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An Overview of Cesium-137 Contamination in a Southeastern Swamp Environment

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Abstract

In the early 1960s, an area of privately owned swamp adjacent to the Savannah River Site (SRS) was contaminated by site operations. Studies conducted in 1974 estimated that approximately 925 GBq of ¹³⁷Cs and 37 GBq of ⁶⁰Co were deposited in the swamp. Subsequently, a series of surveys was initiated to characterize the contaminated environment. These surveys—composed of 52 monitoring locations—allow for continued monitoring at a consistent set of locations. Initial survey results indicated maximum ¹³⁷Cs concentrations of 19.5 Bq g⁻¹ in soil and 8.7 Bq g⁻¹ in vegetation. By the 2004–2005 surveys, maximum concentrations had declined to 1–2 Bq g⁻¹ in soil and 0.4 Bq g⁻¹ in vegetation.

Key words: monitoring, environmental; contamination, environmental; surveys; dose assessment

Background

The Creek Plantation is a privately owned land area located in South Carolina along the Savannah River on the southeastern border of the Savannah River Site (SRS). The land largely is undeveloped and agricultural; the primary uses are equestrian-related operations. A portion of Creek Plantation along the Savannah River is a low-lying swamp known as the Savannah River Swamp, which is uninhabited and not easily accessible. This swamp is used as an undeveloped wildlife habitat, and for occasional private hunts.

At SRS, two production reactors (P and L Reactors) discharged effluents to the Savannah River via Steel Creek prior to their shutdown in 1988. Approximately 10.35 TBq of ¹³⁷Cs were discharged down Steel Creek from 1954–1974. A majority of these discharges occurred in the early 1960s from P Reactor. An area of the Savannah River Swamp on Creek Plantation—specifically, the area between Steel Creek Landing and Little Hell Landing—was contaminated by these discharges (Fig. 1). Water from Steel Creek flowed along the lowlands comprising the swamp when river levels were high, resulting in deposition of radioactive material. This water eventually discharged to the Savannah River at Little Hell Landing, leading to the contamination of a portion of the Savannah River Swamp. This diversion occurred when the Savannah River stage exceeded 27.5 m above mean sea level (approximately 375.3 m³ s⁻¹). For the period 1954–1974, this threshold was exceeded approximately 21.5% of the time; this is consistent with the long-term (1954–2005) rate of 20.8%.

This potential source of contamination initially was identified in 1959. Subsequently, land- and air-based surveys of the area were conducted intermittently through 1969. These surveys indicated the presence of small amounts of fission products, although no elevated exposure rates were observed. More rigorous aerial surveys of the area in 1971 and 1972 showed noticeably elevated exposure rates of $1.24 \times 10^{-8} \text{ C kg}^{-1} \text{ h}^{-1}$ (3.7 mSv y^{-1}) above background. These results were confirmed by land surveys conducted during 1971–1974 to more completely define the area of contamination and to identify and quantify the contaminants. This was accomplished by (1) measurements using field scintillator detectors, (2) the placement of thermoluminescent dosimeters (TLDs), and (3) the collection of soil and vegetation samples. In 1974, it was estimated that approximately 925 GBq of ^{137}Cs and 37 GBq of ^{60}Co had been deposited in the swamp (Carlton, 1994). The impacted area was determined to be approximately 6 km in length, with a width varying between 300 and 1,000 m.

Development of Periodic Surveys

As part of the investigation conducted in the early 1970s, a series of 10 sampling trails ranging from 70 to 1,000 m in length was established through the swamp (Fig. 2). Fifty-two fixed monitoring locations were designated on the trails to allow for continued monitoring at a consistent set of locations. Monitoring in the swamp using these sites has continued for the past 30 years, although information needs and survey objectives have changed over time.

