

PRE-OPERATIONAL RADIO-ENVIRONMENTAL STUDIES OF PLANT VOGTLE (U)

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Savannah River Site
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OF PLANT VOGTLE**

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May 1, 1989

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EXECUTIVE SUMMARY

This baseline study evaluates radioactivity in the environment near Plant Vogtle before initial reactor startup in 1987. These data will distinguish between any future radio-environmental effects from SRS and Plant Vogtle. Alpha, beta, and gamma-spectrometric methods analyzed river, stream, sediment, and soil samples. The study detected manmade radionuclides ^3H , ^{60}Co , ^{134}Cs , ^{137}Cs , ^{239}Pu , ^{240}Pu , and ^{241}Pu . However, all concentration levels are extremely low and are consistent with levels expected from fallout and from SRS operations in its early years. The measurements begun in this study continue to be used to monitor Vogtle post-startup effluents.

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PRE-OPERATIONAL RADIO-ENVIRONMENTAL STUDIES OF PLANT VOGTLE

I. INTRODUCTION

A. Objective

This study develops baseline radioactivity data in the SRS/Vogtle environment to allow recognition of any future contamination and its source. The location of the Plant Vogtle Power Reactors, adjacent to the Savannah River Plant, lead to this pre-operational assessment. Reliable and rapid identification of SRS or Vogtle sources will facilitate steps to address any associated problems.

B. History

The Savannah River Plant began operations in the early 1950s. SRS Health Protection Department (HP) and the Savannah River Laboratory Environmental Technology Division (ETD) have conducted continuing radio-environmental studies (ref 1). Over the years, improved detection techniques have steered better controls over SRS effluents and emissions. Today, overall concentrations of manmade isotopes are quite low in the Savannah River and soils on the SRS site. The largest levels (low compared to regulatory guides) are in streams and flood plains that drain from the various nuclear process areas to the Savannah River. Most radioactive releases from SRS occurred during its early history.

Georgia Power Company began planning for Plant Vogtle in 1974, and construction began in 1977. The plant has two 1160 MWe pressurized water reactors developed by Westinghouse, along with cooling towers, turbines, and other auxiliary equipment. Unit 1 had initial startup on March 1, 1987 and reached 100% power on May 31. The utility scheduled startup of Unit 2 in 1989.

C. Present Study

The present study measures the low-level radiation in the SRS/Vogtle vicinity before startup of Vogtle Unit 1 in March 1987. It places emphasis on manmade radionuclides in nearby streams and soils.

Stream samples from the Savannah River and from mouths of its inlet streams contain activity from effluent discharges, fallout, and surface deposition carried by water runoff. The selected inlet streams primarily characterize effluent sources from the SRS site. Plant Vogtle effluents reach the Savannah River more directly, through an underwater discharge pipe and an open concrete channel. Analyses of soil samples, collected within seven miles of Plant Vogtle, characterize backgrounds at suitable locations for later reference. Any future inadvertent release can be traced to its source.

Analyses of stream, sediment, and soil samples show the presence of transuranics, tritium, and gamma-emitting radionuclides. The analyses emphasized manmade ^3H , ^{60}Co , ^{134}Cs , ^{137}Cs , ^{239}Pu , and ^{240}Pu . They are also sensitive to natural radioactivities. Environmental concentrations of all of these nuclides are very low relative to concentration guides (ref 1).

The analyses used ultra-sensitive methods, including sample concentration and low-level counting techniques. In particular, ion exchange resin concentrators collected some of the stream samples for a two-week period. The Underground Counting Facility counted many of the samples overnight or longer. Low-background alpha, beta, or gamma detectors measured radionuclides in every sample.

II. STUDIES OF RADIOACTIVITY IN PLANT VOGTLE ENVIRONMENT

A. Overview

A.1. Savannah River and Inlet Streams

Studies focusing on the Plant Vogtle stream environment commenced in December, 1986. The present study emphasizes samples collected up to April 9, 1987. Although low-power startup tests had commenced on March 1, the results for the final samples are consistent with the earlier ones.

Figure 1 gives collection locations for both aqueous and sediment samples. Observed levels of manmade ^{60}Co and ^{137}Cs are due to fallout and SRS sources. The levels continue to be very low and are consistent with past SRS HP studies (ref 1). The observed tritium and plutonium levels are also very low and are consistent with HP studies. Radioactivity levels agreed for samples just above and below the Vogtle outfall, indicating that Plant Vogtle did not discharge radioactive effluents to the river through this period.

A.2. Soils

Soil samples, all collected by the end of January 1987, characterize areas near Plant Vogtle. Uncultivated soils exhibit trace quantities of manmade radioactivity deposited from the atmosphere. In flood plains, the soils may also contain activities sorbed on particles washed into the area from upstream locations. The soils also contain long-lived naturally occurring radionuclides and their daughters.

A sampling program collected soils at thirty locations within seven miles of Plant Vogtle on both sides of the Savannah River (Figure 1). ^{137}Cs is the only manmade activity detected at all locations; overall its levels are consistent with world-wide fallout. However, near Four Mile Creek, ^{137}Cs is noticeably higher, and measurements of a single sample from near its delta detected ^{60}Co . These findings are consistent with previous surveys; the radioactivity is due to releases from SRS in its early years of operation. Alpha and mass spectrometry on four samples show Pu levels and isotopics that are characteristic of fallout from atmospheric nuclear weapons tests conducted many years ago.

B. Sampling Techniques

B.1 Aqueous Samples

Water. The primary analyses on water samples were for tritium. These used surface waters collected in 250 ml bottles. SRL individually mixed two 3 ml aliquots from each sample with 20 ml of Ready-Solv[®] in a liquid scintillation vial¹. Addition of a 250 μl tritium standard (nominally 17,000 pCi/ml) to one of the two vials calibrated the liquid scintillation counting by the standard addition method.

Concentrators. Concentrator resins in porous nylon bags collected radionuclides. Measurements at different concentrator resin bag locations required normalization for reliable interpretation of results. Integrated flow samplers, using potassium-cobalti-ferrocyanide (KCFC), gave more precise normalization values. However, electrical requirements for the sampler pumps limited their application. A combined approach, using both types of samplers, yielded quantitative results for all locations.

¹® Trademark of Beckman Instruments, Inc.

Each concentrator bag contained weighed amounts (~25 g) of ion exchange resin and concentrator materials. The resin collects a variety of radionuclides of which ^{60}Co and ^{137}Cs are most apparent in this work. The concentrator collects a variety of radionuclides also, but specifically enhances collection of ^{137}Cs . (Post-startup studies demonstrate small releases of ^{51}Cr , ^{54}Mn , ^{57}Co , ^{58}Co , ^{59}Fe , ^{95}Nb , and ^{95}Zr by Plant Vogtle). The typical collection period for these samples was two weeks. Drying and ashing these samples at SRL reduced their volume for more efficient gamma-ray spectrometry.

The KCFC sampler also collects ^{60}Co and ^{137}Cs samples (refs 2,3) during two-week intervals comparable to those of the concentrator resin bags. This work uses KCFC sampler data from Shell Bluff and Highway 301 Bridge. A prefilter removes any particulates as the sampler pumps about 500 l of water over a two-week period. Compressing both resin and filter to small volumes improved gamma counting efficiency.

B.2 Sediment Samples

A newly developed scoop retrieves sediment samples. This scoop is a ~6" diam x ~12" long metal can, fashioned from the bottom of a compressed gas cylinder. Two guide legs on either side orient the can so a cutting edge on the rim will plow a sample into the scoop when pulled along the bottom of a stream. After pulling the scoop along the bottom with a rope, the collected sample is pulled to the surface.

HPGe detectors collected gamma spectra for scoop samples in 1-liter Marinelli beakers. Counting these samples before drying effected a more consistent calibration geometry. (The final spectral analyses utilize the dried weights). Typical dried sample weights were about 1 Kg.

B.3. Soil Samples

A core sampler took ten soil cores, each about 7 cm deep and 10 cm diameter, along a straight line at 15 cm intervals at each sampling site. Soil cores from each site were composited, dried, and weighed. A 2-liter Marinelli beaker held about half of each blended sample for HPGe gamma-ray spectrometry. Ratioing the soil weight in the beaker to total dry weight gave the fraction counted for areal (mCi/km^2) data.

C. Counting Methods

C.1. Facilities

SRL Environmental Technology Division used its various counting facilities for this work. The Underground Counting Facility (UGF) usually counted the stream and sediment samples, although the Ultra-Low-Level Counting Facility (ULLCF) counted a few. An underwater NaI detector assisted operations in the field. The TRAC mobile laboratory counted the dried soil samples, and a portable HPGe detector made in-situ measurements at some sites. The ETD mass spectrometer measured Pu isotopics and SRS HP Division counted the sediment and soil samples for Pu.

The Underground Counting Facility located at Building 735-A incorporates a number of advantages for low-level counting (ref 4). In particular, cosmic-ray backgrounds are lower by an order of magnitude. Efficient filtration reduces airborne particulates to Class 10,000 Clean Room Standards. Low-level lead and steel shield the detectors. Nitrogen displaces radon within the sample counting regions. Very stable electronics and constant background allow counting the stream and sediment samples overnight or longer.

The Ultra-Low-Level Counting Facility also located at 735-A is a ground-level counting facility. The facility is shielded by 12"-thick walls of pre-WWII steel. It also utilizes HEPA filtered air to achieve low backgrounds (ref 5,6). The ULLCF routinely gamma-counted the KCFC samples, though the UGF recounted several as a consistency check. Also, Pu separated from concentrator samples were alpha-counted here.

The TRAC mobile laboratory also accommodates sensitive low-level counting through its clean environment and special shielding (ref 7). This facility gamma-counted soil samples by HPGe spectrometry.

In-Situ counting facilities include a pontoon boat for the underwater NaI detector and a van/trailer for a portable HPGe detector. Typically, ~1 hour in-situ counts provide a preliminary site examination. By contrast, samples returned to the laboratory facilities yielded the detailed final results.

The mass spectrometry facility is also in 735-A. A clean room houses the three-stage thermal-ionization mass spectrometer.

HP Facilities are located at 735-A (ref 1). HP personnel analyzed plutonium in sediment and soil samples.

C.2. Liquid Scintillation/Tritium

A TRI-CARB 2050 CA/LL Liquid Scintillation System located in the ground-level control room of the UGF counted tritium. Each of the triplicate counts lasted 10 minutes, and the system automatically corrects all results for quenching.

The liquid scintillation system has a low-background design. It has ~4 cpm background in the tritium window and an efficiency of ~35%. Counting samples for 30 min yielded a detection limit of ~2 pCi/ml for tritium in this work.

C.3. HPGe Spectrometry/Gamma Emitting Nuclides

Each of the three HPGe detectors has a special cryostat design that allows shielding the detector from molecular sieve in the dewar. (The LN₂-cooled sieves maintain a vacuum in the HPGe cryostat, but their content of naturally occurring radionuclides contributes noticeable backgrounds if unshielded).

The UGF utilizes two of these detectors. Low-level lead encloses both detectors, and the liquid nitrogen evaporated from the dewars purges radon from the sample cavities. One of the detectors has 25% efficiency (relative to 3" x 3" NaI for 25 cm source-to-detector detection of 1332 keV gamma of ⁶⁰Co). The other has 20% efficiency, and its fabrication from specially selected materials give it a very low background. The TRAC HPGe is 16% efficient. Thick (10 cm) high-purity lead encased in 0.8 cm thick pre-WWII steel shields this detector. In addition, OFHC copper and cadmium line the inside of the shield. The 2-liter Marinelli beaker displaces virtually all air and radon from the shield volume.

The UGF detectors were calibrated for vials (ashed resins) and 1-liter Marinelli beakers (sediment samples). A small attenuation correction (Appendix A) transforms the efficiency curves based on aqueous standards to those appropriate for sediments. Figures 2 and 3 show typical spectra for concentrator and sediment samples. The TRAC detector calibrations include those for soils in 2-liter Marinelli beakers. All calibrations used NBS-traceable standards.

The gamma spectroscopy code GRABGAM analyzed the HPGe data (ref 4). SRL developed this code and has tested it with numerous low-level applications over the past four years. Its isotope libraries contain gamma-ray energies and intensities. These are consistent with the well-established values from a variety of compilations (ref 8). An (EG&G ORTEC) ADCAM system collected the spectral data for the UGF (and ULLCF) detectors. This is a multichannel analyzer (MCA) composed of an IBM-PC/XT computer and auxiliary modules. A Compaq 386 computer used GRABGAM to analyze TRAC spectra collected by a Canberra Series 85 MCA.

C.4. Dual NaI Spectrometry/Coincident-Gamma Emitting Nuclides

The UGF dual NaI detector operates in coincidence to yield sensitive results for various isotopes, including ^{60}Co in particular (ref 4). An active NaI shield reduces the cosmic background, and the sample essentially displaces the background radon in air. For a point source located at the center of the well, the absolute coincident peak efficiency (1173 and 1332 keV gammas of ^{60}Co) is 12%.

