CHAPTER 11

RADIONUCLIDES IN WILD GAME

ABSTRACT

This chapter discusses radionuclide concentrations measured in wild game collected at the Savannah River Site (SRS). We evaluated these data with regard to their potential usefulness for dose reconstruction. We also attempted to validate the data by making comparisons of concentrations among as many sources as possible. This included original, hand-written compilations for many years. We found these original data to consistently correspond to the data reported in monthly, semi-annual, and annual summary reports.

We compiled and examined wild game data and other environmental data to determine their usefulness for source term verification, model validation, and direct exposure assessment. In general, the wild game data are most valuable for direct exposure assessment. However, because range and eating habits for the various animals are not well defined, the data are not particularly useful for source term verification or model validation. Appendix K further discusses potential uses for environmental monitoring data.

INTRODUCTION

Before the Atomic Energy Commission acquired the SRS in 1950 and 1951, the white-tailed deer (*Odocoileus virginianus*) population was estimated at several dozen animals. Under conditions of virtually absolute protection, the population increased to approximately 1400 animals in 1963 and to approximately 5000 animals in the spring of 1965 when managed public hunts were initiated to control the expanding population (Rabon 1976). Deer at the SRS represent a potentially important exposure pathway for historical exposures of the public from radionuclides because large numbers of deer have been harvested during these annual hunts. In addition, smaller numbers of feral hogs have been harvested from the SRS during the public hunts.

Other fur-bearing animals, including cats, mice, rats, foxes, raccoons, dogs, bobcats, squirrels, and opossums, have also been trapped and analyzed by the SRS to determine radionuclide concentrations. Additionally, waterfowl, including gulls, grebes, coots, and several species of duck, have been collected, primarily from Par Pond, and analyzed to determine radionuclide concentrations. The following discussion focuses on deer concentrations because they represent the most significant pathway for potential exposure to the general public. However, this chapter also examines concentrations in other wild game species.

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

Several additional documents have been reviewed for information pertaining to deer monitoring at the SRS. These include monthly monitoring reports from 1962 through 1965, weekly monitoring reports from 1959 through 1962, and aperture card printouts (handwritten data entry sheets) from 1970 through 1981. Although these printouts were sometimes not legible, they provided general verification of data presented in the monitoring reports. The results were not summarized, but reported concentrations are consistent with those given in the monitoring reports. Original field data from 1965, 1966, 1982, 1984, and 1985 were also reviewed. In general, the data provided in these documents are also consistent with the data provided in the monitoring reports. Additionally, aperture card printouts from 1970 through 1981 provided general verification of the data provided in the monitoring reports for waterfowl and other animals.

The radionuclides for which data are available for wild game include nonvolatile beta, ^{137}Cs, $^{129,131}I$, $^{89,90}Sr$, $^{238,239}Pu$, ^{65}Zn, and ^{3}H. Appendix A details analytical and counting procedures for wild game. Concentrations of heavy metals (chromium, cadmium, lead, and mercury) in deer tissue were also reported in 1987 and 1989 (Mikol et al. 1988b and Cummins et al. 1990), and most concentrations were below the detection limit.

Figure 11-1 shows the general time periods for which individual radionuclide concentrations were reported for deer in the various environmental monitoring reports and data summaries.

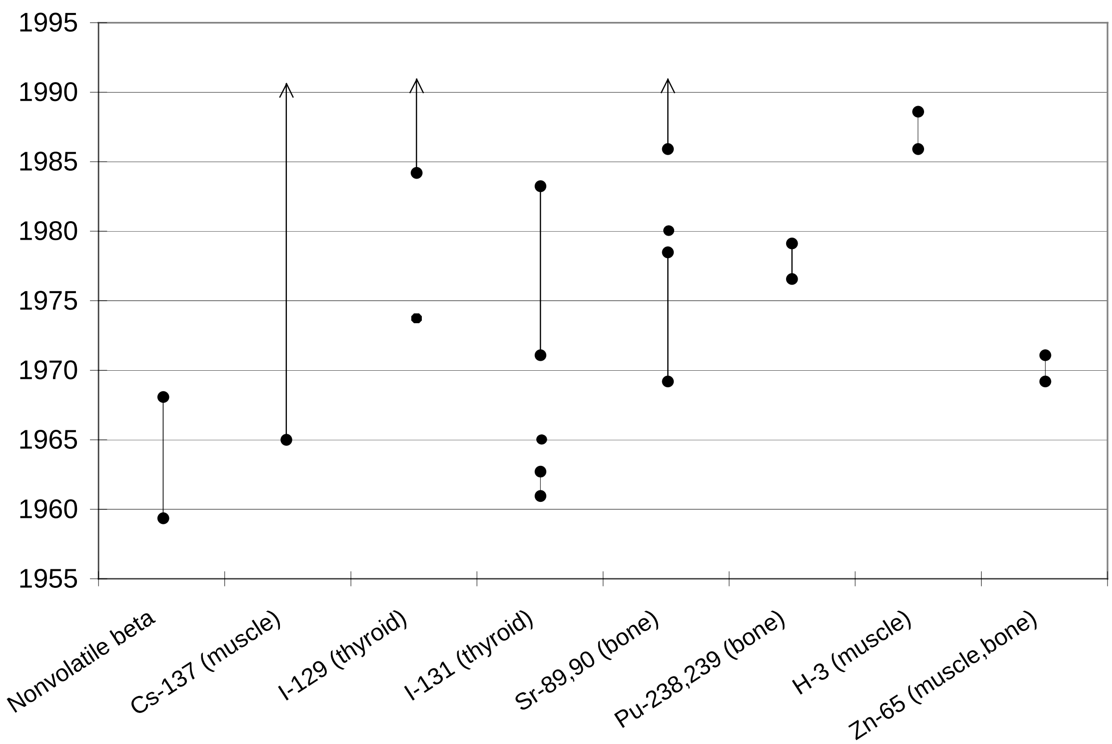

Figure 11-1. General time periods for which individual radionuclide concentrations were reported for deer. Link to tabulated figure data.

RADIONUCLIDE CONCENTRATIONS MEASURED IN DEER

Nonvolatile Beta and Cesium-137

Cesium-137 distributes in body tissues similarly to potassium, residing primarily in soft tissues such as muscle. Consequently, the majority of analyses have focused on ^{137}Cs concentrations in muscle tissue. The SRS has made field measurements on deer killed during annual public hunts since 1970. The fraction of deer analyzed in the laboratory for field measurement verification from 1970 through 1992 ranged from 2 to 20%, with an annual average of 7 %. An average of 1064 animals has been harvested annually from 1965 through 1992.

Before 1965, only nonvolatile beta concentrations were reported for muscle tissue. Nonvolatile beta activity refers to activity resulting from the presence of radionuclides that do not escape during sample preparation, such as evaporation or wet-ashing. The primary radionuclides that could potentially contribute to nonvolatile beta activity at the SRS include ^{137}Cs, ^{65}Zn, ^{90}Sr, ^{32}P, and naturally occurring ^{40}K. In general, ^{137}Cs is the radionuclide of greatest concern because of its relatively long half-life (30 years) and its tendency to accumulate in edible (muscle) tissues.

Nonvolatile beta and ^{137}Cs concentrations were reported from 1965 through 1968. Table 11-1 summarizes the information provided in the environmental monitoring reports for nonvolatile beta and ^{137}Cs concentrations in muscle during the years both were reported. The nonvolatile beta concentrations are very similar to the ^{137}Cs concentrations from 1965 through 1969. It is not known whether the ^{137}Cs concentrations for those years were derived from the nonvolatile beta concentrations, but based on their similarity it appears possible. Regardless, the nonvolatile beta concentrations reported for the few deer collected before 1965 appear similar to or less than the concentrations reported since 1965. Unfortunately, very few deer were analyzed, and it is difficult to make many conclusions based on the values reported before 1965. Public exposure to deer from the SRS would likely have been minimal before 1965, when public hunts on the SRS were initiated. However, since the precise range and mobility of the deer residing on the SRS is not known, it is certainly possible that some animals spending the majority of time on the SRS migrated offsite and were harvested by hunters.

Since 1987, several deer muscle samples have been analyzed annually by the Department of Physiology and Biophysics at the University of Tennessee in Memphis. In general, the laboratory analyses conducted by the University of Tennessee have been in good agreement with the laboratory analyses conducted by the SRS and they provide some measure of validation for the measurements reported by the SRS (Table 11-2). While not explicitly stated in the monitoring reports, it is assumed that the muscle tissue samples sent to the University of Tennessee for analysis represented a portion or subset of the tissue samples routinely collected for field measurement verification. Without information regarding the specific concentrations measured for individual deer by the two laboratories, this information is admittedly of limited value.