Initial surveys were conducted in 1971–1974 to define the area of contamination and to identify and quantify the contaminants. In 1974, an additional detailed survey was conducted of the most contaminated area—an approximately 0.17-km^2 area bordering SRS. Approximately 19,000 exposure rate measurements at a height of 1 m were conducted over a grid with 30-m spacing during this survey. These measurements were supplemented with TLDs and shallow core samples with a maximum depth of 19 cm. Survey meter results indicated that most locations were less than $1.5 \times 10^{-8} \text{ C kg}^{-1}$, with a maximum observed level of $3.1 \times 10^{-8} \text{ C kg}^{-1}$ (10.5 mSv y^{-1}); TLD readings showed a maximum of 5.8 mSv y^{-1} . Soil ^{137}Cs concentrations indicated that more than 70% of the activity was contained in the top 6 cm of the soil column; the highest observed concentration was 19.5 kBq kg^{-1} .

All 52 locations were resampled in 1975, while a subset of 30 sites (three sites per sampling trail) was sampled in 1976 and 1977. During 1978–1981, the surveys were limited to exposure rate determination via TLDs, with no media sampling; this marked the establishment of limited (cursory) annual surveys, supplemented by a much more detailed (comprehensive) survey every fifth year. In general, this philosophy has been followed to the present, although the specific components of cursory and comprehensive surveys have been modified. Table 1 shows a history of annual surveys conducted in the swamp.

Recent Survey Results

The 2005 survey, conducted in November, was identified as a comprehensive survey, requiring extensive media sampling and analysis—as well as exposure rate measurement. Approximately 30 soil samples and 30 vegetation samples could not be obtained because of high water levels and a lack of vegetation. At five locations (one on each of five trails), shallow core samples were collected to evaluate vertical distribution. Four samples in 7.6-cm increments were collected to a total depth of 30.5 cm at these sites. The scheduled exposure rate determination via TLDs could not be completed because of high water levels during the measurement period.

As anticipated on the basis of source term information and historical survey results, ^{137}Cs was the primary manmade gamma-emitting radionuclide detected. It was detected in all soil samples, and concentrations varied from 0.005 Bq g^{-1} to approximately 2.4 Bq g^{-1} . This concentration range is consistent with recently observed survey results. The location of maximum concentration (2.4 Bq g) had a concentration of 7.2 Bq g in the 1974 survey. However the location of maximum observed concentration (19.5 Bq g^{-1}) from the initial (1974) survey was not sampled in 2005 because of high water, but when last sampled in 2000, the measured soil concentration was 11 Bq g^{-1} . Generally, a similar trend—in which the decrease in concentration was greater than simple physical decay—was observed.

Higher levels of ^{137}Cs in soil usually were observed in the shallower samples. As noted in previous surveys, this vertical distribution profile in soil is not as pronounced as it generally is in undisturbed areas. Likewise, relative to the initial (1974) survey, the vertical profile was not as pronounced. In 1974, approximately 70% of the activity was in the top 6 cm, while in 2005 about 34% of the activity was in the top 7.6 cm. Approximately 66% of the activity was located in the top 15.2 cm.

Dose Assessment

There are no permanent residents of the swamp, nor are there likely to be any because of its inhospitable conditions. Therefore, the swamp is not considered a realistic location for the hypothetical maximally exposed individual, which is used to demonstrate compliance with the DOE 1-mSv y^{-1} dose standard.

Only the recreational-hunter and fisherman scenarios are considered reasonable and realistic. The adolescent trespasser scenario was considered but not evaluated because: (1) institutional controls (postings) are in place to provide warning and discourage illegal entry, (2) illegal activity is often excluded from dose compliance evaluations, and (3) trespasser exposure parameters are bounded by the other scenarios.

The hunter and fisherman exposure pathways include: (1) external exposure to gamma rays, (2) fish or deer consumption, (3) inhalation of resuspended particles, and (4) incidental ingestion of soil. Because actual site-specific information concerning hunting and fishing usage times on Creek Plantation was not available, exposure parameters were estimated. Table 2 provides the parameter estimates, which are considered reasonable and maximum for these pathways.

These two scenarios were evaluated using 2005 data. The recreational-fisherman scenario yielded a maximum dose of 0.0052 mSv—approximately equally split between exposure to contaminants (external exposure, ingestion, and inhalation) at the fishing location (0.0028 mSv) and fish consumption (0.0024 mSv). The recreational-hunter scenario yielded a maximum dose of 0.083 mSv, which was dominated by the deer consumption pathway (0.054 mSv). Exposure to contaminants (external exposure, ingestion, and inhalation) accounted for 0.024 mSv. This pathway resulted in a significantly higher dose for the hunting scenario than the fishing scenario.