The dual NaI system calibrations use a bootstrap technique for non-standard sample geometries. Specifically, HPGe detectors recount the sediment samples counted by the dual NaI system for a more sensitive examination of ^{60}Co . Both types of detectors observed ^{60}Co in numerous samples. By normalizing the sample responses of the dual NaI system to the measured ^{60}Co values from the HPGe analysis, these sediment samples indicated a ^{60}Co absolute coincident peak efficiency of $6 \pm 2\%$, where the relatively large error corresponds to sample size/geometry effects as opposed to the much smaller statistical counting errors. Accordingly, the detector is quite useful for approximating the concentrations of radionuclides in low-level environmental samples. The smaller ashed resin samples, counted in the middle of the dual NaI detector well, had little self-attenuation. Thus, the more accurate point source efficiency of 12% applied for these cases.

The code GRABDUAL analyzed the dual NaI data (ref 4). A Canberra Series 88 MCA initially collects the spectrum and the monitor of an IBM PC/XT displays the final 64×64 contour plot, as illustrated in Figure 4. Here two regions of interest for coincident ^{60}Co gammas (1173 keV and 1332 keV), along with concentric background regions yield the sample count rate.

C.5. In-situ Counting/Gamma Emitting Nuclides

The Underwater NaI detector, a 9" diam x 4" thick NaI(Tl) detector, views its surroundings through a 13" diameter, thin-walled stainless steel hemisphere. A watertight stainless steel assembly contains the detector, preamplifier, and high voltage supply. These receive power and generate detector signals through a 40 m waterproof cable connected to auxiliary electronics on the pontoon boat. A COMPAQ portable computer with an (EG&G ORTEC) ACE/ADCAM MCA card processes the amplified detector signals. Figure 5 shows typical spectra collected with this system. A 5 hp gasoline generator powers the electronics.

The portable HPGe Detector counts gamma-ray spectra on-site. This detector, mounted 0.7 meter above ground on a tripod, operates near the van/trailer. It has 14% relative efficiency and a liquid-nitrogen dewar with 24 hr hold-time. The van housed a Canberra Series 40 MCA and associated detector electronics; a small generator in a clam-shell trailer powers the equipment. Thirty meter long cables aided placing the detector at a variety of locations.

C.6. Alpha Spectrometry and Mass Spectrometry/Plutonium

Surface barrier detectors counted alpha spectra for ^{238}Pu and $^{239}\text{Pu}+^{240}\text{Pu}$ separated from concentrator resins, sediments, and soils. The detectors do not distinguish ^{239}Pu and ^{240}Pu , because the alpha energies are too close for accurate resolution. Each concentrator resin sample was spiked with ^{236}Pu standard from Oak Ridge National Laboratory. The ashed sample was leached with HCl, purified by solvent extraction and ion exchange, and electroplated onto a platinum disk. A surface barrier detector counted the sample disk for a week, and an ADCAM MCA/PC system processed the alpha spectra.

Plutonium from the sediment and soil samples was counted in the HP Counting Room in 735-A. Nitric acid dissolved each sample, an ion exchange resin extracted/eluted the Pu, and a surface barrier detector counted the sample (ref 1).

Mass spectrometry provided plutonium isotopic data. Only soil samples yielded useful results due to sample size considerations. However, other evidence (discussed later) indicates all samples are consistent with fallout isotopics.

C.7. QA Checks

Tritium liquid scintillation determinations used standard addition methods. Duplicate 3 ml samples were prepared and one was spiked with 250 μl of tritiated water made from NBS-4927 standard¹.

Calibrations relative to NBS standards verified the HPGe and dual NaI detector measurements. Table 1 summarizes direct measurements performed with these detectors for samples of NBS soil standards SRM-4350B, SRM-4353, and SRM-4355. The measurements agree well with the NBS values; this is as expected, since the commercial (Amersham International plc) standard sources used in routine calibrations have certified NBS-Traceability. The HPGe analysis code also checks consistency of all major gammas in each radionuclide's decay. This serves as an internal check on counting efficiency and sample self-attenuation corrections.

The plutonium analyses use spikes of ORNL ^{236}Pu , which follow the entire analysis. The surface barrier detectors are calibrated with NBS-traceable standards.

D. Sample Collection Sites

D.1. River/Inlet Streams

Figure 1 gives an overview of the sampling sites, and Appendix Table B.1 lists downstream sites sequentially, giving the river miles and a detailed description of each site. The overall sampling philosophy emphasized sites close to Plant Vogtle, and yet included other sites that might explain any background fluctuations attributable to SRS sources. The Savannah River enters the SRS area at Shell Bluff, reaches Plant Vogtle about 10 miles downstream, and is well beyond inlet streams from both plant sites at Highway 301 Bridge, which is 32 miles further downstream. Thus, both plants may contribute to the increase in stream radioactivity from Shell Bluff to Highway 301 Bridge. On the other hand, Plant Vogtle primarily accounts for downstream increases bracketed by samples collected 0.3 miles above, 0.1 miles below, and at the Plant Vogtle outfall. SRS inlet stream areas within a few miles of Vogtle were also sampled to identify any localized source-streaming effects that could cause background non-uniformities near the Vogtle outfall. Finally, a few additional samples further upstream and downstream served to better characterize the activity growth from Shell Bluff to Highway 301 Bridge.

¹NBS was renamed NIST (National Institute of Standards and Technology) in 1988.

The above sample locations are quite appropriate. Indeed, measurements at Shell Bluff and Highway 301 Bridge have successfully monitored SRS effluents for some years (ref 1). Plant Vogtle has had controlled releases of ^{58}Co and other nuclides during routine operations following startup. Samples 0.1 mile below the outfall and also at Highway 301 Bridge have shown this activity. However, samples taken 0.3 mile above the outfall have not detected any trace of this activity. Also, river sediments near Vogtle have not displayed any radioactivity variations that suggest any new streaming backgrounds from SRS sources.

D.2. Soils

Results of this baseline study can be compared to future activity levels in soils, should a release from Plant Vogtle or SRS occur. Ample location information can guide sampling teams returning to the sites. Appendix Table B.2 describes the site locations and lists the Latitude and Longitude determined by Loran-C. Figure 1 also shows the locations.

Loran-C precision is about 60 meters in the SRS vicinity. Calibration at four known locations in the Plant Vogtle vicinity removed systematic offsets in the Micrologic ML-5000A Loran data. Offsets added to the position data are $+0.06'$ and $-0.10'$ Latitude and Longitude respectively. Loran data can return personnel to the correct vicinity should future sampling be necessary, while site descriptions in Table B.2 pinpoint the sample locations.

E. Sample Analysis Results

E.1. Aqueous Collections

Table 2 summarizes the average ^3H , ^{60}Co , ^{137}Cs , ^{239}Pu , and ^{240}Pu found in aqueous samples. The highest ^3H tritium level in the Savannah River was observed at Highway 301 bridge where the concentration was 3.0 ± 1.0 pCi/ml. This was barely detectable by our sensitive counting. For inlet streams, the maximum was much larger at 250 ± 5 pCi/ml within the mouth of Four Mile Creek. Results for ^{60}Co follow a similar pattern, except that the concentration levels are about a million times lower. For example, the value at Highway 301 Bridge is 2.6 ± 0.9 fCi/l (where $1 \text{ fCi/l} = 10^{-6}$ pCi/ml). The measurements for ^{137}Cs also agree with these trends, and are sensitive enough to illustrate that levels in the river increase monotonically by an order of magnitude from Shell Bluff to Highway 301 Bridge, where 56.9 ± 1.3 fCi/l of ^{137}Cs was observed. By contrast, an average $^{239}\text{Pu} + ^{240}\text{Pu}$ of 2.3 ± 0.2 fCi/l applies uniformly to all downstream locations, implying that their source is from world-wide fallout. Accordingly, the Pu isotopic ratios for the aqueous samples should be the same as those for soils, as discussed in Section E.3 and summarized in Table 5.

Figure 6 plots concentrations for ^{137}Cs as a function of time. The results are constant within the $\sim 30\%$ random fluctuations observed. Time-dependent data for ^{60}Co also indicate consistency with constant levels; however, many of the values are below detection limits. Only one set of ^3H samples was measured before the cutoff date (April 9) for this study. However, the continuing measurements program indicates that monthly measurements into July generally display this constancy with time. The latest 3 measurements at mouth of Four Mile Creek are higher, each indicating about 570 pCi/ml tritium. Appendix Tables C.1 and C.2 detail time-dependent concentrations for ^{60}Co and ^{137}Cs for all samples included in this study. Also, Appendix C gives further details concerning the calculation of results.

In addition to the above radionuclides, traces of ^{134}Cs were also observed occasionally. Specifically, at the mouth of Four Mile Creek, an average of 2.2 ± 0.2 fCi/l was observed, and at Highway 301 Bridge a value of ~ 0.6 fCi/l appeared intermittently. This concentration is just above the detection limit. Both ^{134}Cs concentrations were $\sim 1\%$ of the corresponding ^{137}Cs levels. No other manmade radionuclides were identified.

Finally, the natural activities collected by the concentrator resin bags promised to be an appropriate internal calibration check, as was the case with the sediment samples discussed below. Unfortunately, these natural activities varied by more than an order of magnitude, probably due to large fluctuations in suspended particles in the river.

E.2 Sediments

Table 3 summarizes the ^{60}Co , ^{137}Cs , ^{238}Pu , and $^{239}\text{Pu}+^{240}\text{Pu}$ concentrations for the sediment samples. Similarly to the aqueous samples, the concentrations in the river tend to increase for sample sites further downstream. (A noticeable exception to this was at Hancock Landing, where the sample was primarily composed of clay which concentrates radionuclides through an ion exchange process). In particular, ^{137}Cs increases by an order of magnitude from Shell Bluff to Highway 301 Bridge, where the concentration averaged 240 pCi/kg. The corresponding ^{60}Co averaged 3.4 pCi/kg, yielding $^{60}\text{Co}/^{137}\text{Cs}$ of $\sim 1/70$ while it was $\sim 1/20$ for the concentrator resin sample. This lower $^{60}\text{Co}/^{137}\text{Cs}$ ratio is probably due to differences in the absorbent features of the sediment and concentrator resins. The maximum ^{60}Co was at the mouth of Four Mile Creek, as was the case with the resins; however, the maximum ^{137}Cs was at the Steel Creek Branch site. ^{238}Pu is not positively observed anywhere and has an upper limit maximum of 6.8 pCi/kg at Highway 301 Bridge. (An upper limit maximum is used, as ^{238}Pu values include an interference from natural sources). The combination $^{239}\text{Pu}+^{240}\text{Pu}$ was not detected at all. Further details on the sediment results are given in Appendix Tables C.3 - C.12.

The only other manmade radionuclide detected was ^{134}Cs , which was detected only at the mouth of Four Mile Creek. This ^{134}Cs was 43 ± 5 pCi/kg, which is $\sim 1\%$ of the corresponding ^{137}Cs , as was the case with the concentrator resin bags.

The natural radioactivities in these sediments were also examined, as an internal calibration check. Three types of soil types were classified according to isotope and moisture concentrations, as listed in Table 4. Clay and sediment were seen primarily; however, a very fine sand was observed for Upper Three Runs samples. The overall data are consistent with that measured for the terrestrial soil samples. Detailed data are given in Appendix Tables C.6 to C.12.

E.3. Soils

Tables 5 and 6 report gamma-ray analysis results for specific activities (pCi/kg) and aerial depositions (mCi/km^2). Table 4 includes prominent naturally occurring radionuclide concentration ranges, and Appendix Tables C.13 and C.14. give detailed values. Pu isotopic ratios in Table 5 are consistent with world-wide fallout.

One soil sample (#5) from an area near Four Mile Creek delta contained detectable ^{60}Co . Radioactivity at this location reflects contributions from previous SRS operations. The maximum ^{60}Co in sediments is at the mouth of Four Mile Creek; this is consistent with HP surveys.

III. DISCUSSION

A. Summary of Results

Tables 2-6 summarize the results, and Appendix C tabulates further details.

The stream measurements yielded no evidence of any unusual radioactivity for locations near the Vogtle outfall. The corresponding manmade activities in the Savannah River were essentially constant at this location. In particular, aqueous samples yielded 12 ± 1 fCi/l ^{137}Cs , ~ 0.8 fCi/l ^{60}Co , 2.1 ± 0.3 fCi/l $^{239}\text{Pu} + ^{240}\text{Pu}$, and < 2.1 pCi/ml ^3H . The corresponding sediment samples also displayed no strong positional trends, although sample fluctuations in activity are larger. Typical levels in these sediments are ~ 10 pCi/kg ^{137}Cs , ~ 2 pCi/kg ^{60}Co , < 7 pCi/kg ^{238}Pu , and < 1 pCi/kg $^{239}\text{Pu} + ^{240}\text{Pu}$.