Table 11-1. Mean Nonvolatile Beta[a] and ^{137}Cs[b] Concentrations (pCi g^{-1}) in Deer Muscle

Year	Nonvolatile beta (number of deer)	^{137}Cs (number of deer[c])
1958[d]	9 (1)	nr[e]
1959[d]	3 (1)	nr
1960	3 (2)	nr
1961	5 (3)	nr
1962	4 (2)	nr
1963	(0)	(0)
1964	8 (6)	nr
1965	11 (146)	10 (198)
1966	6 (212)	6 (541)
1967	10 (126)	9 (1032)
1968	11 (58)	11 (699)

[a] Reported in Du Pont (1959, 1960a, 1960b, 1961, 1962c, 1962d, 1963d, 1963e, 1964c) and Ashley (1965, 1966, 1967, 1968, 1969).
[b] Reported in Ashley and Zeigler (1976).
[c] This likely represents the total number of deer harvested and not the number of deer analyzed.
[d] Reported in Harvey and Rabon (1965).
[e] nr = not reported.

Table 11-2. Comparison of ^{137}Cs Concentrations (pCi g^{-1}) Measured by the SRS and the University of Tennessee[a]

Year	SRS analysis: Number of samples	SRS analysis: Mean ± 2 SD[b]	University of Tennessee analysis: Number of samples	University of Tennessee analysis: Mean ± 2 SD
1987	35	8.3 ± 21.7	24	3.8 ± 5.0
1988	67	9.8 ± 19.5	6	10.4 ± 10.0
1989	96	8.9 ± 10.2	41	6.0 ± 11.0
1990	92	8.1 ± 8.8	10	11.1 ± 15.6
1991	124[c]	3.3 ± 5.1	28	2.9 ± 5.1

[a] Data are from Mikol et al. (1988b), Davis et al. (1989b), Cummins et al. (1990, 1991), and Arnett et al. (1992).
[b] SD = standard deviation.
[c] Includes measurements for both deer and hogs.

Since 1968, ^{137}Cs concentrations have also been reported for South Carolina Coastal Plain (SCCP) deer. The SCCP is an 18,000-acre controlled hunting camp located approximately 65 mi southeast of the SRS in Beaufort County. In 1974, 10 deer from Beaufort, South Carolina, (approximately 100 mi southeast of the SRS) were analyzed, and in 1979, four deer from the Fort Jackson military reservation (approximately 15 mi southeast of Augusta, Georgia) were analyzed. The SCCP deer and the additional deer sampled in 1974 and 1979 have served as indicators of background ^{137}Cs burdens from weapons testing fallout that would be found in deer living in similar environments. The SRS deer concentrations are lower than the concentrations in deer taken from offsite; therefore, they do not appear to be elevated above expected background concentrations. Table 11-3 summarizes the measured concentrations in 1974 and 1979.

Table 11-3. Comparison of Mean ^{137}Cs Concentrations[a] ($pCi\ g^{-1}$) in Deer from the SRS and Vicinity

Year	SRS	SCCP	Beaufort	Ft. Jackson
1974	5 (n=1551)	9 (n=89)	10 (n=10)	
1979	10 (n=1079)	12 (n=57)		15 (n=4)

[a] Data are from Du Pont (1975a, 1980a, and 1981a).

The authors of the monitoring reports have consistently maintained that the ^{137}Cs concentrations measured in deer from the SRS are due almost entirely to worldwide fallout resulting from weapons testing. Soils from the lower coastal plain of the southeastern U.S. are typically sandy and low in clay content, organic matter, and available potassium. This leads to increased amounts of ^{137}Cs available for plant uptake and subsequent deer ingestion relative to other areas of the continental U.S., which makes it difficult to distinguish SRS-derived ^{137}Cs from global fallout resulting from weapons testing. However, concentrations measured in deer collected from offsite locations give no indication that mean ^{137}Cs burdens in SRS deer are elevated above expected background concentrations. Van Middlesworth (1993) concluded that most of the ^{137}Cs in deer from the SRS, SCCP, and other parts of the southeastern U.S. can be attributed to worldwide fallout.

The mean concentrations have consistently been lower for SRS deer than for deer collected from the SCCP. This is likely the result of different soil characteristics for the two areas. The SRS is situated on the boundary of the Piedmont and Coastal Plains. The SCCP is, as the name implies, located in the Coastal Plain area. Soils in the Coastal Plain area are characterized by more sand and organic matter, less clay, more ammonia, and a higher water table, all of which contribute to increased ^{137}Cs mobility (Whicker 1997). Therefore, higher mean concentrations would be expected for deer taken from this area. Consequently, the fact that mean concentrations have been consistently lower for SRS deer than for SCCP deer does not necessarily indicate that SRS activities have not affected ^{137}Cs concentrations in the resident deer population. To estimate exposure to hunters who harvested deer from the SRS, it may be necessary to quantify the extent of SRS-derived ^{137}Cs in onsite deer.

In 1989, Winn (1990) attempted to distinguish whether ^{137}Cs measured in individual deer originated from the SRS or global fallout. Cesium releases from the SRS have an identifiable $^{134}Cs/^{137}Cs$ fingerprint that is different from that of global fallout. This method alone was considered insufficient to identify SRS deer, but the calculated isotopic ratios (0.001–0.003) were consistent with global fallout and were comparable to those calculated for offsite deer. The results of the study also implied that deer feed primarily on land areas, as opposed to the banks of effluent streams. However, the scope of the study was limited because only six animals were analyzed.

The annual maximum concentrations for SRS deer have consistently been higher than those measured in offsite deer. These higher concentrations likely reflects uptake of ^{137}Cs from contaminated streams or ponds for a few individual deer, but based on the annual means, not a significant portion of the population. The maximum concentration in 1966 was for an animal taken from along Four Mile Creek, and the maximum concentrations for 1967 through 1970 and 1979 were for animals taken from near Steel Creek. This suggests that the maximum concentrations in deer from the SRS are likely to be found in animals residing and feeding near the most contaminated areas (e.g., on the banks of contaminated onsite streams).

Since 1965, during the annual public hunts, there has been only one deer confiscated (204 pCi g^{-1} in 1969) and only three additional deer with a measured ^{137}Cs concentration greater than 100 pCi g^{-1} (104 pCi g^{-1} in 1967, 103 pCi g^{-1} in 1969, and 117 pCi g^{-1} in 1970). In addition, several deer collected during special sampling along Four Mile Creek in July 1968 had concentrations greater than 100 pCi g^{-1}, and one had a concentration of 204 pCi g^{-1} (Hagelston 1970). Consequently, that location was not included in the public hunt plans for 1968.

As previously discussed, many of the deer with the highest concentrations were collected from locations near Steel Creek. Following shutdown of the L-Reactor in February 1968, Steel Creek was narrowed significantly. This allowed for growth of vegetation on the exposed contaminated sediment. The new vegetation was palatable, available to deer, and had higher radionuclide concentrations (Hagelston 1970). Consequently, deer feeding on this vegetation may have accumulated higher levels of ^{137}Cs relative to years before the L-Reactor shutdown.

The maximum measured concentrations for deer from the SRS are not significantly elevated above concentrations that have been measured at other locations in the southeastern United States. Jenkins and Fendley (1969, cited in Rabon 1976) reported concentrations, attributed to global fallout, up to 153 pCi g^{-1} in deer from south Georgia and northern Florida in 1968. For comparison, the maximum measured concentration for SCCP deer was 80 pCi g^{-1} in 1968. Five deer collected from Eglin Air Force Base near Pensacola, FL in February 1968 had a mean ^{137}Cs concentration of 78 pCi g^{-1}, and eight deer collected from the same area in March had a mean ^{137}Cs concentration of 43 pCi g^{-1} (Du Pont 1968c). For comparison, the mean concentration measured in SRS deer during February was 8 pCi g^{-1} and during March was 7 pCi g^{-1}.

The reported measured concentrations in SRS deer since 1965 also likely reflect the maximum seasonal concentrations because most deer have been harvested in the fall. Several researchers have attributed increased ^{137}Cs body burdens in ruminants to seasonal changes in diet (Rabon 1968, 1976; Jenkins and Fendley 1968, 1969, cited in Rabon 1976; Svenson and Liden 1965; Hanson and Palmer 1965; Whicker et al. 1965). The seasonal changes in diet for deer at the SRS result from the abundance of autumnal food items such as acorns and fungi, which are tenacious concentrators of cesium. The range of measured concentrations in deer has been attributed by the SRS to concentration variability in the diets of these deer.

Figure 11-2 shows mean and maximum concentrations provided in the annual environmental monitoring reports for SRS and SCCP deer from 1968 through 1991 (note the logarithmic scale for the y-axis). Watt et al. (1983) reported the same concentrations. The concentrations appear to have declined during this period, and the data were best described by exponential functions. Linear regression of the log-transformed data confirmed slopes statistically different from zero ($p<0.01$ for both SRS and SCCP deer). The effective half-times for ^{137}Cs in the SRS and SCCP deer during this time period have been about 16.6 and 12.5 years, respectively. Although the effective half-times are not the same, they are statistically indistinguishable at the 95% confidence level. There are no apparent reasons for differing effective half-times for the two populations of deer. The noted differences are likely due to spatial heterogeneity, differences in diet, accumulation of some SRS-derived ^{137}Cs in the SRS deer, additional fallout resulting from Chinese atmospheric weapons tests, and general variability in the data.