Only the survey data (exposure rates and/or soil concentrations) were documented and trended during early surveys; no corresponding dose assessments were performed. However, recent dose assessments show a significant decrease—100 to 1,000 times lower—from the single-pathway, external-exposure-only estimates (3.7–10.5 mSv) produced during the early surveys.

Conclusions

A systematic surveillance program was established to monitor a large area of swampland contaminated during the early years of SRS operations. This area has continued to be extensively monitored since 1974. Significant reductions in the observed contaminant concentration and resultant doses have been observed, often decreasing at rates greater than those based on physical decay only. Using the systematic and extensive dataset obtained from these surveys, a thorough assessment of the “ecological half-life” of ¹³⁷Cs in a swamp environment is currently being performed at SRS.

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References

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TABLE 1
Historical Survey Summary

YEAR	SURVEY TYPE^a	MEDIA
1974	Comprehensive	Soil, Vegetation, Exposure
1975	Comprehensive	Soil, Vegetation, Exposure
1976	Comprehensive	Soil, Vegetation, Exposure
1977	Comprehensive	Soil, Vegetation, Exposure
1978	Cursory	Exposure
1979	Cursory	Exposure
1980	Cursory	Exposure
1981	Cursory	Exposure
1982	Comprehensive	Soil, Vegetation, Exposure
1983	Cursory	Exposure
1984	Cursory	Exposure
1985	Comprehensive	Soil, Vegetation, Exposure
1986	Cursory	Soil, Vegetation, Exposure
1987	Cursory	Soil, Vegetation, Exposure
1988	Cursory	Soil, Vegetation, Exposure
1989	Cursory	Soil, Vegetation, Exposure
1990	Comprehensive	Soil, Vegetation, Exposure
1991	Cursory	Soil, Vegetation, Exposure
1992	Cursory ^b	N/A
1993	Cursory	Soil, Vegetation, Exposure
1994	Cursory	Soil, Vegetation
1995	Not Conducted	N/A
1996	Comprehensive	Soil, Vegetation
1997	Not Conducted	N/A
1998	Not Conducted	N/A
1999	Not Conducted	N/A
2000	Comprehensive	Soil, Vegetation, Exposure
2001	Cursory	Soil, Vegetation, Exposure
2002	Cursory	Soil, Vegetation, Exposure
2003	Not Conducted	N/A
2004	Cursory	Soil, Vegetation, Exposure ^c

NOTES:

^aThe meaning of “comprehensive” and “cursory” surveys has changed with time. Generally, comprehensive surveys involve extensive sampling with detailed analyses, while cursory surveys involve a more limited level of sampling and analysis.

^bThe survey was initiated but not completed because of high water.

^cThe exposure rate determination was not completed because of high water.

**Table 2
Parameters for Dose Evaluation**

PARAMETER	VALUE	DISCUSSION
Fisherman Location	Near the Savannah River bank at the Steel Creek Landing.	
Fish Consumption	19 kg y ⁻¹	Assumed individual fish consumption for southeastern U.S.
Fishing Duration	250 h	68 kg whole fish y ⁻¹ x 3.7 h kg ⁻¹ = 250 h y ⁻¹ 68 kg whole fish = 19 kg edible fish 3.7 h kg ⁻¹ = average catch rate for fish in Savannah River (from Creel Surveys)
Fish Concentration	Average concentrations of radionuclides measured in the worst-case species of fish from the Steel Creek mouth	
Hunt Location	Survey point that has the maximum exposure rate at 1 m above the ground, or at the point of maximum average soil concentration— whichever leads to the highest annual dose	
Deer Consumption	81 kg	Assumed individual meat consumption for southeastern U.S.
Hunting Duration	120 h	15 d y ⁻¹ x 8 h d ⁻¹ = 120 h Based on 15 days (a full 2-week vacation); part of the Creek Plantation operates as a vacation-type hunt club for the plantation's owner, family, and acquaintances
Deer Concentration	Average concentration of ¹³⁷ Cs measured in deer harvested on site during the year	
Inhalation Rate	0.96 m ³ h ⁻¹	RESRAD Default
Soil Ingestion Rate	0.1 g d ⁻¹	RESRAD Default