The overall stream measurements give a picture of how the Savannah River accumulates low levels of radiation after it passes into the SRS/Vogtle vicinity at Shell Bluff and completely traverses it by the time the river reaches Highway 301 Bridge. This study illustrates that the river already receives some radioactive SRS effluents from Beaver Dam Creek, Four Mile Creek, and Steel Creek. Consequently, ^{137}Cs increases from 5.3 fCi/l at Shell Bluff to 57 fCi/l at Highway 301 Bridge. Before and during this study, this increase was due entirely to fallout and SRS sources, but post-startup values now include routine minor contributions of other radionuclides from Plant Vogtle. ETD is continuing studies of contributions from Plant Vogtle using samples collected near its outfall.

Future soil resamples would primarily assess the impact of stack emissions, which typically spread over larger areas than effluents in streams. Manmade backgrounds of the present soil samples are from earlier weapons fallout and from earlier SRS releases to floodplains. The present study encompassed a 7-mile radius about Plant Vogtle, yielding typical values of ~ 500 pCi/kg (50 mCi/km²) of ^{137}Cs , and < 8 pCi/kg (0.8 mCi/km²) of ^{60}Co . A notable exception was site #5, which yielded 1540 pCi/kg ^{137}Cs and 93 pCi/kg ^{60}Co . Site #5 is in the flood plain of Steel Creek, which retains the bulk of past SRS effluents.

Soil/sediment activity ratios are ~ 50 for manmade activities. Several factors account for this activity ratio. These include differences in activity profiles between soils and sediments due to mixing activity to greater depths in sediments. They also include leaching of activity from sediments in streams.

All the above manmade isotopic levels result either from SRS sources or fallout, since these are all pre-startup measurements. Post-startup measurements have already illustrated that samples collected just above and below plant Vogtle monitor the radioactive effluents from that plant. Other methods will distinguish between activity sources as necessary. For example, mass spectrometry measures of the $^{240}\text{Pu}/^{239}\text{Pu}$ isotopic ratio are useful. These distinguish whether a Pu increase is due to SRS, fallout, or Vogtle, where the respective ratios are 0.06, 0.18, and ~ 0.40 (refs 10-12).

B. Comparison with Related Studies

The present studies are consistent with those reported annually by SRS HP Division (ref 1). Table 7 compares appropriate data from the present work with some of the more recent HP data. Overall, the agreement is within a factor of 2, which is reasonable, when allowing for differences in exact sample location. In many cases, the ultra-sensitive measurements of the present work are below the detection limits of routine HP monitoring capabilities.

The higher levels of ^{60}Co observed in soils at Four Mile Creek are consistent with EG&G aerial surveys of the Savannah River floodplain (ref 9). Such aerial surveys identify important areas for detailed study. Aerial surveys with fine spatial resolution are available for the entire Savannah River Plant site. SRS Health Protection Department also collects and analyzes soil samples from each of four quadrants around each of the separations areas, at the SRS boundary, and at two control locations approximately 100 miles from SRS. Since the HP sampling locations are not the same as those used in this effort, Table 7 compares ranges of values.

Finally, the continuation of the stream study is showing overall consistency with the present pre-operational study. (These followup studies have now processed samples collected up to April 1989, spanning almost two years of full-power operation of Unit 1). In addition, the continuation study has demonstrated the ability to monitor small amounts of radioactivity from Vogtle effluents. Thus, the adequacy of the sample site selection is well established. In particular, the studies detected ^{58}Co and other effluent radionuclides just below Vogtle and at Highway 301 Bridge during and after Vogtle planned releases in 1987 and 1988. However, none of these radionuclides were detected up-river from Vogtle.

ACKNOWLEDGEMENTS

The authors wish to thank M.V. Kantelo and J.A. Olivares for analyzing river samples for Pu. They also thank Jita Morrison and Sandra Boynton of HP for conducting similar analyses for the sediment and soil samples. They appreciate the efforts of C.D. Ouzts and R.J. Roseberry for coordinating sample collections in the field, and for counting the samples in the Underground Counting Facility. E.H. Dillon also assisted in the field and fabricated the scoop for collecting sediment samples. R.J. Tunstall and S.J. Hite collected and counted the soil samples.

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Table 1. Calibration Comparison with NBS Standards

Isotope	Activity (mBq/g) ^a		Detector ^b	NBS Source ^c
	NBS ^d	UCF ^e		
⁴⁰ K	560	550 ± 16	HPGe	SRM-4350B SRM-4353 SRM-4355
	723 ± 69	717 ± 18		
	585	559 ± 39		
⁶⁰ Co	4.64 ± 0.23	4.95 ± 0.39	Dual NaI	SRM-4350B
¹³⁷ Cs	29.0 ± 1.8	31.9 ± 1.0	HPGe	SRM-4350B SRM-4353
	17.6 ± 0.8	15.2 ± 1.1		
¹⁵² Eu	30.5 ± 1.2	28.7 ± 1.2	HPGe	SRM-4350B
²⁰⁸ Tl	13.5	15.6 ± 1.8	HPGe	SRM-4355
²²⁶ Ra[f]	35.8 ± 3.6	34.2 ± 0.8	HPGe	SRM-4350B SRM-4353
	43.0 ± 2.8	41.1 ± 0.9		
²²⁸ Th	33.5	32.1 ± 1.0	HPGe	SRM-4350B SRM-4353 SRM-4355
	70.8 ± 3.6	67.8 ± 1.7		
	42.2 ± 2.1	43.7 ± 3.5		
²³⁰ Th[f]	39.7 ± 2.0	29.8 ± 1.8	HPGe	SRM-4355

(a) 1 mBq = 1 decay per 1000 sec = 0.027 pCi = 27 fCi

(b) 25% efficiency HPGe used in this work. Other HPGe detectors were cross-calibrated with common sources.

(c) SRM-4350B - River Sediment (9/9/81, 11.57 g)
SRM-4353 - Rocky Flats Soil No. 1 (12/15/80, 11.37 g)
SRM-4355 - Peruvian Soil (6/1/82, 11.37 g)

(d) Certified NBS values are given with an uncertainty that includes random and systematic uncertainty combined in quadrature, for a value three-sigma of the mean. Uncertified NBS values are tabulated without the uncertainties.

(e) The UCF (Underground Counting Facility) uncertainty is the statistical one-sigma counting error.

(f) UCF values determined from ²¹⁴Bi and ²¹⁴Pb, may be low due to ²²²Rn escape.

Table 2. Summary Results Water in Savannah River and Inlets^a
(R = River / I = Inlet)

Location	³ H pCi/ml	⁶⁰ Co fCi/l	¹³⁷ Cs fCi/l	²³⁹ Pu+ ²⁴⁰ Pu ^b fCi/l
Shell Bluff (R)	<1.1	<1.0	5.3 ± 0.5	2.3 ± 0.3
Upper Three Runs (I)	2.0 ± 0.9	~1.0	12.3 ± 0.5	[d]
Georgia Inlet (I)	<1.7	~0.9	3.3 ± 0.2	[d]
Beaver Dam (I)	5.5 ± 1.0	7.6 ± 0.5	11.4 ± 0.5	[d]
Hancock Landing (R)	<1.2	[c]	[c]	[c]
Above Vogtle (R)	<1.8	~0.7	14.1 ± 0.8	2.3 ± 0.3
Vogtle Outfall (R)	<2.1	[c]	[c]	[c]
Below Vogtle (R)	<1.9	~0.9	11.9 ± 0.6	2.1 ± 0.3
Four Mile Creek (I)	250 ± 5	13.8 ± 0.4	307 ± 2	[d]
Steel Creek Branch (I)	3.8 ± 1.0	4.6 ± 0.4	176 ± 2	[d]
Hwy 301 Bridge (R)	3.0 ± 0.9	2.5 ± 0.9	56.9 ± 1.3	2.5 ± 0.5

(a) The average 1-sigma counting errors are presented here, and these are much smaller than the sampling errors of about 30%. Concentrations given as ~1.0, ~0.9, etc were just marginally detected. Also note the concentration units for ³H are pCi/mL; those for ⁶⁰Co, ¹³⁷Cs, and Pu are fCi/L. (See Appendix Tables C.1 and C.3 for more extensive data on water measurements).

(b) One week counts on surface barrier detectors gave these low values.

(c) Location was not suited for placing concentrator bag.

(d) Analysis was not performed.

Table 3. Summary Results Sediments in Savannah River and Inlets^a
(R = River / I = Inlet)

Location	⁶⁰ Co pCi/kg	¹³⁷ Cs pCi/kg	²³⁸ Pu ^b pCi/kg	²³⁹ Pu ^c + ²⁴⁰ Pu ^c pCi/kg
Shell Bluff (R)	<1	26 ± 3	<0.7	<0.7
Upper Three/Left Runs (I) Right	<1 <2	<6 <3	[d] [d]	[d] [d]
Georgia Inlet (I)	<1	24 ± 2	[d]	[d]
Beaver Dam (I)	82 ± 5	161 ± 9	[d]	[d]
Hancock Landing (R)	2.8 ± 0.5	174 ± 7	[d]	[d]
Above /Left Vogtle (R) Middle Right	2.3 ± 0.3 <1.6 ~1.0	<15 23 ± 2 9 ± 4	[d] [d] <3.2	[d] [d] <0.9
Vogtle Outfall (R)	<1.2	<5	[d]	[d]
Below /Left Vogtle (R) Middle Right	~3.1 ~1.2 <1.0	10 ± 3 24 ± 2 12 ± 4	[d] [d] <5.0	[d] [d] <1.0
Four Mile Creek (I)	263 ± 4	4460 ± 20	[d]	[d]
Below /Left Four Mile Middle Creek (R) Right	~2.1 ~1.6 1.1 ± 0.2	22 ± 2 18 ± 2 9 ± 2	[d] [d] [d]	[d] [d] [d]
Still Water Site (R)	<1.0	13 ± 3	[d]	[d]
Steel Creek Branch (I)	73 ± 2	35900 ± 100	[d]	[d]
Highway 301 /Middle Bridge (R) Right	3.3 ± 0.5 3.6 ± 0.5	213 ± 2 264 ± 2	[d] <6.8	[d] <2.0

- (a) Table uses average 1-sigma counting errors and marginally detected cases (e.g., ~1.2). Sampling errors are ~25%. (See Appendix Tables C.3 - C.12 for more extensive data).
- (b) The ²³⁸Pu measurements are treated as upper limit values, as natural backgrounds in sample also contribute.
- (c) Isotopics were not obtained from mass spectrometry due to the very low levels.
- (d) Analysis was not performed.

**Table 4. Natural Activities of Stream-Bed and Terrestrial Samples
(pCi/kg)**

Nuclide	Stream-Bed ^a			Terrestrial ^b Soil
	Sediment	Clay	Fine Sand	
⁴⁰ K	8510 ± 450	15100 ± 1800	110 ± 35	239-15400
²⁰⁸ Tl	100 ± 10	530 ± 40	40 ± 10	114-658
²¹² Pb	310 ± 30	1760 ± 190	95 ± 30	406-2208
²¹⁴ Pb	390 ± 30	1720 ± 160	200 ± 40	289-1980
²¹⁴ Bi	385 ± 20	1660 ± 150	210 ± 40	297-1930
²²⁶ Ra	950 ± 90	4100 ± 370	490 ± 60	575-1470
²²⁸ Ac	270 ± 20	1390 ± 100	110 ± 30	316-1890
Samples	15	6	2	30
%-Moisture	20.8 ± 0.4	37.4 ± 2.1	17.9 ± 0.8	--

(a) All uncertainties are standard deviations of mean (Individual sample uncertainties are larger by square root of number of samples).

(b) No individual soil classifications were made, as no obvious distinctions were identified.

Table 5A. Soil Concentrations - Manmade Radionuclides^a Neutron Activation and Fission Products (pCi/kg)

Site	⁶⁰ Co	¹³⁷ Cs
#01, Sector A 5.5 miles	< 3	87 ± 2
#02, Sector A 4.0 miles	< 5	437 ± 5
#03, Sector A 5.5 miles	< 6	747 ± 7
#04, Sector A 5.25 miles	< 7	792 ± 8
#05, Sector B 1.9 miles	93 ± 4	1540 ± 10
#06, Sector C 4.5 miles	< 9	507 ± 8
#07, Sector B 3.2 miles	< 7	1030 ± 10
#08, Sector C 3.5 miles	< 5	495 ± 6
#09, Sector C 2.5 miles	< 9	93 ± 5
#10, Sector D 3.0 miles	< 5	139 ± 3
#11, Sector E 4.0 miles	< 9	222 ± 7
#12, Sector D 5.5 miles	< 7	45 ± 4
#13, Sector E 4.5 miles	< 9	901 ± 12
#14, Sector R 6.75 miles	< 5	190 ± 4
#15, Sector Q 6.75 miles	< 10	274 ± 8

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site description.