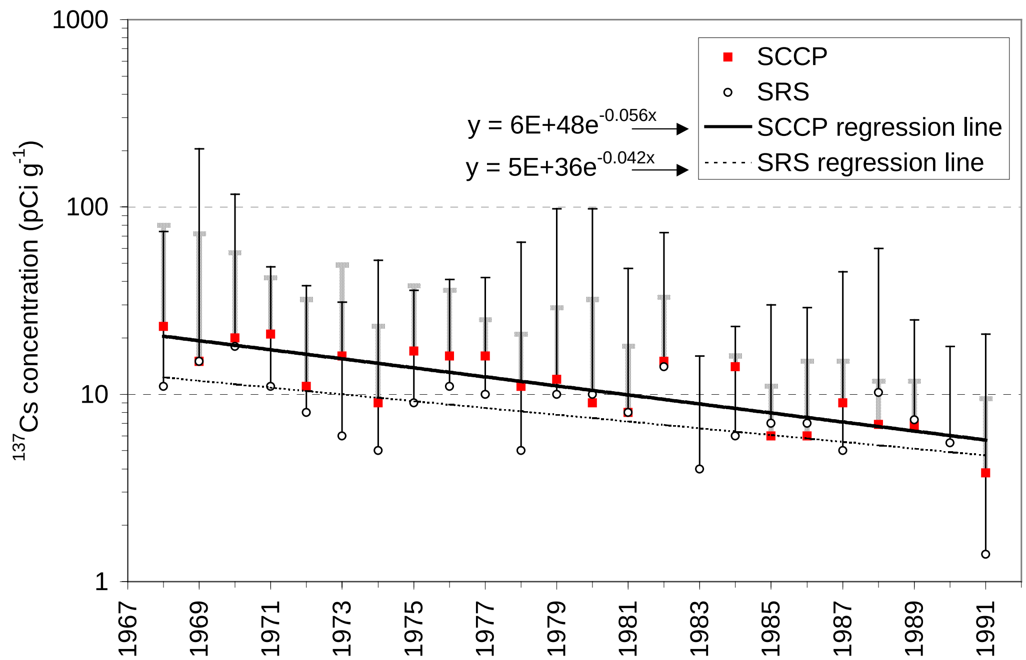

Figure 11-2. Annual mean ^{137}Cs concentrations in deer collected from the SRS and the SCCP. Thick and thin error bars represent maximum concentrations measured each year for the SCCP and SRS deer, respectively. The lower limit of detection (LLD) was 1 pCi g^{-1}. Link to tabulated figure data.

Figure 11-3 shows the maximum measured ^{137}Cs concentrations since 1965 for SRS and SCCP deer. It is clear that annual maximum concentrations have been consistently higher for SRS deer. It also appears that maximum measured concentrations are decreasing as a function of time for both locations. In addition, the maximum measured concentrations in SRS appear to peak during the late 1960s, during the late 1970s through the early 1980s, and during the late 1980s.

Frequency distributions of ^{137}Cs concentrations measured in the field indicate log-normally distributed data (Addendum 11A). For the 1985 data in particular, it is clear that including concentrations reported as 1 pCi g^{-1}, which was the apparent detection limit[1], results in a large number of animals in the 0–1 pCi g^{-1} category. These data were compiled from raw data sheets for the years 1965, 1966, 1982, 1984, and 1985. The data sets from 1982, 1984, and 1985 appeared to provide data for all deer analyzed in those years. The data sets from 1965 and 1966 provided data for only a subset of the total number of deer harvested in those years (approximately 20% of forelegs were retained for laboratory analysis). Watts et al. (1983) indicated ^{137}Cs concentrations measured in SCCP deer between 1975 and 1979 to also be qualitatively described as log-normally distributed.

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

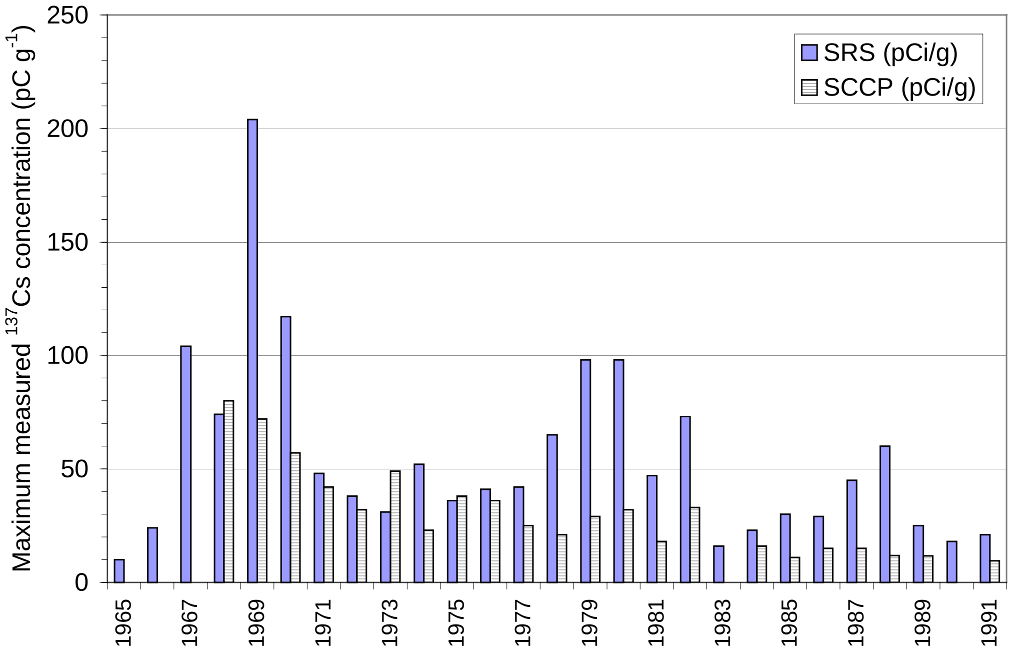

Figure 11-3. Maximum ^{137}Cs concentrations measured in deer collected from the SRS and the SCCP since 1965. SCCP deer were not collected until 1968. Link to tabulated figure data.

To complete the deer exposure pathway, it may ultimately be necessary to further examine the deer data because routinely reported arithmetic mean concentrations are likely not the best descriptors for central tendencies in deer concentrations. Estimates of live weight-dressed weight and live weight-edible meat relationships may also be necessary to fully evaluate the pathway; this information is provided in Severinghaus (1949) for white-tailed deer.

Radioiodine

Radioisotopes of iodine are released from SRS facilities and are also an important component of weapons fallout (see Chapter 6 for more details regarding other sources of contamination). With a short half-life of about 8 days, ^{131}I does not persist in the environment. Therefore, concentrations measured in the environment reflect recent releases. Iodine-129, in contrast, has a very long half-life and does persist in the environment. Radioiodine concentrations were reported for deer thyroid samples beginning in 1961. The thyroids were analyzed because of their ability to concentrate iodine; therefore, they are a sensitive indicator of the impact of SRS releases. Consumption of deer thyroid, however, is not considered a human exposure pathway.

Mean annual radioiodine concentrations measured in thyroid tissue are shown in Figure 11-4. Iodine-131 concentrations were measured in thyroid tissue in 1961, 1962, 1965, 1967, and from 1971 through 1983. Elevated concentrations were reported in 1961, 1962, 1976, and 1977. SRS researchers attributed these increases to fallout from Soviet and Nevada Test Site testing in the early 1960s and Chinese weapons testing in 1976 and 1977. There was also a significant release of ^{131}I from an F-Area stack during May and June 1961, which may have contributed to the elevated concentrations measured during that year. Thirty-three deer thyroids were analyzed in 1967, and the maximum measured concentration (160 pCi g^{-1}) was attributed to a 6 Ci release of ^{131}I from the F-Area dissolver off-gas stack on March 1, 1967 (Du Pont 1968c). Concentrations for the remaining years were near the limits of detection (6 pCi g^{-1} in 1965 and 1 pCi g^{-1} since 1976). Similar concentrations of ^{131}I have been reported for North American deer collected in Alaska, California, Colorado, Maryland, Washington, and Wyoming during 1961 and 1962 (Hanson et al. 1963).