Figure 1
Transport of Activity to Steel Creek Swamp

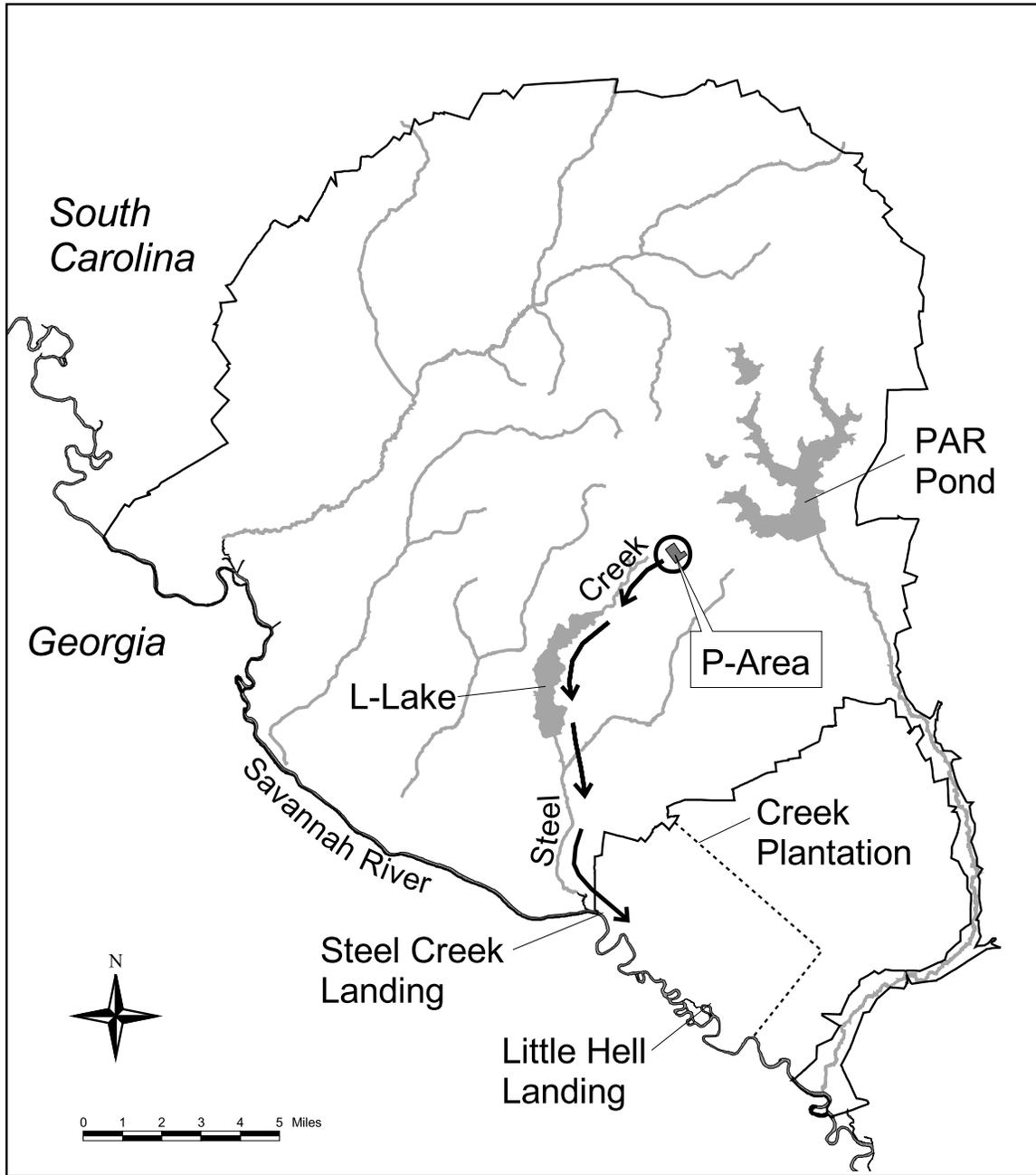


Figure 2
Steel Creek Swamp Sampling Trails