Table 5A. Soil Concentrations - Manmade Radionuclides^a Neutron Activation and Fission Products (pCi/kg) - Continued

Site	⁶⁰ Co	¹³⁷ Cs
#16, Sector Q 1.75 miles	< 7	35 ± 4
#17, Sector P 1.90 miles	< 7	712 ± 9
#18, Sector P 5.5 miles	< 3	827 ± 3
#19, Sector Q 5.2 miles	< 5	320 ± 6
#20, Sector M 2.7 miles	< 3	919 ± 5
#21, Sector L 2.8 miles	< 11	468 ± 11
#22, Sector L 1.6 miles	< 5	779 ± 8
#23, Sector K 3.5 miles	< 7	542 ± 9
#24, Sector K 4.5 miles	< 4	561 ± 6
#25, Sector S 4.5 miles	< 4	502 ± 5
#26, Sector H 6.5 miles	< 9	450 ± 10
#27, Sector G 4.3 miles	< 5	449 ± 6
#28, Sector F 1.75 miles	< 10	244 ± 6
#29, Sector H 5.2 miles	< 5	646 ± 7
#30, Sector F 7 miles	< 14	191 ± 8

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site description.

Table 5B. Soil Concentration - Manmade Radionuclides^a Plutonium Isotopes (pCi/kg)

Site	²³⁸ Pu ^a	²³⁹ Pu+ ²⁴⁰ Pu
#06, Sector C 4.5 miles	< 3	11 ± 2
#14, Sector R 6.75 miles	< 7	2 ± 1
#24, Sector K 4.5 miles	< 3	12 ± 2
#30, Sector F 7.0 miles	< 9	4 ± 1

(a) The ²³⁸Pu measurements are treated as upper limit values, as natural backgrounds in sample also contribute.

Mass Spectrometry Isotope Ratios^b Atom Percent

Site	²⁴⁰ Pu/ ²³⁹ Pu	²⁴¹ Pu/ ²³⁹ Pu
#06, Sector C 4.5 miles	0.172 ± 0.006	0.0083 ± 0.0008
#14, Sector R 6.75 miles	0.185 ± 0.010	(c)
#24, Sector K 4.5 miles	0.179 ± 0.010	0.0080 ± 0.0011
#30, Sector F 7.0 miles	0.188 ± 0.019	(c)

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site description.

(b) All values are consistent with fallout isotopic ratios.

(c) High instrument background prevented measurement.

Table 6A. Soil Deposition - Manmade Radionuclides^a Neutron Activation and Fission Products (mCi / km²)

Site	⁶⁰ Co	¹³⁷ Cs
#01, Sector A 5.5 miles	< 0.32	10.8 ± 0.2
#02, Sector A 4.0 miles	< 0.65	52.4 ± 0.6
#03, Sector A 5.5 miles	< 0.76	88.6 ± 0.8
#04, Sector A 5.25 miles	< 0.67	76.0 ± 0.8
#05, Sector B 1.9 miles	6.77 ± 0.31	111.6 ± 0.7
#06, Sector C 4.5 miles	< 0.92	54.6 ± 0.9
#07, Sector B 3.2 miles	< 0.44	61.8 ± 0.6
#08, Sector C 3.5 miles	< 0.59	58.3 ± 0.7
#09, Sector C 2.5 miles	< 1.00	10.9 ± 0.6
#10, Sector D 3.0 miles	< 0.63	17.6 ± 0.4
#11, Sector E 4.0 miles	< 0.92	24.0 ± 0.8
#12, Sector D 5.5 miles	< 0.95	6.3 ± 0.5
#13, Sector E 4.5 miles	< 0.82	86.3 ± 1.1
#14, Sector R 6.75 miles	< 0.57	20.7 ± 0.4
#15, Sector Q 6.75 miles	< 0.97	27.0 ± 0.8

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site description.

Table 6A. Soil Deposition - Manmade Radionuclides^a Neutron Activation and Fission Products (mCi / km²) - Continued

Site	⁶⁰ Co	¹³⁷ Cs
#16, Sector Q 1.75 miles	< 0.80	3.9 ± 0.5
#17, Sector P 1.90 miles	< 0.74	78.3 ± 1.0
#18, Sector P 5.5 miles	< 0.33	79.1 ± 0.3
#19, Sector Q 5.2 miles	< 0.48	30.1 ± 0.6
#20, Sector M 2.7 miles	< 0.25	66.2 ± 0.4
#21, Sector L 2.8 miles	< 0.93	39.4 ± 0.9
#22, Sector L 1.6 miles	< 0.46	70.3 ± 0.7
#23, Sector K 3.5 miles	< 0.72	59.8 ± 1.0
#24, Sector K 4.5 miles	< 0.41	56.7 ± 0.6
#25, Sector S 4.5 miles	< 0.48	61.7 ± 0.6
#26, Sector H 6.5 miles	< 0.73	37.9 ± 0.8
#27, Sector G 4.3 miles	< 0.46	42.4 ± 0.6
#28, Sector F 1.75 miles	< 0.73	18.4 ± 0.5
#29, Sector H 5.2 miles	< 0.48	59.2 ± 0.6
#30, Sector F 7.0 miles	< 1.33	18.1 ± 0.8

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site description.

**Table 6B. Soil Deposition - Manmade Radionuclides^a Plutonium Isotopes
(mCi/km²)**

Site	²³⁸ Pu ^b	²³⁹ Pu+ ²⁴⁰ Pu
#06, Sector C 4.5 miles	< 0.32	1.2 ± 0.2
#14, Sector R 6.75 miles	< 0.76	0.22 ± 0.07
#24, Sector K 4.5 miles	< 0.30	1.2 ± 0.16
#30, Sector F 7.0 miles	< 0.85	0.38 ± 0.10

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site description.

(b) The ²³⁸Pu measurements are treated as upper limit values, as natural backgrounds in sample also contribute.

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Table 7. Comparisons with Earlier Studies

Aqueous Samples ^c				
Isotope Units	Location ^a	Measurements ^b		
		HP-1985	HP-1986	ETD-1987
³ H pCi/ml	Shell Bf/R-2	0.46 ± 0.09	0.36 ± 0.06	<1.1
	Up 3Run/U3R-4	2.7 ± 0.2	2.2 ± 0.3	2.0 ± 0.9
	Abv Vogl/R-3A	2.4 ± 0.5	1.3 ± 0.2	<1.8
	Blo Vogl/R-3B	0.61 ± 0.06	0.71 ± 0.37	<1.9
	301 Brig/R-10	3.7 ± 0.3	3.9 ± 0.5	3.0 ± 0.9
	/R-10B	-	4.1 ± 0.9	"
⁶⁰ Co fCi/l	Shell Bf/R-2	590 ± 385	-	<1
	4Mi Mou/FM-6	1700 ± 2700	-	13.8 ± 0.4
	Stl Ck / SC-5	1500 ± 2100	-	4.6 ± 0.4
	301 Brig/R-10	430 ± 240	-	2.6 ± 0.9
¹³⁷ Cs fCi/l	Shell Bf/R-2	100 ± 66	-	5.3 ± 0.5
	/KCFC	15 ± 2	21 ± 2	"
	4Mi Mou/FM-6	430 ± 490	-	307 ± 2
	Stl Ck /Sc-5	280 ± 350	-	176 ± 2
	301 Brig/R-10	110 ± 64	-	59.6 ± 1.3
	/KCFC	71 ± 7	114 ± 6	"
²³⁹ Pu + ²⁴⁰ Pu fCi/l	Shell Bf/R-2	gross-alpha 70 ± 27	gross-alpha 120 ± 39	Pu-alpha 2.3 ± 0.3
	Abv Vogl/R-3A	20 ± 22	50 ± 25	2.3 ± 0.2
	Blo Vogl/R-3B	70 ± 35	70 ± 36	2.1 ± 0.4
	301 Brig/R-10	30 ± 22	110 ± 40	2.5 ± 0.5

Table footnotes are on the last page of Table 7.

Table 7. Comparisons with Earlier Studies (Continued)

Sediment Samples ^d				
Isotope Units	Location ^a	Measurements ^b		
		HP-1985	HP-1986	ETD-1987
⁴⁰ K pCi/kg	Up 3Run	-	8800 ± 1100	110 ± 10[e]
	Blo 4Mi	-	12000 ± 730	8000 ± 100
	Steel Ck	-	13000 ± 1600	10100 ± 100
	301 Brig	16000 ± 740	15000 ± 790	9190 ± 50
⁶⁰ Co pCi/kg	Up 3Run	<20	<20	<1[e]
	Blo 4Mi	<20	<20	~2
	Steel Ck	<20	220 ± 30	73 ± 2
	301 Bridge	<20	<20	3.4 ± 0.5
¹³⁷ Cs pCi/kg	Up 3Run	-	460 ± 80	<3[e]
	Blo 4Mi	-	780 ± 50	20 ± 2[f]
	Steel Ck	-	13000 ± 1600	35900 ± 100
	301 Brig	1000 ± 50	990 ± 60	233 ± 30
²³⁸ Pu pCi/kg	Demier Ld	0.4 ± 1.0	0.2 ± 0.2	<0.7 [g]
	Blo 4Mi	0.1 ± 1.0	0.2 ± 0.8	<5.0 [g]
	301 Bridge	2. ± 3.	0.2 ± 0.5	<6.8 [g]
²³⁹ Pu + ²⁴⁰ Pu pCi/kg pCi/kg	Demier Ld	1.3 ± 1.0	0.5 ± 0.3	<0.7
	Blo 4Mi	0.4 ± 5.	0.8 ± 1.0	<1
	301 Bridge	0.5 ± 2.	2.0 ± 7.0	<2

Table footnotes are on the next page.

Table 7. Comparisons with Earlier Studies (Continued)

Soil Samples ^h		Measurements ^b		
Isotope Units	Location ^a	HP-1986	EG&G ⁱ	ETD-1987
⁶⁰ Co pCi/kg	30 Sites	-	-	≤93
	Plant Perimeter	-	-	-
	100-Mile Radius	-	-	-
	Flood Plain	-	≤820	-
¹³⁷ Cs pCi/kg	30 Sites	-	-	≤1540
	Plant Perimeter	390 - 600	-	-
	100-Mile Radius	≤1.0	-	-
	Flood Plain	-	≤2400	-
²³⁸ Pu pCi/kg	4 Sites	-	-	3 - 9
	Plant Perimeter	-	≤1.3	-
	100-Mile Radius	-	≤1.0	-
²³⁹ Pu pCi/kg	4 Sites	-	-	2 - 12
	Plant Perimeter	7.7 - 15	-	-
	100-Mile Radius	6 - 8	-	-

Footnotes for Table 7.

- (a) Locations: [ETD-1987]/[HP-198-] = [Table 3]/[DPSPU-87-30]
- (b) HP-1985 from DPSPU-86-30; HP-1986 from DPSPU-87-30; ETD-1987 from present study.
- (c) Aqueous HP errors are 2 x standard deviation of mean; ETD values from Table 4 with 1-sigma counting error.
- (d) Sediment HP errors are 2-sigma counting errors. ETD values from Tables 5 and B.6 with 1-sigma counting error.
- (e) Samples were very fine sand, and may not be representative.
- (f) Value increases to ~4500 pCi/kg at Four Mile Creek mouth.
- (g) Measured Pu-238 are treated as upper limit values, as natural backgrounds of sample also contribute.
- (h) ETD surveyed new soil sites for this work; therefore, a direct comparison with previous surveys is not possible. Ranges of data are compared for this survey with ranges observed at other locations in previous surveys.
- (i) EG&G from reference 9.