Iodine-129 concentrations were reported for thyroid tissue in 1974 and from 1984 through 1991 (Zeigler et al. 1985, 1986a, 1986b, 1987a, 1987b; Mikol et al. 1988a, 1988b; Davis et al. 1989a, 1989b; Cummins et al. 1990, 1991; Arnett et al. 1992). Four thyroids sampled in 1974 had ^{129}I concentrations ranging from 2 to 18 pCi g^{-1} and a mean of 9 pCi g^{-1}. The mean concentration reported in 1984 was calculated excluding a 210 pCi g^{-1} sample, and the mean concentration reported in 1989 was calculated excluding a 2145 pCi g^{-1} sample (Zeigler et al. 1985; Cummins et al. 1990). The lower limit of detection (LLD) was not given, but concentrations appear low through 1988, after which concentrations increased somewhat. However, Van Middlesworth (1993) reported no distinguishable temporal trend between 1985 and 1991 for ^{129}I in thyroids taken from SRS deer. In 1991, the average concentration was 49 pCi g^{-1}, but 90% of the samples were less than 50 pCi g^{-1} and 50% were less than 1.5 pCi g^{-1}. In general, ^{129}I concentrations have been significantly elevated only in a few isolated individuals. Because thyroids are not typically consumed, this is unlikely to represent a significant exposure pathway to hunters or their families who consumed the deer meat.

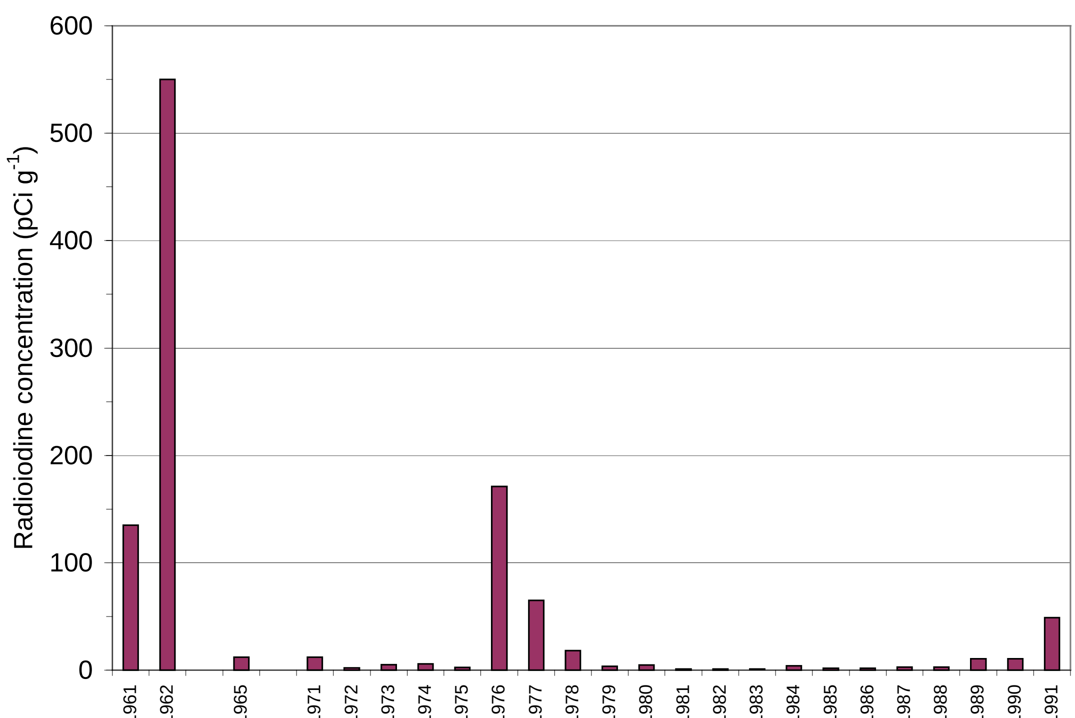

Figure 11-4. Mean radioiodine concentrations reported for deer thyroids. Iodine-131 concentrations were reported in 1961, 1962, 1965, and 1971 through 1983. Iodine-129 concentrations were reported from 1984 through 1991. Link to tabulated figure data.

Other Radionuclides

Strontium-89,90 concentrations were reported for bone tissue sampled from 1969 through 1980 and from 1986 through 1991. Radionuclides of the element strontium are metabolically similar to calcium and, thus, are found primarily in the bone of vertebrate animals. With a half-life of about 28 years, the fission product strontium-90 is an important relatively long-lived component of weapons fallout. It has also been released from SRS facilities. As with thyroid samples, bone samples were analyzed to assess SRS impact and not as a human exposure pathway.

Mean ^{89,90}Sr concentrations ranged from 2 to 54 pCi g^{-1}, with a maximum value of 207 pCi g^{-1} in 1974. Concentrations measured in 1986 and 1987 (26.7 and 54.2 pCi g^{-1}, respectively) were higher than other years, but relatively few samples were analyzed (six and five, respectively). Rabon (1968) reported a negative correlation of radiostrontium concentration with deer age (that is, younger deer had higher concentrations), and no correlation between radiostrontium concentration and deer size and sex or season.

Zinc-65 is a relatively short-lived (half-life 245 days) activation product produced in nuclear reactors and in the fallout from nuclear weapons detonations. Zinc-65 concentrations were reported for 1969 through 1971 for a few animals, but the mean concentrations were at or below the detection limit. Aside from ^{65}Zn and naturally occurring ^{40}K, ^{137}Cs has been the only gamma-emitting radionuclide reported as detected in deer taken from the SRS.

Plutonium-238,239 concentrations, alpha-emitting radionuclides, were reported for bone tissue sampled in 1977, 1978, and 1979. Concentrations of ^{238}Pu ranged from 0.6 to 5.6 fCi g^{-1}, and concentrations of ^{239}Pu ranged from <0.18 to 3.4 fCi g^{-1} with a mean of 1.7 fCi g^{-1} for both isotopes (1 femtocurie [fCi] is equal to 10^{-15} Ci).

Tritium concentrations were reported from 1986 through 1988. This beta-emitting radionuclide is incorporated into the water molecule; consequently, it is present in all tissues. In 1986, nine muscle tissue samples were analyzed and they had a mean concentration of 17 pCi mL^{-1}. In 1987, three samples were analyzed and they had a mean concentration of 250 pCi mL^{-1}, which was largely the result of one 645 pCi mL^{-1} sample. In 1988, 98 samples were analyzed and most had concentrations less than 1 pCi mL^{-1}.

RADIONUCLIDE CONCENTRATIONS MEASURED IN FERAL HOGS AND OTHER TERRESTRIAL ANIMALS

Smaller numbers of feral hogs have also been collected from the SRS during the annual public hunts. In general, mean ^{137}Cs concentrations have been similar to or less than concentrations reported for deer (Figure 11-5). Little information was available with regard to radionuclide concentrations in hogs before 1971. Nonvolatile beta concentrations reported for a few hogs collected in 1963 and 1964, though, were similar to those reported for deer.

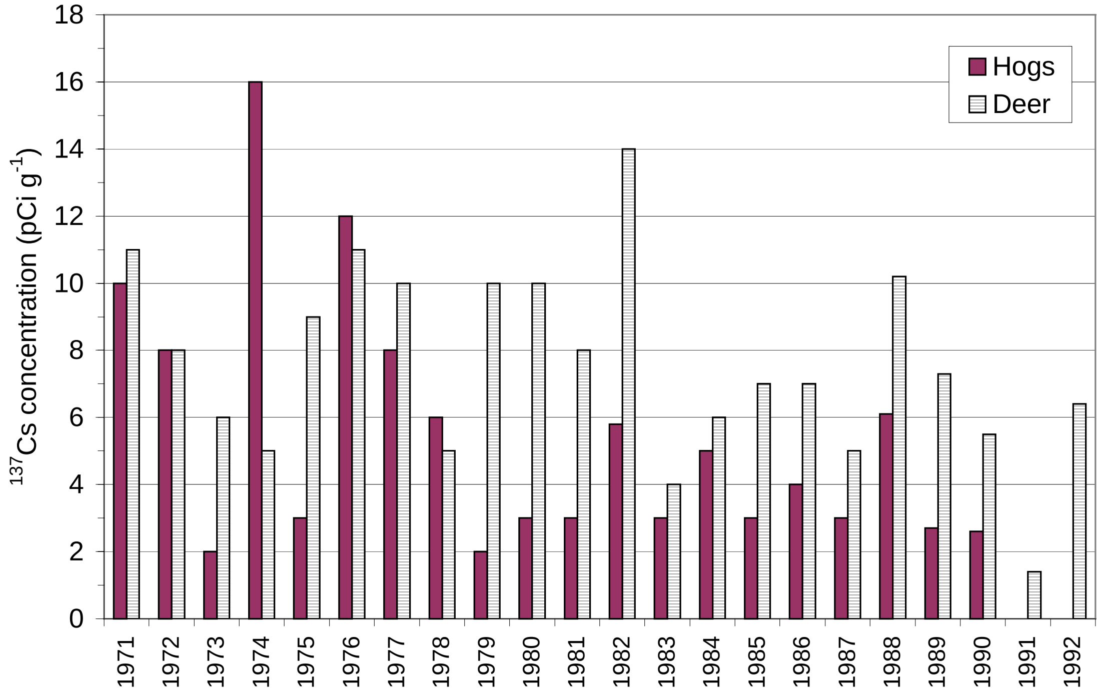

Figure 11-5. Mean ^{137}Cs concentrations reported for feral hogs and deer from 1971 through 1992. Link to tabulated figure data.

