculating Changes in Release Rates (Ci/yr)[a]

Nuclide	Beaver Dam Creek	Four Mile Creek	Indian Grave Branch/ Pen Branch	Total release[b]
H-3	2.80×10^{3}	1.35×10^{4}	1.18×10^{4}	3.08×10^{4}
Co-58,60	-	2.64×10^{-5}	2.94×10^{-4}	7.41×10^{-4}
Sr-89,90	1.42×10^{-2}	5.49×10^{-1}	1.32×10^{-3}	5.72×10^{-1}
Pu-239	3.25×10^{-4}	1.13×10^{-2}	7.86×10^{-5}	1.19×10^{-2}
U-235,238	-	-	-	6.23×10^{-2}

a. Values are 5-year averages, 1980 through 1984, provided by Du Pont.
b. Total releases also include Tims Branch/Upper Three Runs Creek, Par Pond/ Lower Three Runs Creek, and Steel Creek.

Table D-16. Changes in Release of Tritium to Savannah River from K- and C-Reactors in First Year for Each Cooling Water Alternative[a]

Alternative cooling water system	Reactor	Change in release (Ci)
Recirculating cooling towers	K	-425
Once-through cooling tower,[b] discharge to Indian Grave Branch	K	-50.0
Recirculating cooling towers	C	-425
Once-through cooling tower,[b] discharge to Four Mile Creek	C	-50.0

a. DOE, 1984b.
b. Either a mechanical or a natural-draft once-through cooling-tower that receives its water by pumping or gravity feed.

The release of tritium to the Savannah River for the K- and C-Reactor once-through cooling-tower alternatives (pumped or gravity feed and mechanical or natural draft) is expected to be reduced by about 50 curies per year because of increased evaporation and a corresponding increase in the tritium released to the atmosphere. Similarly, the tritium released to the Savannah River from the K- and C-Reactor recirculating cooling-tower alternatives would also be reduced by about 425 curies and a correspondingly greater increase in the tritium released to the atmosphere. The difference between the release rates of the recirculating cooling towers and once-through cooling tower is based on the differences in cooling-tower evaporation and blowdown rates.

D.5.3 OTHER RADIONUCLIDE RELEASES TO ONSITE STREAMS

Source terms for other radionuclides are presented in Table D-15.

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