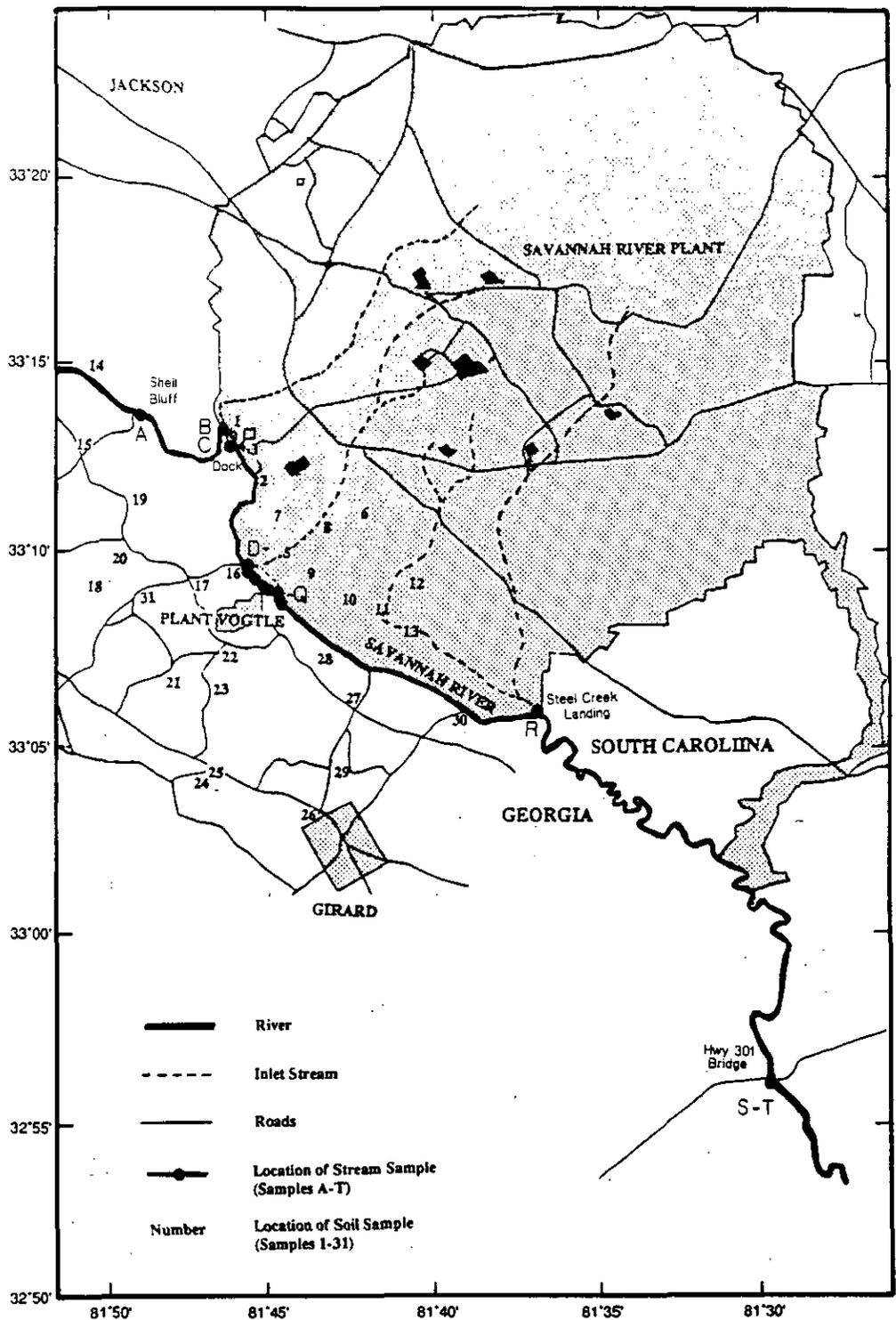


Figure 1. Sampling Locations for Plant Vogtle Baseline Survey (see Tables B.1 and B.2 for detailed site location)

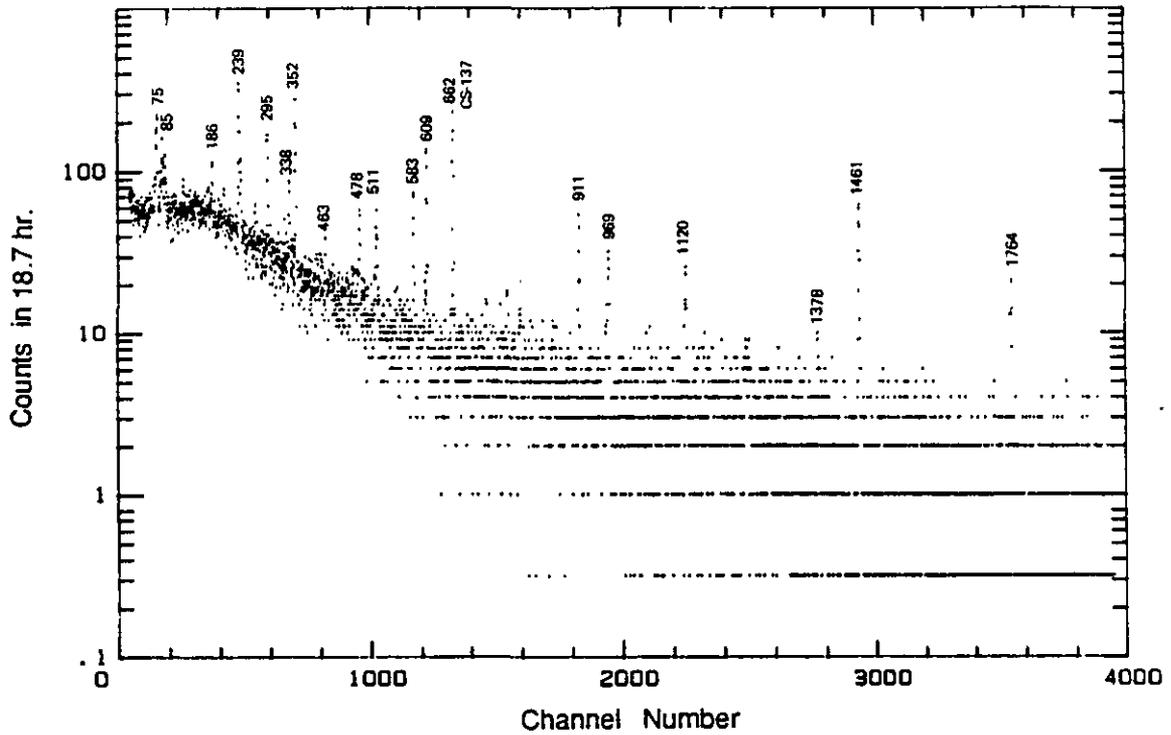


Figure 2. HPGe Gamma Spectrum of Resin Concentrator Bag 0.1 mi Below Plant Vogtle Outfall, Collected Jan 29 - Feb 12, 1987. Cs-137 is only manmade isotope in spectrum.

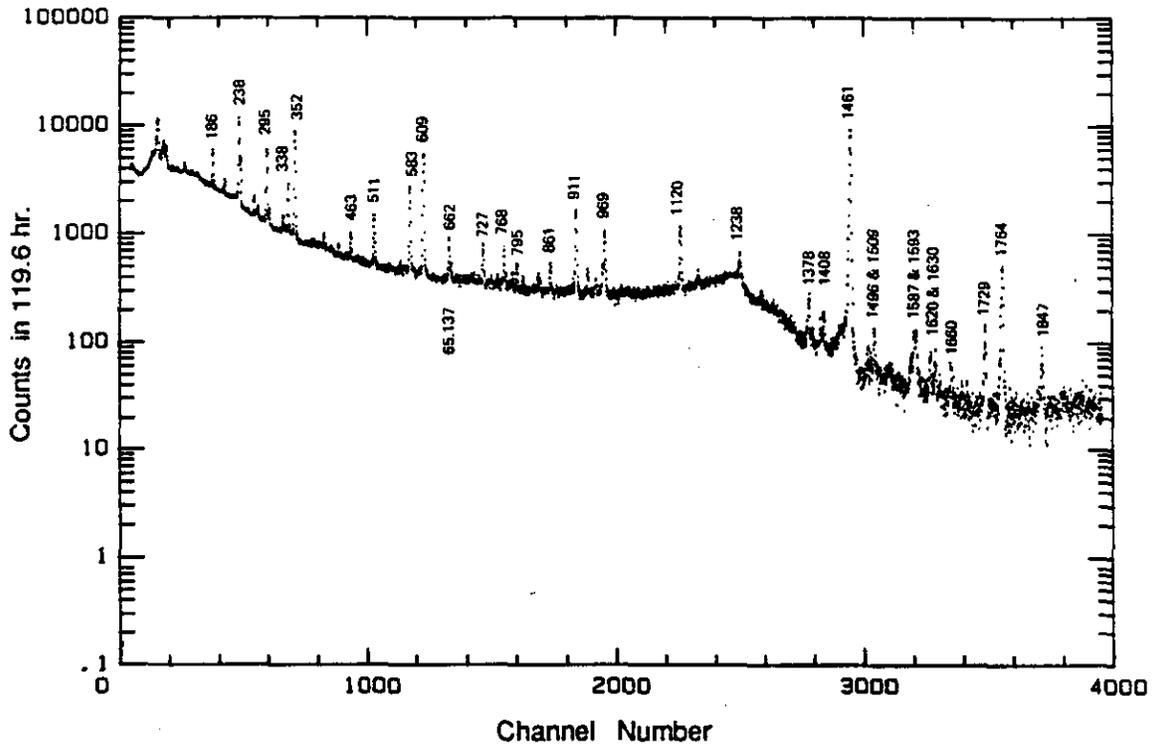
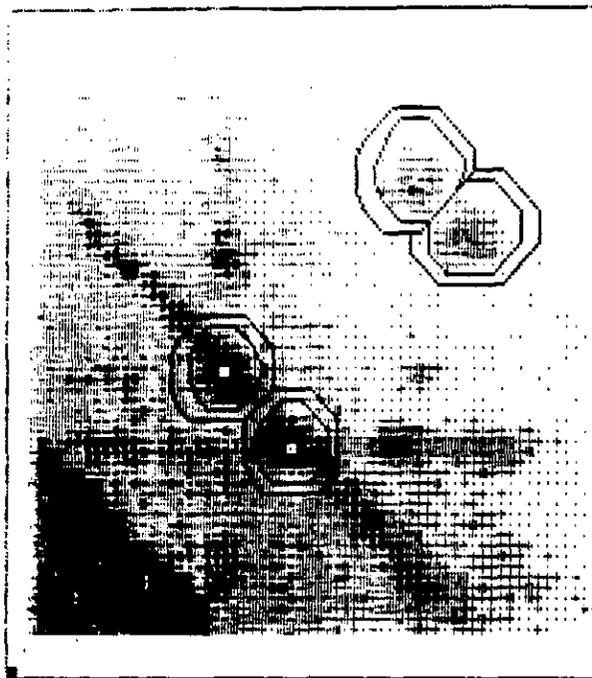


Figure 3. HPGe Gamma Spectrum of Sediment Sample 0.1 mi Below Plant Vogtle, Collected on Feb 12, 1987. Cs-137 is only manmade isotope in spectrum.



KEY SELECTIONS

```

A cursor on
B cursor off
  x-ch 34
  y-ch 39
C energy cal
  x-en 1348 keV
  y-en 1188 keV
  sum 2535 keV
D define ROI
  R-4 Co-60
  gross 731
  bkgnd 190
  total 541
E erase ROI
F find ROIs
P print ROIs
R recall ROIs
S save ROIs
T transplots
X replot
Z end all

```

Figure 4. Dual NaI Contour Spectrum for Resin Concentrator Bag Sample from Mouth of Four Mile Creek, Collected March 26-April 9, 1987. Co-60 is detected in upper right pair of windows; middle pair contain natural background peaks.

Underwater NaI

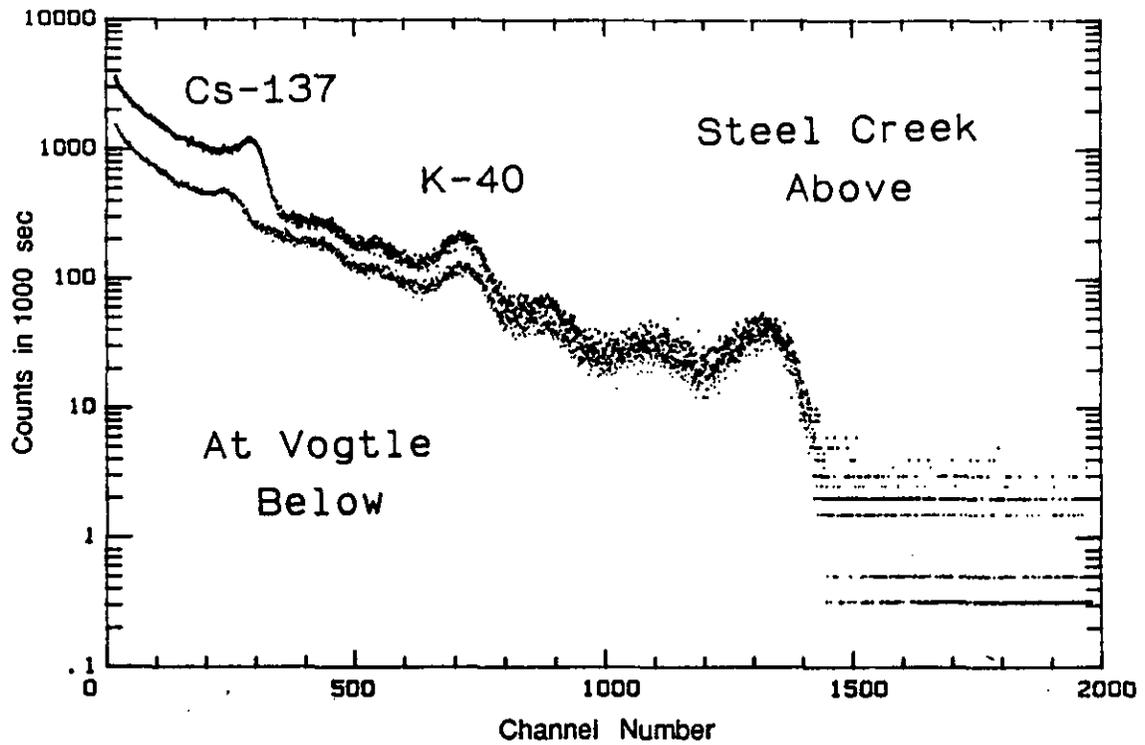


Figure 5. *In Situ* Underwater NaI Detector Comparison of Sediments at Steel Creek Branch and Plant Vogtle Outfall