Other terrestrial animals have also been routinely trapped, including cats, mice, rats, foxes, raccoons, dogs, bobcats, squirrels, and opossums. Routine trapping locations were not clearly specified, but maximum concentrations were generally found in animals collected from locations in the vicinity of Four Mile Creek, Lower Three Runs, Steel Creek, Burial Grounds, H-Area and F-Area seepage/retention basins, R-Area seepage basins, and K-Area containment/seepage basins.

Figure 11-6 shows mean radionuclide concentrations for rabbits, raccoons, and opossums from 1951 through 1989 (note the logarithmic scale). Nonvolatile beta concentrations are shown from 1951 through 1970, and ^{137}Cs concentrations are shown from 1971 through 1989. Concentrations appear to have decreased significantly since the late 1960s. In general, concentrations measured in these animals are similar and within the ranges of concentrations reported for other fur-bearing animals. However, concentrations for carnivorous animals (raccoons and opossums) appear slightly higher than concentrations for herbivorous animals (rabbits). A special animal trapping program in 1974 concluded that concentrations in 37 trapped animals were within the range of concentrations detected in deer for that year (Ashley and Zeigler 1975). Mean concentrations for such animals were, however, often heavily influenced by significantly elevated concentrations measured in a few individual animals. This is evident in 1956 and for several years during the 1960s and early 1970s. As mentioned previously, the highest concentrations were measured in animals collected from locations in the vicinity of contaminated areas.

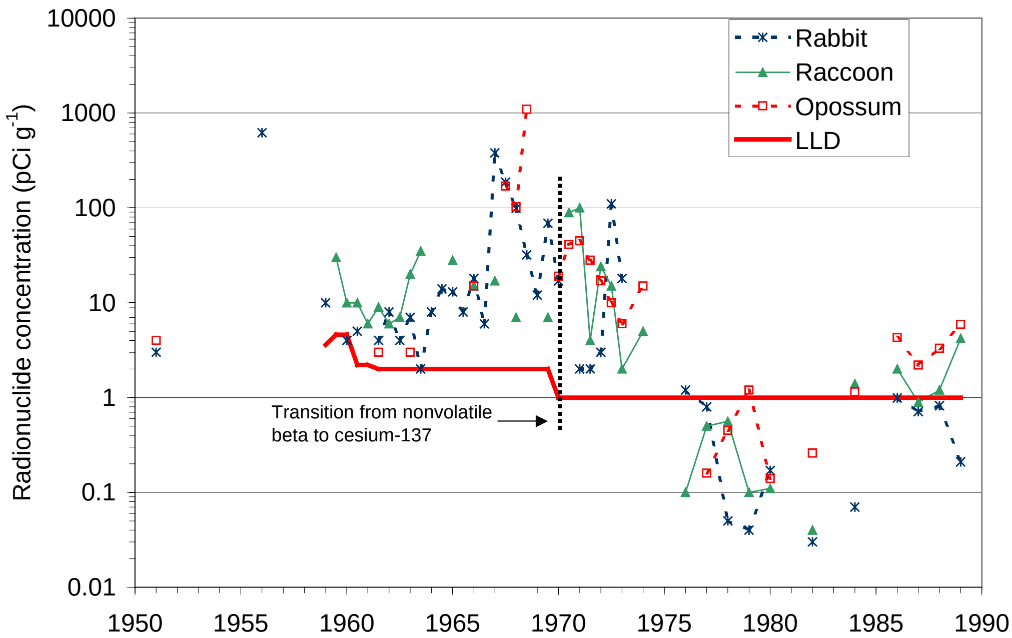

Figure 11-6. Mean radionuclide concentrations reported for rabbits, raccoons, and opossums. Nonvolatile beta (1951 through 1970) and ^{137}Cs (1971 through 1989) concentrations are shown. Link to tabulated figure data.

Significantly elevated concentrations have been measured in animals collected from the vicinity of contaminated areas such as the R-Area seepage basins, which were back-filled in late 1960. Table 11-4 shows mean nonvolatile beta concentrations that were measured in domestic cats and raccoons collected from the vicinity of the R-Area seepage basins and from random onsite locations in 1960. Concentrations in cats are clearly elevated for R-Area locations, and concentrations were also significantly elevated for mice collected from this area. The same trends are not apparent for raccoons. A maximum concentration of 20,400 pCi g^{-1} nonvolatile beta activity was measured in a domestic cat collected from this area during the first half of 1960. Slightly elevated concentrations (significantly lower than in 1960) were also noted for animals collected from locations in the vicinity of the R-Area seepage basins in 1961 after they were back-filled (Du Pont 1962c, 1962d). Though the reports did not clearly specify this, it is presumed that feral cats were occasionally caught during the routine trapping program and referred to as domestic cats.

Table 11-4. Mean Nonvolatile Beta Concentrations[a] (pCi g^{-1}) Measured in Raccoons and Domestic Cats Collected from Locations in the Vicinity of the R-Area Seepage Basins and from Random Onsite Locations in 1960

	January through June		July through December	
Location	Cats	Raccoons	Cats	Raccoons
R-Area	4900	10	4800	8
Random onsite locations	3	10	4	10

[a] Data from Du Pont (1960b and 1961).

Figure 11-7 (note the logarithmic scale) shows the maximum reported radionuclide concentrations documented for trapped terrestrial animals from 1956 through 1989. Nonvolatile beta concentrations are shown from 1956 through 1970, and ^{137}Cs concentrations are shown from 1971 through 1989. Maximum concentrations have been measured in a number of species of animals, including rats, domestic cats, squirrels, opossums, raccoons, rabbits, and bobcats. Almost invariably, the highest concentrations measured in terrestrial animals have been in those animals collected from the vicinity of waste disposal areas.

In 1958, ^{134}Cs and ^{137}Cs were reportedly the radionuclides that comprised the majority of nonvolatile beta activity (75 pCi g^{-1}) in a raccoon (Harvey et al. 1959a). Cesium-137 was reportedly the radionuclide that comprised the majority of activity in muscle tissue for most fur-bearing animals in 1961 (Du Pont 1962d). Raccoons were an exception because ^{65}Zn comprised the majority of activity in muscle tissue. This may be related to the fact that raccoons are aquatic feeders, and ^{65}Zn concentrations were typically higher for aquatic animals than for terrestrial animals. The terrestrial animal trapping program was discontinued in 1990.

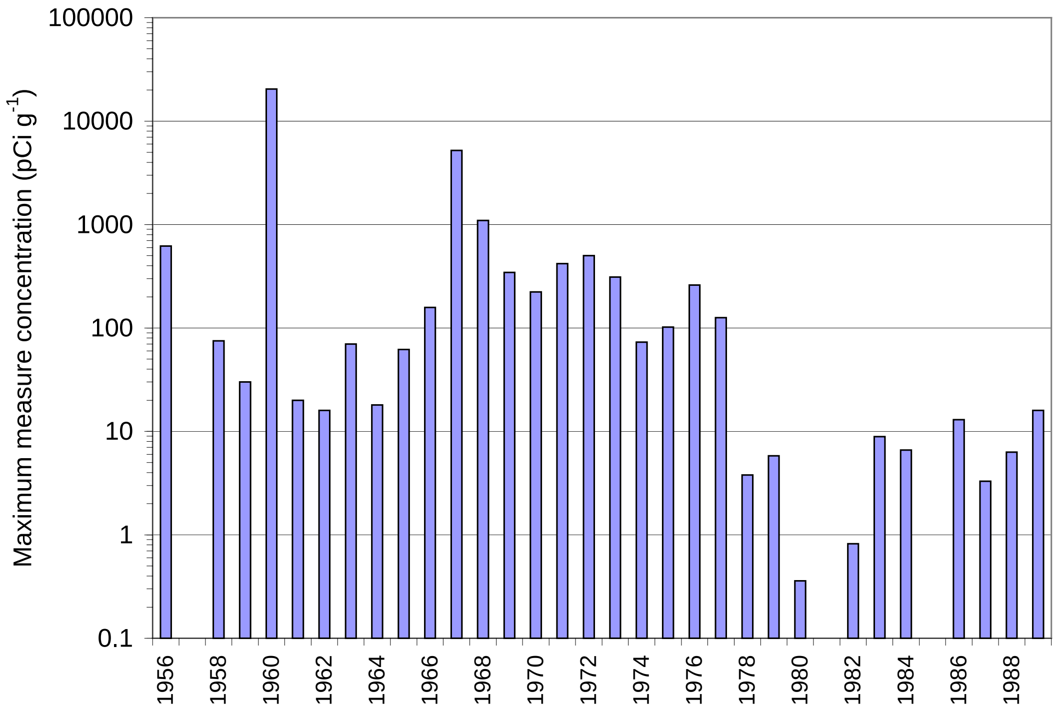

Figure 11-7. Maximum radionuclide concentrations measured in trapped fur-bearing animals. Nonvolatile beta (1956 through 1970) and ^{137}Cs (1971 through 1989) concentrations are shown. Link to tabulated figure data.