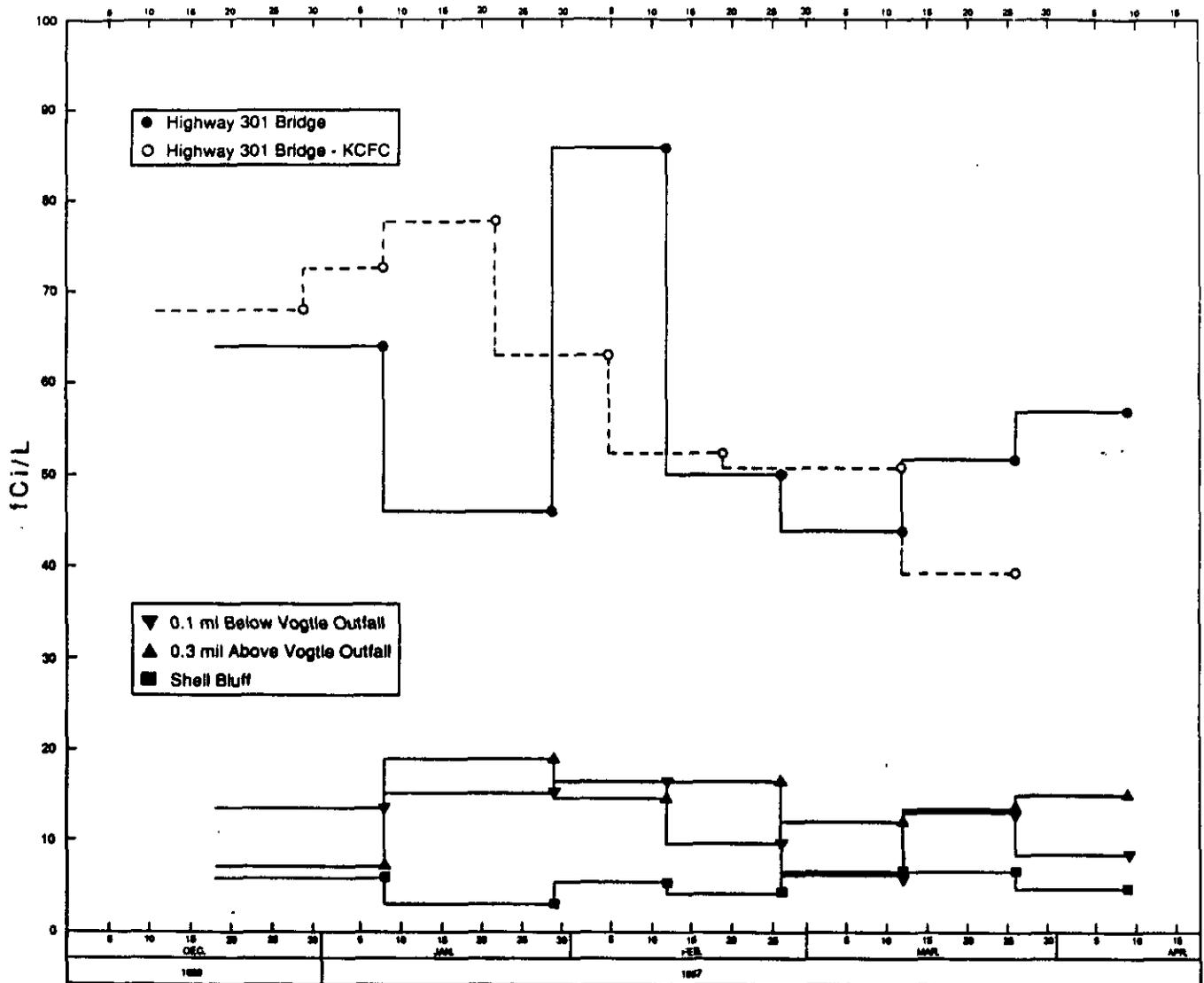


Figure 6. Time-Department Resin Concentrator Bag Measurements of Cs-137 in Savannah River (Points denote when sample removed)

APPENDIX A

DETECTOR CALIBRATIONS

HPGe Detectors. The HPGe detector calibrations for three sizes of aqueous sample vials used NBS traceable solutions from Amersham International. The standard (Amersham # QCY.46) emits eleven gammas of known intensity, ranging in energy from 88 KeV to 1836 keV. The three calibrated vial types are for volumes (diameter x height range) of 23 mm x 0-50 mm, 32 mm x 0-32 mm, and 62 mm x 0-60mm. The ashed absorbers had a density close to that of water, after compression into disks that fit into the 32 mm vials. Therefore, the above calibrations apply. However, one liter Marinelli sediment samples needed corrections for density and geometry.

The Marinelli sediment samples used efficiencies developed as follows. About 300 g from a previously counted Marinelli sample, which showed a large 1461 keV peak from ^{40}K , filled a large 62 mm diameter vial to its maximum calibration height of 60 mm. The vial was then counted. Next, a calculation corrected 1461 keV gamma-ray attenuation for the sediment density and vial sample geometry. The resulting attenuated efficiency was 0.9235 of the efficiency calibrated for aqueous solutions. The attenuation correction modeled the efficiency as a function of height, viz

$$\epsilon = k \int_0^h e^{-\mu y} \frac{dy}{(y + h_0)^2}$$

where ϵ = efficiency
 k = constant
 μ = attenuation coefficient for 1461 keV
(water or sediment)
 y = height variable for integral
 h = sample height in vial
 h_0 = distance from bottom of vial to effective detector center, based on calibration data.

The ratio of calculated efficiencies for sediment and water yielded the efficiency correction. Calculations of the ^{40}K concentrations use the corrected vial efficiency. This allows calibrating the Marinelli for ^{40}K , but provides an absolute calibration for 1461 keV gammas only. It yields one point on the efficiency curve for the Marinelli sediment samples. However, the corresponding profile of the efficiency curve was readily deduced using the relative gamma intensities from natural species (particularly ^{214}Bi) in the Marinelli sediment spectrum. The entire procedure above was performed for two samples for the two HPGe detectors.

Dual NaI Detector. Calibration of the Dual NaI detector for ^{60}Co used a point source made from a known ^{60}Co solution. An HPGe detector calibrated this source against an NBS-traceable point standard (Amersham # QCD.1). The source was then centered in the dual NaI detector cavity to calibrate the detector. Finally, a sample of NBS SRM-4350B (Table 1) confirmed the adequacy of the calibration.

^{60}Co calibrations for sediment samples utilize the results from Marinelli samples that contained relatively large amounts of ^{60}Co . As noted in section II C.4, the resulting efficiency was about half that for the centered point source. Uncertainties from geometrical/attenuation effects render a corresponding uncertainty of about 30%. Nevertheless, the system provided the most sensitive detection for confirming the presence of ^{60}Co in the sediment samples.

APPENDIX B

DETAILED DESCRIPTION OF SAMPLE SITES

Tables include detailed descriptions of sample sites to assist possible future comparisons of activities at the same sites. Table B.1 describes the stream sites and Table B.2 describes the terrestrial sites.

Table B.1. Sample Location Descriptions - Stream Sites

(A = ashed absorber / S = sediment sample / T = tritium)

Site	River Mile	Description
A. Shell Bluff	161.7	Near pontoon boat, in middle of River (A,S,T).
B. Upper Three Runs	157.2	About 50 yards into mouth (A,T). Near east and west banks (S).
C. Georgia Inlet	156.7	Across from SRP dock, 50 yds beyond houseboat (A, S, T).
D. Beaver Dam Creek	152.1	About 30 yds into mouth (A, S, T).
E. Hancock Landing	151.7	About 15 yds from shore and 25 yds downstream (S, T).
F. Above Vogtle Right Bank	151.0	Near overhanging trees on GA side and ~7 yd from bank (A, S, T).
G. Above Vogtle Middle	151.0	Middle of river (S).
H. Above Vogtle Left Bank	151.0	~10 yd from SC side (S).
I. Vogtle Outfall	150.7	~10 yd downstream from the outfall (S, T).*
J. Below Vogtle Right Bank	150.6	Near overhanging trees on GA side and ~7 yd from bank (A, S, T).
K. Below Vogtle Middle	150.6	Middle of river (S).
L. Below Vogtle Left Bank	150.6	~10 yd from SC side (S).
M. Four Mile Creek	150.4	~30 yd into mouth, near middle (A, S, T).

*This refers to concrete duct outfall gate. An underwater pipe outfall is about 20 yd downstream from this.

**Table B.1.
(Continued)**

Sample Location Descriptions - Stream Sites

(A = ashed absorber / S = sediment sample / T = tritium)

Site	River Mile	Description
N. Below Four Mile Right Bank	150.3	~15 yd from GA side bank (S).
O. Below Four Mile Middle	150.3	Middle of river (S).
P. Below Four Mile Left Bank	150.3	~15 yd from SC side bank (S).
Q. Still Water Site	150.0	In still water ~3 yd from bank of river bend on GA side (S).
R. Steel Creek Branch	141.5	~50 yd into a cut between creek and landing (A, S, T).
S. Highway 301 Bridge Right Bank	118.7	Near pontoon boat on GA side (A, S, T).
T. Highway 301 Bridge Middle	118.7	Middle of river (S).

Table B.2. Plant Vogtle Sample Location Descriptions - Terrestrial Site

Site ID	Latitude/ Longitude	Plant Vogtle Area Emergency Map Sector	Location Description
#01	33°13.22' 81°45.87'	Sector A, 5.5 miles	Site is N/W of D Area near the intersection of Rd A-4.7 to the dock road. The site is N/W of the intersection; 66' from the centerline of A-4.7 and 69' from centerline of dock road.
#02	33°11.82' 81°45.27'	Sector A, 4.0 miles	Site is at the end of Rd A-4.7 near the gate of 681-5G pump-house on the right side of the road, 3' from N. corner of fence between fencepost and guard rail.
#03	33°12.78' 81°45.49'	Sector A, 5.5 miles	Site is near the intersection of Rd. 3 and Rd A.4, 90' from of A-4 and 45' from of Rd 3 in the N/E Quadrant.
#04	33°12.99' 81°46.00'	Sector A, 5.25 miles	From Rd A-4.7 going North from TNX, turn left. The site is 153' from the boat dock, in line with ladder toward the woods.
#05	33°10.18' 81°44.49'	Sector B, 1.9 Miles	From Highway 125, take Rd A-13 south along Four Mile Creek take last road to the right before A-13 turns S/E. Continue going S/W along Four Mile Creek to a dead end. On a curve, to your right, will be the only large pine in the immediate vicinity. Also there is an oak south of the pine about 30'. The site is about 25'8" from the pine, heading 198 and 5'4" from the oak, heading 37 .
#06	33°11.16' 81°42.48'	Sector C, 4.5 miles	Go to railroad tracks on Rd A-13 near 400 D Area. Site is 3'6" at heading 231 from concrete buried cable marker, SC-002420.

Table B.2. Plant Vogtle Sample Location Descriptions - Terrestrial Site (Continued)

Site ID	Latitude/ Longitude	Plant Vogtle Area Emergency Map Sector	Location Description
#07	33°11.12' 81°44.99'	Sector B, 3.2 miles	Take road A 12.2 South from D Area. Turn on first dirt road right and go to end of road Site is to the right in the woods, next to an oak tree about 6'6" circumference marked #30.
#08	33°11.01' 81°43.40'	Sector C, 3.5 miles	Go South on A-13 from Highway 125. Go beyond A 212 intersection to first dirt road to the left. A-13 curves right. Site is at the point where tangent lines to curve A-13 intersect.
#09	33°09.79' 81°43.58'	Sector C, 2.5 miles	Along Rd A-13, site is on slight right hand curve. First curve after first road to left after road turns east. Site is where tangent lines to the curve intersect.
#10	33°09.31' 81°42.60'	Sector D, 3.0 miles	Site is at the hog barn on Rd A-13. It is inline with the west side of the barn 50' from the corner nearest the road. Heading is generally N/NE.
#11	33°08.96' 81°41.79'	Sector E, 4 miles	Site is on Rd A-13, west of the Hog Barn on the curve where A-13 turns North. The site is 50' from of the road heading 180 through the point of intersection of the curve.
#12	33°09.48' 81°40.72'	Sector D, 5.5 miles	Site is where A-17.1 crosses the railroad track. Go 30' at 258 from buried cable marker, SC 002401 to sample point.
#13	33°08.25' 81°41.14'	Sector E, 4.5 miles	Go South on A-17 from the East end of A-17. Turn on the first road to the right. Bear right along Tom Roberson Road. An orange marker is on the left side in the swamp. 217.5 from marker is a metal box on a tree marked with an orange triangle. Sample point is in line with marker and tree. It is 8' from the base of the largest pine in the area.

**Table B.2. Plant Vogtle Sample Location Descriptions - Terrestrial Site
(Continued)**

Site ID	Latitude/ Longitude	Plant Vogtle Area Emergency Map Sector	Location Description
#14	33°15.00' 81°50.46'	Sector R, 6.75 miles	Sample site is 25' at heading 74 from a concrete marker. The marker is 6' west of the gate at Shell Bluff landing.
#1	33°12.68' 81°50.93'	Sector Q, 6.75 miles	The sample point is marked by an angle iron 102' at heading 360 from of the intersection of GA 56 spur and GA 80.
#16	33°09.59' 81°45.90'	Sector Q, 1.75 miles	On Hancock Road going North to Hancock Landing, take right fork. Go about 90 yards down road. On right side of road, down a steep hill, is a concrete survey marker next to the fence. Sample point is 9.5' from marker (heading 40).
#17	33°09.22' 81°47.47'	Sector P, 1.90 miles	From the center of the intersection of Hancock Landing Road and River Road, go 110' for about 30' to a bench mark. Site sample point is 3' due North of bench mark.
#18	33°09.59' 81°50.73'	Sector P, 5.5 miles	Go to Fairfield Church Cemetery north of the intersection of GA 23 and Road. Sample point is 58' (heading 245) from S/W corner of the church.
#19	33°11.59' 81°49.57'	Sector Q, 5.2 miles	Allen's Chapel is on Road 58, off of off of River Road about 1.5 miles. It is East of GA 80 and GA 56 Spur/River Road intersection. From the grave marker of Anderson Dewey Jones, in the Allen's Chapel cemetery, go 248' for 10' to the sample point.

**Table B.2. Plant Vogtle Sample Location Descriptions - Terrestrial Site
(Continued)**

Site ID	Latitude/ Longitude	Plant Vogtle Area Emergency Map Sector	Location Description
#20	33°09.74' 81°49.82'	Sector M, 2.7 miles	From GA 23 take Hancock Landing Road North to Claxton Lively Intersection. Turn right on CR104. Go 0.9 miles to intersection of CR101. Turn right on CR101. Go to first set of power lines. Site is on the North side of the road, West of the power lines at the end of the fence, 25'6" from the West survey marker heading 18 .
#21	33°06.81' 81°48.11'	Sector L, 2.8 miles	Go South from Vogtle main gate on CR 96. Turn right on first road, CR97. Go about 2 miles to emergency siren on right. From siren, go 20' (heading 60) to sample site.
#22	33°07.45' 81°46.64'	Sector L, 1.6 miles	Take CR96 South from Vogtle main gate about 0.5 miles, to Ebenezer Baptist Church cemetery. Sample point is is S/E corner of the cemetery, 15' West of the corner survey marker.
#23	33°06.46' 81°46.88'	Sector K, 3.5 miles	Take Rd 96 South from Vogtle gate about 3 miles to intersection of 96 and two dirt roads. The road running North/South has a gate. From the West side of the gate, go 13' at 325 to the sample point.
#24	33°04.68' 81°47.41'	Sector K, 4.5 miles	From # of the intersection of CR 96 and GA 23, sample site is 60'8" heading 207 . Also from survey marker on the south side of the road, 14' (heading 225) to sample point.
#25	33°04.49' 81°46.01'	Sector S, 4.5 miles	From the Easternmost intersection of GA 23 and CR 95, go north on CR95 until it turns sharply West. From the point where tangent lines to the curve intersect, go 30' at 05° to the sample site. Also from the end fencepost on the South side of the road, go 63' at 302° to sample site.

**Table B.2. Plant Vogtle Sample Location Descriptions - Terrestrial Site
(Continued)**

Site ID	Latitude/ Longitude	Plant Vogtle Area Emergency Map Sector	Location Description
#26	33°03.31' 81°43.42'	Sector H, 6.5 miles	Turn North on CR 85 from inter- of GA 23 & CR 85. Bethany Church is on the left and the cemetery is on the right. At the N/E corner of the cemetery is a concrete survey marker. From this marker go 23'9" at 137° to the sample site The heading from site to N/E corner of church is 257°.
#27	33°05.96' 81°42.67'	Sector G, 4.3 miles	From the intersection of CR59 (River Road) and CR85 (Griffins Landing Road), go West on CR59. Cochran Grove Church cemetery is to the right. From the grave marker of Rosa Mae Mobley, go 10.5' at 315° to the site.
#28	33°07.59' 81°43.37'	Sector F, 1.75 miles	Take River Road East from Vogtle East gate. Turn on first road to left to Plant Vogtle Landing. East of the landing is Jetty #65. From the first piling on the East side of the jetty, go 16' at 235° to the sample site.
#29	31°04.40' 81°43.24'	Sector H, 5.2 miles	From GA 23, North of Girard take CR85 (Griffins Landing Road) to CR86 (Chance Road). Turn West on CR86. Go about 0.1 miles to first emergency siren pole. Site is 8' at 215° from pole.
#30	33°05.80' 81°39.11'	Sector F, 7 miles	From Girard, GA, take CR79 (Bingham's Landing Road) North. At Bingham's Landing there is a Plant Vogtle siren on the West side. The site is 10' at 360° from the siren pole.
#31	33°08.88' 81°48.78'	Sector N, 3 miles	From the GA23 and CR98 (Hancock Landing Road) intersection go North on CR98 about 3.5 mi to a dirt road on right marked Daniel Grove Church Cemetery. From the grave marker of Leo E. Godbee, the site is 1' at 270° from the south end of the headstone.

APPENDIX C

DATA ANALYSIS AND RESULTS

Tables 2-6 of the main text summarize the measurement results, and Tables C.1-C.12 of this Appendix detail them further. This Appendix deals only with the gamma-ray measurements, as the beta liquid scintillation measurements for H-3 are already self-contained in text Table 2. The discussion below details the gamma-ray analyses with references to the appropriate appendix table. (Note: text table values summarize the appendix tables).

Table C.1 / Detailed ^{60}Co Results for Water Samples. Each ^{60}Co value used measurements from both the HPGe and dual NaI detectors. The analysis incorporates ^{60}Co measured on both the resin and the concentrator. In general, each result incorporates three measurements:

A_1 = HPGe ^{60}Co activity of resin

A_2 = HPGe ^{60}Co activity of concentrator

A_3 = Dual NaI ^{60}Co activities sum of
resin and concentrator.

Dividing by the volume of water that passed through the absorbers leads to aqueous concentrations (fCi/l). The water was calculated as

$$W_1 = C_1 \times M_1$$

$$W_2 = C_2 \times M_2$$

$$W_s = C_1 \times M_1 + C_2 \times M_2 + \dots + (\text{any additional absorbers})$$

where the C's are experimentally measured constants and the M's are the masses of the absorbers. Thus, Table C.1 shows the ^{60}Co concentrations as appropriate weighted averages of the corresponding A_1/W_1 , A_2/W_2 , and A_3/W_s calculations. For the individual dated entries, the dual NaI measurements provided the most sensitive data for several cases. In particular, all less-than (<) and approximate (~) values are from the dual NaI results. Some of these entries have errors given as $a/3$, $j/2$,...etc, and these indicate that the samples were counted in groups a,j,... having 3,2,... samples each. Accordingly the activity of each of these entries is the average for the group; however, these entries are fairly representative for these marginally or non-detected ^{60}Co cases. When data include uncertainties, the entries are primarily from HPGe measurements.

Several averaging techniques yielded the values in the last column of the table. The fCi/l average is an unweighted average of selected data entries. If all entries are < values, the table lists an average of these values. If it lists < and ~ values, their average includes only the ~ values. Finally, if the table shows <, ~, and \pm values, their average includes ~ and \pm values, and in addition, the average 1-sigma values. The above policies give the summary values in Table 2 that are representative of typical values and counting errors.

Normalizing entries to 100% of the average in the last column helps display the time-dependent scatter in the sample collection. The column includes sample standard deviations for the normalized averages when appropriate, and had a range of 19%-50%, with typical values being about 40%.

Table C.2 / Detailed ^{137}Cs Results for Water Samples. These results used only measurements from the HPGe detectors. Calculation of ^{137}Cs concentrations as A_1/W_1 and A_2/W_2 is similar to ^{60}Co in Table C.1. The weighted averages of these two numbers, based on counting statistics, yielded the time-dependent entries given in Table C.2.

Each fCi/l average in the final column includes all corresponding time-dependent entries, except those that are less-than (<). The fCi/l average error is given as a guide to the typical counting error. The entries are normalized to 100% of the average value, and a typical sample standard deviation is ~30%.

Table C.3 / Reference for Detailed Sediment Sample Locations. This table acts as a template guide for identification of sample locations for sediment results presented in Tables C.4-C.12. Each letter entry A,B,... corresponds to the location descriptions listed in Appendix Table B.1.

Table C.4 / Detailed ^{60}Co Results for Sediment Samples. Measurements of about 1 kg of each sediment sample with HPGe and Dual NaI gave these results. All less-than (<) values are from the dual NaI results, due to its better sensitivity. All results for sediments within the Savannah River were also from measurements with the dual NaI, since a HPGe marginally detected or did not detect these levels at all. The better calibrated HPGe detectors measured the larger amounts in inlet sediments. The error shown is 1-sigma counting uncertainty.

Tables C.5-C.12 / Detailed Isotope Results for Sediment Samples. All results are from HPGe measurements of the Marinelli sediment samples. For isotopes having several well-detected gamma rays, such as ^{214}Bi and ^{228}Ac , the value is a weighted average along with its weighted 1-sigma counting error.

Tables C.13-C.14 / Natural Isotopic Levels for Soil Samples. For completeness, the tables include natural levels for soil samples in the same format used in Tables 5-6 for corresponding manmade radionuclides.

Table C.1. Detailed ⁶⁰Co Results for Water Samples^a

Location & Units	1986-87 Sampling Intervals								Average & Error
	12/15	12/18	01/08	01/29	02/12	02/26	03/12	03/26	
	12/18	01/08	01/29	02/12	02/26	03/12	03/26	04/09	
Sh Bluff									
fCi/l	<1.4	<1.5	<0.6	<0.6	<0.6	<0.6	<0.6	<0.9	<1.0
err	a/3	b/3	c/3	d/2	d/2	c/3	c/3	e/2	
Norm	<140	<150	<60	<60	<60	<60	<60	<90	<100
Up Thr Rn									
fCi/l	—	—	—	—	—	—	~1.0	<0.9	~1.0
err	—	—	—	—	—	—	f/2	e/2	
Norm	—	—	—	—	—	—	~100	<90	~100
Ga Inlet									
fCi/l	—	—	—	—	—	—	~1.0	~0.8	~0.9
err	—	—	—	—	—	—	f/2	g/2	
Norm	—	—	—	—	—	—	~111	~89	~100
Bvr Dam									
fCi/l	—	—	—	—	—	—	8.7	6.6	7.6
err	—	—	—	—	—	—	±0.6	±0.3	±0.5
Norm	—	—	—	—	—	—	114	87	100±19
Abv Vogtl									
fCi/l	<1.4	<1.5	~0.5	~0.9	~0.9	~0.5	~0.5	~0.7	~0.7
err	a/3	b/3	h/3	i/2	i/2	h/3	h/3	j/2	
Norm	<200	<214	~71	~129	~129	~71	~71	~108	~100
Blw Vogtl									
fCi/l	<1.4	<1.5	~1.0	~1.0	~1.0	~1.0	~1.0	~0.7	~0.9
err	a/3	b/3	k/3	l/3	l/3	k/3	k/3	j/2	
Norm	<156	<167	~111	~111	~111	~111	~111	~78	~100
4 Mi Ck									
fCi/l	—	—	—	—	—	—	18.1	9.4	13.8
err	—	—	—	—	—	—	±0.3	±0.4	±0.4
Norm	—	—	—	—	—	—	131	68	100±45
St Cr Br									
fCi/l	—	—	—	—	—	—	2.9	6.2	4.6
err	—	—	—	—	—	—	±0.4	±0.4	±0.4
Norm	—	—	—	—	—	—	63	134	100±50
Hwy 301									
fCi/l	~3.0	4.1	<1.2	~1.4	~1.4	~3.0	3.1	1.4	2.5
err		±1.4		m/2	m/2		±1.0	±0.5	±0.9
Norm	~120	165	<48	~56	~56	~120	125	56	100±44

(a) See explanation of table notations in Appendix C text.