RADIONUCLIDE CONCENTRATIONS MEASURED IN WATERFOWL

Waterfowl were also routinely collected by the SRS, primarily from Par Pond. In 1972, the program was expanded to include Steel Creek, and concentrations were reported for waterfowl collected from Pond B beginning in 1976. The types of waterfowl that were collected included carnivorous (animal-eating) species, such as gulls and grebes, omnivorous (plant- and animal-eating) species, such as coots, and herbivorous (plant-eating) species, such as ring-neck, mallard, ruddy, wood, scaup, teal, and bufflehead ducks. We have compiled data reported for ring-neck ducks and coots collected from Par Pond that have been reported in the various annual environmental monitoring reports.

Nonvolatile beta concentrations were sporadically reported before 1962. Maximum concentrations ranged from 15 to 80 pCi g^{-1}. Cesium-137 and ^{65}Zn were the primary radionuclides measured in waterfowl flesh in 1962 (Du Pont 1963d). Elevated ^{65}Zn concentrations were reported from 1962 through 1964 (maximum of 210 pCi g^{-1} in a coot), after which concentrations were reported as below the LLD. In general, ^{137}Cs concentrations appear higher in carnivorous and omnivorous species than in herbivorous species. Brisbin (1982) reported higher ^{137}Cs concentrations for coots than for any of the several species inhabiting Par Pond during studies conducted in 1971 and 1972. Figure 11-8 shows average ^{137}Cs concentrations reported for coots (omnivorous) and ducks (herbivorous) collected from Par Pond from 1962 through 1988. Concentrations are consistently higher for coots. Significantly elevated concentrations were reported for coots in 1963 and 1964, and concentrations appear to have generally decreased during this time period. Concentrations similar to those shown in Figure 11-8 were reported for coots collected from Par Pond in 1971–1972 and 1975–1976 (Brisbin 1982).

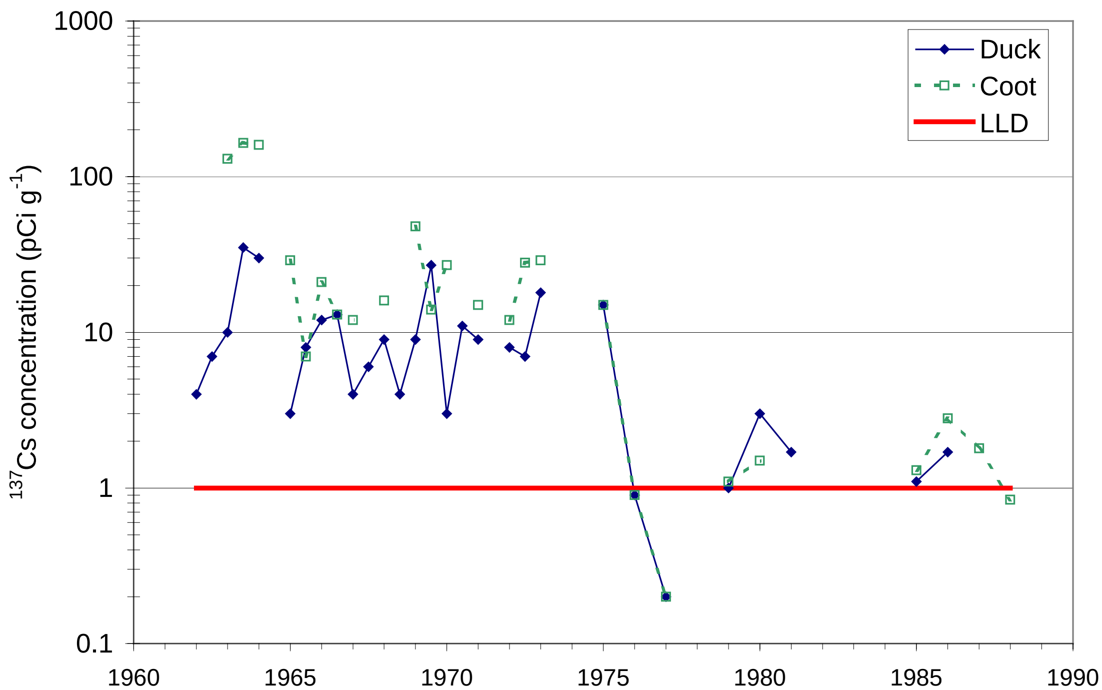

Figure 11-8. Mean ^{137}Cs concentrations measured in ducks and coots collected from Par Pond from 1962 through 1988. Link to tabulated figure data.

There is evidence to suggest that waterfowl residing on more highly contaminated ponds or streams (such as Pond B and Steel Creek) may have accumulated greater burdens of ^{137}Cs than waterfowl residing on Par Pond. Table 11-5 shows concentrations measured in waterfowl collected from Par Pond as well as concentrations measured in waterfowl collected from Pond B and Steel Creek.

Table 11-5. Mean ^{137}Cs Concentrations[a] (pCi g^{-1}) Measured in Ducks and Coots Collected from Par Pond, Steel Creek, and Pond B

	Ducks		Coots	
Year	Par Pond	Steel Creek	Par Pond	Pond B
Jan–June 1972	8	130		
July–Dec 1972	7	49		
1973	18	67		
1974		74		
1975	15	20		
1987			1.8	73.8
1988			0.8	54

[a] Data from Ashley and Zeigler (1974, 1975, 1976, 1978a), Mikol et al. (1988b), and Davis et al. (1989b).

Fendley et al. (1977) reported ^{137}Cs concentrations for wood ducks kept in an enclosure on Steel Creek in 1974. Twenty male and female ducks accumulated an average concentration of 16.6 pCi g^{-1} after 30 days. The time to reach equilibrium was estimated at 17 days, with a biological half-time estimate of 5.6 days.

ELECTRONICALLY COMPILED WILD GAME DATA

The various data summarized in this chapter are electronically compiled in two Microsoft Excel® workbooks. One workbook (Ch11-Figure_data.xls) contains the figures depicted in this chapter (including the addendum to this chapter) as well as the tabulated data that were used to produce the figures. In this workbook, there is a separate worksheet for each figure and one worksheet that contains the tabulated data for all of the figures. The second workbook (Ch11-All_data.xls) contains the data that have been tabulated from various environmental monitoring reports, aperture card printouts, and raw data sheets. The workbook contains several named worksheets that include brief summary of the compiled data.

Table 11-6 summarizes the data that have been electronically compiled for wild game collected as part of the routine environmental monitoring program maintained by the SRS. It also provides the names of the individual spreadsheets in which these data are compiled (including a brief description of the data).

Table 11-6. Description of Data That Have Been Electronically Compiled for Wild Game

Workbook name	Worksheet name	Brief description of data
Ch11-Figure data.xls	Figures 11-1 through 11-9	Each worksheet contains a separate figure depicted in this chapter
	Figures 11A-1 through 11A-4	Each worksheet contains a separate figure depicted in the addendum to this chapter
	Data for figures	This worksheet contains the tabulated data for each of the figures
Ch11-All data.xls	Cs-137 (SRS)	Summary of ^{137}Cs concentrations in deer collected from the Savannah River Plant
	Cs-137 (SCCP)	Summary of ^{137}Cs concentrations in deer collected from the South Carolina Coastal Plain
	Radioiodine	Summary of Iodine concentrations measured in SRP deer
	Sr-89,90	Summary of ^{89,90}Sr concentrations measured in SRP deer
	Pu-238,239	Summary of ^{238,239}Pu concentrations measured in SRP deer
	H-3	Summary of tritium concentrations measured in SRP deer
	Annual report, 1964—1976	Data from Environmental Monitoring at the Savannah River Plant annual reports, 1964—1976
	Annual report, 1971—1983	Data from Environmental Monitoring in the Vicinity of the Savannah River Plant, 1971—1983
	Field-lab compare	Comparison of field and laboratory ^{137}Cs measurements
	% verified	Percent of field measurements verified by laboratory measurements
	U. of Tennessee	Results of analysis of deer muscle samples analyzed by the University of Tennessee
	A.C. 1970–1981	Summary of aperture card printouts for 1970–1981
	Raw field data	Raw field data for 5 years
	Furbearers	Summary of concentrations reported for other wild game (hog, rabbit, opossum, raccoon)
	Waterfowl	Summary of concentrations reported for waterfowl collected from Par Pond

USEFULNESS AND LIMITATIONS OF THE WILD GAME DATA FOR DOSE RECONSTRUCTION

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

With few exceptions, ^{137}Cs, ^{89,90}Sr, and ^{131}I concentrations reported for deer and other wild game in the monitoring reports have been consistent with concentrations provided in aperture card printouts (1970–1981) and raw data sheets (1965, 1966, 1982, 1984, and 1985). Some slight differences were apparent, but this appears to be the result of incomplete original data for some years (e.g., 1965 and 1966) and occasionally illegible aperture card printouts. In addition, it was not always clear how reported average concentrations were calculated with respect to "background" and "less than" concentrations. In general, though, the aperture card printouts and raw data sheets provided consistent verification of the values reported in the monitoring reports.

Comparisons of field and lab data have shown that field estimates using a portable NaI(Tl) detector provided accurate measurements. Additionally, measurements made by the SRS are generally consistent with measurements made by the University of Tennessee, although information enabling a comparison of measurements for individual deer is unavailable. Some differences were evident, but this appears to have resulted from analysis by the University of Tennessee of only a subset of the total number of samples analyzed by the SRS. There is also no evident disparity between concentrations measured in South Carolina Coastal Plain (SCCP) deer by the University of Georgia from 1968 through 1983 and concentrations measured in SCCP deer by the SRS from 1985 through 1991.

The reported ^{137}Cs concentrations provide a good estimate of concentrations in the SRS deer population because large numbers of deer have been monitored annually. However, an arithmetic average is likely inappropriate for describing the central tendency of ^{137}Cs concentrations in the deer (and other wild game) population because concentrations appear log-normally distributed. Geometric means and geometric standard deviations or medians and percentiles may be more appropriate descriptors of the data. However, arithmetic mean concentrations likely error on the conservative side (i.e., provide an overestimate) of the central tendency for cesium concentrations in deer because the distributions are generally skewed to the right (e.g., log-normal). Examination of entire data sets (i.e., values for individual deer) has only been completed for 1982, 1984, and 1985 at this time; entire data sets have not been located for other years.

The maximum measured ^{137}Cs concentrations from 1965 through 1991 may be most useful for estimating maximum potential exposure to hunters or their families who consumed the deer or hog meat. The maximum ^{137}Cs concentrations measured in SRS deer (204 pCi g^{-1}) are not significantly elevated above concentrations measured at other locations in the southeastern U.S. (153 pCi g^{-1}), though this comparison is of limited use because different soil characteristics can result in different rates of ^{137}Cs uptake.

There is also some question about the appropriateness of using SCCP deer as background indicators because the soil characteristics for the SCCP likely result in greater uptake for these deer than for SRS deer. It is also difficult to establish with certainty the number of deer that may have been impacted by Site operations. To completely assess this exposure pathway, it may be necessary to establish an acceptable method for quantifying appropriate background concentrations as well as the number of deer that may have accumulated excess concentrations of ^{137}Cs resulting from SRS operations.

Furthermore, very limited data are available for wild game and only nonvolatile beta concentrations were reported before 1965. Public exposure to deer from the SRS would likely have been minimal before 1965, when public hunts on the SRS were initiated. However, since the precise range and mobility of the deer residing on the SRS is not known, it is certainly possible that some animals spending the majority of time on the SRS migrated offsite and were harvested by hunters. To assess this exposure pathway, it would be necessary to estimate ^{137}Cs concentrations based on a very small number of measured nonvolatile beta concentrations.

Completely evaluating exposure pathways involving wild game from the SRS may also require acquiring additional data. Major hunting areas and waterfowl migration patterns are examples of additional information that might assist with future phases of the SRS Dose Reconstruction Project. Because the range and eating habits of wild game residing at the SRS are not known with any certainty, though, it will be quite difficult to use the wild game data for definitive source term verification or model validation.

In summary, the information provided in the documents that have been reviewed is potentially quite useful for quantifying radionuclide concentrations, particularly ^{137}Cs, in deer and other wild game at the SRS. In general, the mean concentrations measured in SRS deer have been lower than mean concentrations measured in deer from locations thought to be representative of background concentrations. In addition, with a few exceptions, elevated radioiodine concentrations measured in deer thyroids have consistently corresponded to periods of weapons testing. It can then be concluded that the majority of deer from the SRS reflect radionuclide concentrations that have resulted from atmospheric weapons tests.

However, there is also evidence to suggest that a few individual animals have accumulated SRS-derived radionuclides. This is reflected by the consistently higher maximum ^{137}Cs concentrations measured in SRS deer relative to SCCP deer since 1968. It is also reflected by the significantly elevated radionuclide concentrations reported for other fur-bearing animals collected from areas of known contamination. Elevated ^{129}I concentrations have also been measured in individual deer for years during which weapons tests were not conducted (e.g., 1984, 1989, and 1991). The wild game data are likely most useful for establishing the maximum concentrations of radionuclides, ^{137}Cs in particular, to which hunters may have been exposed, but it will be necessary to establish an acceptable methodology for estimating appropriate background concentrations.

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ADDENDUM 11A

FREQUENCY DISTRIBUTIONS FOR FIELD ANALYSES OF DEER

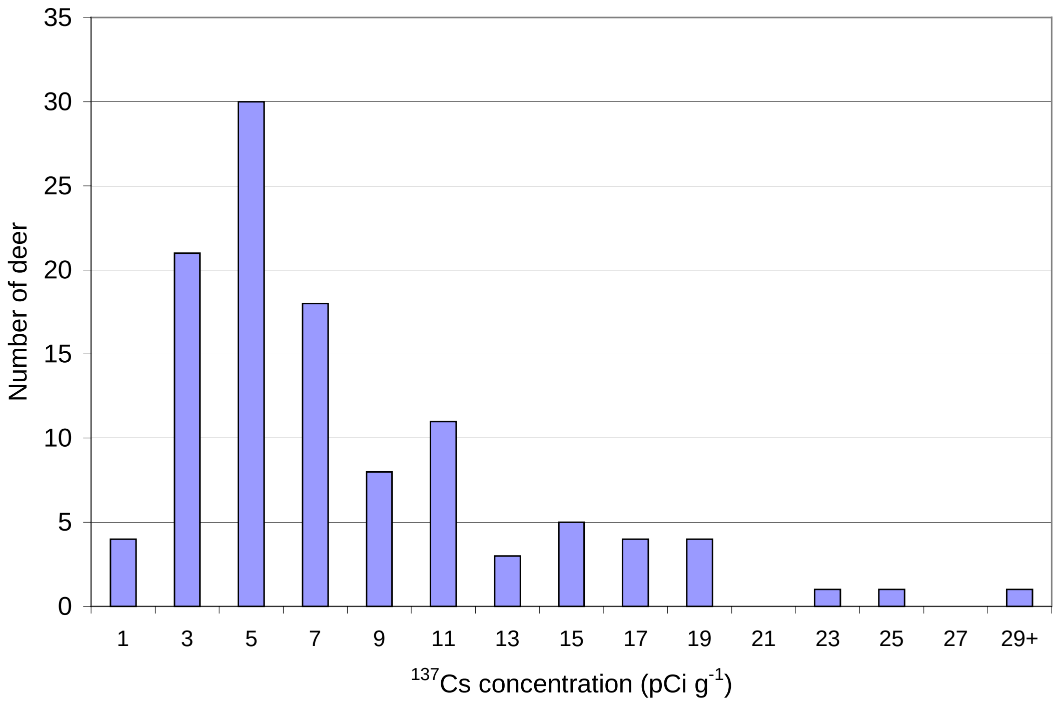

Figure 11A-1. Frequency distribution for 111 field analyses of deer collected from the SRS in 1965 (geometric mean = 5.7, geometric standard deviation = 2.1). Link to tabulated figure data.

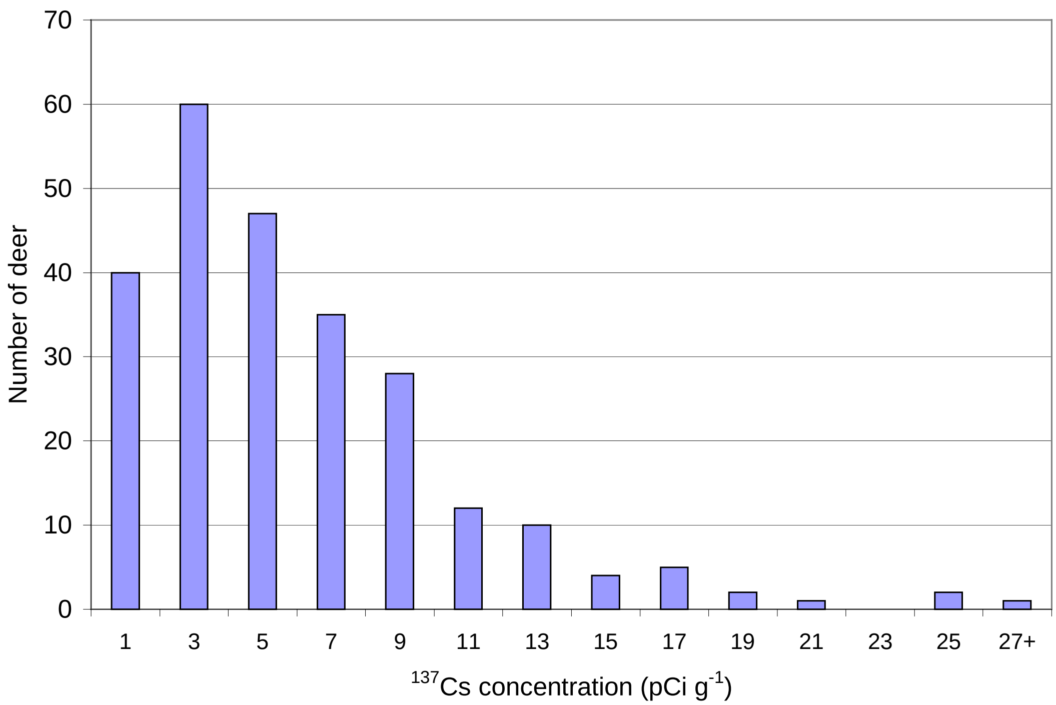

Figure 11A-2. Frequency distribution for 247 field analyses of deer collected from the SRS in 1966 (geometric mean = 3.7, geometric standard deviation = 2.4). Link to tabulated figure data.

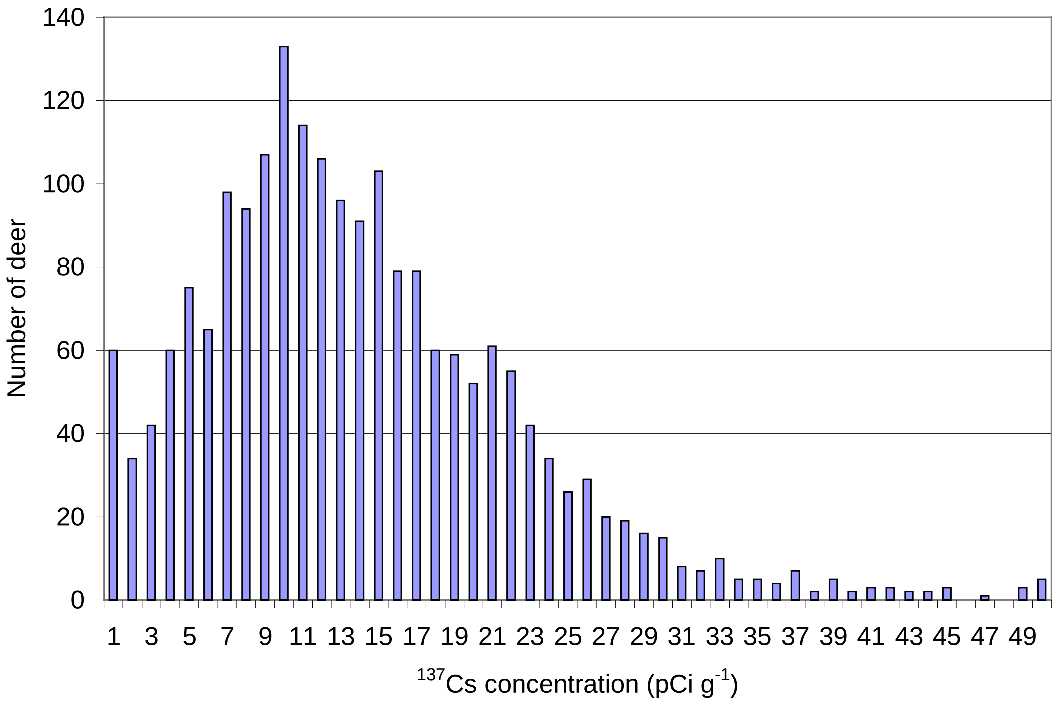

Figure 11A-3. Frequency distribution for 2001 field analyses of deer collected from the SRS in 1982 (geometric mean = 11.3, geometric standard deviation = 2.1). Link to tabulated figure data.

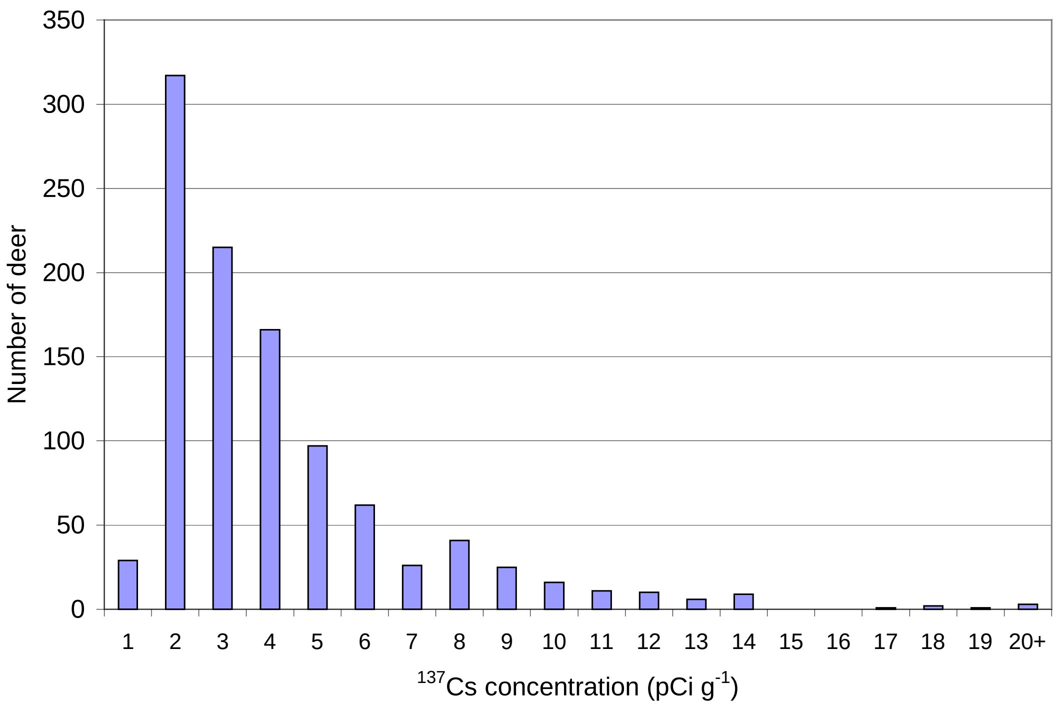

Figure 11A-4. Frequency distribution for 1037 field analyses of deer collected from the SRS in 1984 (geometric mean = 3.5, geometric standard deviation = 1.8). Link to tabulated figure data.

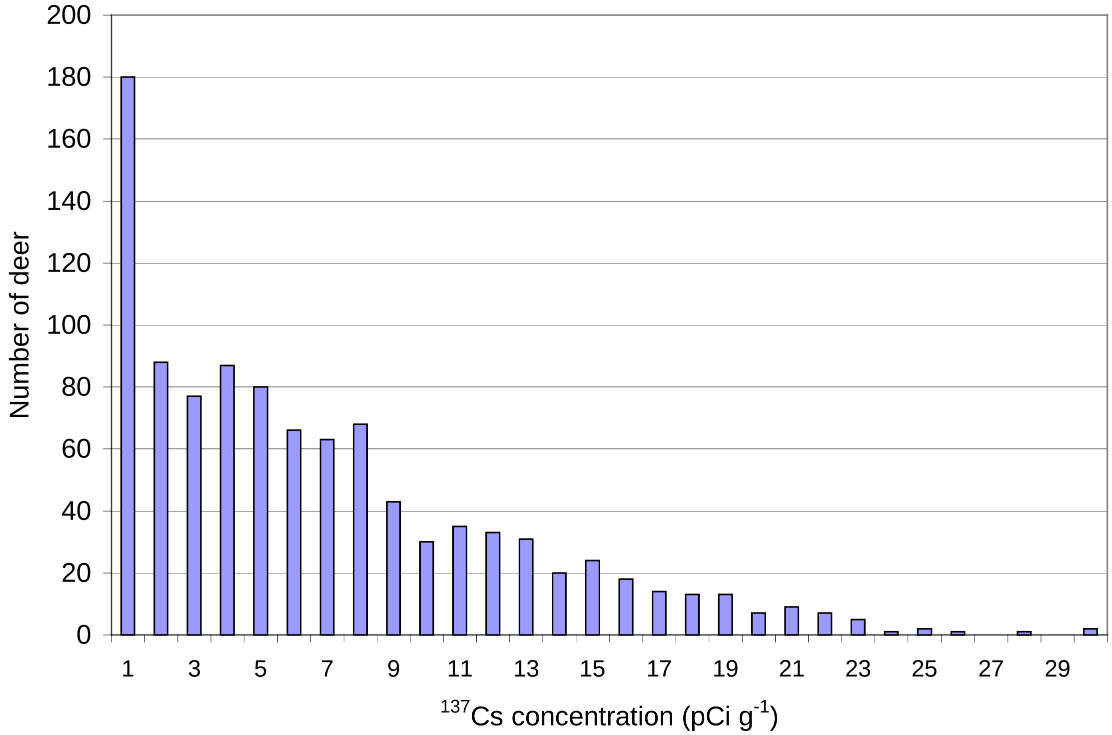

Figure 11A-5. Frequency distribution for 1018 field analyses of deer collected from the SRS in 1985 (geometric mean = 4.7, geometric standard deviation = 2.6). Link to tabulated figure data.