Table C.2. Detailed ¹³⁷Cs Results for Water Samples^a

Location & Units	1986-87 Sampling Intervals								Average & Error
	12/15	12/18	01/08	01/29	02/12	02/26	03/12	03/26	
	12/18	01/08	01/29	02/12	02/26	03/12	03/26	04/09	
Sh Bluff									
fCi/l	<1.7	6.0	3.3	5.4	4.2	6.6	6.6	4.7	5.3
err		±1.2	±0.2	±0.4	±0.3	±0.5	±0.5	±0.4	±0.5
Norm	<33	114	63	103	80	125	125	89	100±24
Up Thr Rn									
fCi/l	—	—	—	—	—	—	5.9	18.6	12.3
err	—	—	—	—	—	—	±0.4	±0.6	±0.5
Norm	—	—	—	—	—	—	48	151	100±73
Ga Inlet									
fCi/l	—	—	—	—	—	—	2.3	4.2	3.3
err	—	—	—	—	—	—	±0.1	±0.3	±0.2
Norm	—	—	—	—	—	—	71	129	100±40
Bvr Dam									
fCi/l	—	—	—	—	—	—	15.1	7.7	11.4
err	—	—	—	—	—	—	±0.6	±0.3	±0.5
Norm	—	—	—	—	—	—	132	68	100±46
Abv Vogtl									
fCi/l	<3.3	7.3	19.3	14.8	16.7	12.2	13.2	15.2	14.1
err		±2.2	±0.6	±0.5	±0.6	±0.4	±0.5	±0.5	±0.8
Norm	<23	52	137	105	118	87	94	108	100±27
Blw Vogtl									
fCi/l	<3.1	13.7	15.3	16.5	9.8	6.4	13.0	8.6	11.9
err		±1.4	±0.6	±0.6	±0.4	±0.4	±0.5	±0.4	±0.6
Norm	<26	115	129	139	82	54	109	72	100±31
4 Mi Ck									
fCi/l	—	—	—	—	—	—	366	247	307
err	—	—	—	—	—	—	±2	±2	±2
Norm	—	—	—	—	—	—	119	80	100±27
St Cr Br									
fCi/l	—	—	—	—	—	—	43.9	309	176
err	—	—	—	—	—	—	±0.6	±2	±2
Norm	—	—	—	—	—	—	25	176	100±106
Hwy 301									
fCi/l	19.1	64.4	46.0	86.1	49.9	43.8	51.5	57.1	56.9
err	±11.7	±2.1	±0.4	±1.4	±0.8	±1.1	±0.5	±1.1	±1.3
Norm	34	113	81	151	88	77	91	100	100±26

(a) See explanation of table notations in Appendix C text.

Table C.3. Reference for Detailed Description of Sediment Sample Locations^a

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	A	--	--
Upper Three Runs	--	--	--	--	B
Georgia Inlet	C	--	--	--	--
Beaver Dam	--	--	--	--	D
Hancock Landing	--	E	--	--	--
Above Vogtle	--	F	G	H	--
Vogtle Outfall	--	I	--	--	--
Below Vogtle	--	J	K	L	--
Four Mile Creek	--	--	--	--	M
Below Four Mile	--	N	O	P	--
Still Water Site	--	Q	--	--	--
Steel Creek Branch	--	--	--	--	R
Highway 301 Bridge	--	S	T	--	--

(a) Locations letters (A,B,...etc) are relative to Table B.1. of Appendix B. Refer to Appendix C text for further details.

Table C.4. Detailed ^{60}Co Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	<1	--	--
Upper Three Runs	--	--	--	--	<2 <1
Georgia Inlet	<1	--	--	--	--
Beaver Dam	--	--	--	--	71 92 ±4 ±5
Hancock Landing	--	2.8 ±0.5	--	--	--
Above Vogtle	--	~1.0	<1.6	2.3 ±0.3	--
Vogtle Outfall	--	<1.2	--	--	--
Below Vogtle	--	<1.0	~1.2	~3.1	--
Four Mile Creek	--	--	--	--	292 233 ±4 ±4
Below Four Mile	--	1.1 ±0.2	~1.6	~2.1	--
Still Water Site	--	<1.0	--	--	--
Steel Creek Branch	--	--	--	--	73 ±2
Highway 301 Bridge	--	3.3 ±0.5	3.6 ±0.5	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.5. Detailed ^{137}Cs Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	26 ±3	--	--
Upper Three Runs	--	--	--	--	<3 <6
Georgia Inlet	24 ±2	--	--	--	--
Beaver Dam	--	--	--	--	103 219 ±7 ±10
Hancock Landing	--	174 ±7	--	--	--
Above Vogtle	--	9 ±4	23 ±2	<15	--
Vogtle Outfall	--	<5	--	--	--
Below Vogtle	--	12 ±4	24 ±2	10 ±3	--
Four Mile Creek	--	--	--	--	4830 4080 ±20 ±20
Below Four Mile	--	9 ±2	18 ±2	22 ±2	--
Still Water Site	--	13 ±3	--	--	--
Steel Creek Branch	--	--	--	--	35900 ±100
Highway 301 Bridge	--	264 ±2	213 ±2	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.6. Detailed ⁴⁰K Results for Sediment Samples ^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	10600 ±100	--	--
Upper Three Runs	--	--	--	--	76 146 ±12 ±9
Georgia Inlet	10900 ±100	--	--	--	--
Beaver Dam	--	--	--	--	9690 17900 ±150 ±200
Hancock Landing	--	15000 ±200	--	--	--
Above Vogtle	--	8260 ±190	9320 ±50	11100 ±200	--
Vogtle Outfall	--	7070 ±70	--	--	--
Below Vogtle	--	4250 ±140	9030 ±40	7430 ±150	--
Four Mile Creek	--	--	--	--	20700 17400 ±100 ±100
Below Four Mile	--	7100 ±70	8560 ±80	8310 ±80	--
Still Water Site	--	7350 ±90	--	--	--
Steel Creek Branch	--	--	--	--	10100 ±100
Highway 301 Bridge	--	9310 ±50	9070 ±50	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.7. Detailed ^{208}Tl Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	140 ±3	--	--
Upper Three Runs	--	--	--	--	30 43 ±2 ±1
Georgia Inlet	122 ±3	--	--	--	--
Beaver Dam	--	--	--	--	544 552 ±9 ±10
Hancock Landing	--	409 ±9	--	--	--
Above Vogtle	--	67 ±6	117 ±2	127 ±8	--
Vogtle Outfall	--	98 ±3	--	--	--
Below Vogtle	--	53 ±6	102 ±1	77 ±5	--
Four Mile Cree	--	--	--	--	665 569 ±7 ±8
Below Four Mile	--	71 ±2	112 ±3	100 ±3	--
Still Water Site	--	71 ±3	--	--	--
Steel Creek Branch	--	--	--	--	470 ±6
Highway 301 Bridge	--	78 ±2	166 ±2	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.8. Detailed ²¹²Pb Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	378 ±6	--	--
Upper Three Runs	--	--	--	--	67 123 ±4 ±3
Georgia Inlet	405 ±7	--	--	--	--
Beaver Dam	--	--	--	--	2100 1530 ±20 ±20
Hancock Landing	--	1190 ±20	--	--	--
Above Vogtle	--	183 ±14	326 ±4	463 ±20	--
Vogtle Outfall	--	342 ±6	--	--	--
Below Vogtle	--	103 ±12	321 ±13	296 ±12	--
Four Mile Creek	--	--	--	--	2480 1570 ±20 ±20
Below Four Mile	--	223 ±5	355 ±7	263 ±7	--
Still Water Site	--	198 ±7	--	--	--
Steel Creek Branch	--	--	--	--	1700 ±20
Highway 301 Bridge	--	236 ±4	568 ±5	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.9. Detailed ^{214}Bi Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	387 ±5	--	--
Upper Three Runs	--	--	--	--	169 253 ±4 ±3
Georgia Inlet	313 ±6	--	--	--	--
Beaver Dam	--	--	--	--	1570 1670 ±20 ±20
Hancock Landing	--	1370 ±20	--	--	--
Above Vogtle	--	285 ±13	435 ±4	534 ±17	--
Vogtle Outfall	--	254 ±5	--	--	--
Below Vogtle	--	275 ±12	383 ±3	376 ±11	--
Four Mile Creek	--	--	--	--	2210 1930 ±20 ±20
Below Four Mile	--	345 ±5	494 ±6	368 ±6	--
Still Water Site	--	442 ±7	--	--	--
Steel Creek Branch	--	--	--	--	1230 ±10
Highway 301 Bridge	--	435 ±4	450 ±4	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.10. Detailed ^{214}Pb Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	379 ±5	--	--
Upper Three Runs	--	--	--	--	165 243 ±4 ±3
Georgia Inlet	323 ±5	--	--	--	--
Beaver Dam	--	--	--	--	1850 1680 ±20 ±20
Hancock Landing	--	1300 ±20	--	--	--
Above Vogtle	--	300 ±11	418 ±14	576 ±16	--
Vogtle Outfall	--	251 ±5	--	--	--
Below Vogtle	--	241 ±11	406 ±3	386 ±10	--
Four Mile Creek	--	--	--	--	2340 1880 ±10 ±20
Below Four Mile	--	375 ±5	509 ±6	356 ±6	--
Still Water Site	--	448 ±7	--	--	--
Steel Creek Branch	--	--	--	--	1290 ±10
Highway 301 Bridge	--	451 ±4	474 ±4	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.11. Detailed ^{226}Ra Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	954 ±54	--	--
Upper Three Runs	--	--	--	--	425 552 ±35 ±29
Georgia Inlet	829 ±57	--	--	--	--
Beaver Dam	--	--	--	--	4400 3540 ±150 ±180
Hancock Landing	--	3070 ±170	--	--	--
Above Vogtle	--	845 ±131	1040 ±40	1340 ±170	--
Vogtle Outfall	--	684 ±49	--	--	--
Below Vogtle	--	873 ±160	1140 ±30	756 ±96	--
Four Mile Creek	--	--	--	--	5730 3950 ±140 ±150
Below Four Mile	--	832 ±43	1120 ±60	701 ±56	--
Still Water Site	--	878 ±71	--	--	--
Steel Creek Branch	--	--	--	--	3930 ±17
Highway 301 Bridge	--	880 ±35	1380 ±40	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.12. Detailed ^{228}Ac Results for Sediment Samples^a
 (All concentrations in pCi/kg)

Location	Inlets/Oxbows Georgia	Savannah River			Inlets/Oxbows Carolina
		Right	Middle	Left	
Shell Bluff	--	--	376 ±6	--	--
Upper Three Runs	--	--	-	--	80 133 ±4 ±3
Georgia Inlet	301 ±8	--	--	--	--
Beaver Dam	--	--	--	--	1280 1480 ±20 ±20
Hancock Land	--	1090 ±20	--	--	--
Above Vogtle	--	211 ±16	317 ±4	297 ±20	--
Vogtle Outfall	--	246 ±6	--	--	--
Below Vogtle	--	119 ±13	269 ±3	222 ±12	--
Four Mile Creek	--	--	--	--	1760 1510 ±20 ±20
Below Four Mile	--	214 ±5	305 ±7	266 ±7	--
Still Water Site	--	230 ±8	--	--	--
Steel Creek Branch	--	--	--	--	1240 ±10
Highway 301 Bridge	--	221 ±4	442 ±5	--	--

(a) All errors are 1-sigma counting errors. Locations relative to Table C.3 vice Table B.1. Refer to Appendix C text for further details.

Table C.13. Natural Activities in Soil^a (Concentrations in pCi/kg)

Site	40K	232Th Decay Chain		
		208Tl	212Bi	228Ac
#01, Sector A 5.5 miles	1450 ±20	186 ±2	647 ±16	548 ±6
#02, Sector A 4.0 miles	2960 ±60	209 ±4	678 ±35	510 ±20
#03, Sector A 5.5 miles	2970 ±60	244 ±4	802 ±37	682 ±14
#04, Sector A 5.25 miles	3050 ±60	555 ±6	1869 ±55	1490 ±20
#05, Sector B 1.9 miles	9380 ±90	571 ±6	1684 ±55	1550 ±20
#06, Sector C 4.5 miles	6790 ±110	264 ±6	869 ±60	761 ±21
#07, Sector B 3.2 miles	9770 ±80	534 ±5	1826 ±44	1470 ±20
#08, Sector C 3.5 miles	612 ±33	183 ±4	636 ±34	493 ±12
#09, Sector C 2.5 miles	7620 ±120	216 ±6	760 ±54	588 ±20
#10, Sector D 3.0 miles	4780 ±70	114 ±3	406 ±31	316 ±10
#11, Sector E 4.0 miles	541 ±53	199 ±6	680 ±60	542 ±21
#12, Sector D 5.5 miles	2860 ±60	658 ±6	2208 ±55	1890 ±20
#13, Sector E 4.5 miles	3730 ±100	103 ±5	415 ±52	319 ±17

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site descriptions.

Table C.13. Natural Activities in Soil^a (Concentrations in pCi/kg) Continued

Site	⁴⁰ K	²³² Th Decay Chain		
		²⁰⁸ Tl	²¹² Bi	²²⁸ Ac
#14, Sector R 6.75 miles	1050 ±40	352 ±5	1093 ±44	981 ±16
#15, Sector Q 6.75 miles	959 ±65	277 ±8	926 67	756 ±26
#16, Sector Q 1.75 miles	1060 ±50	656 ±7	2099 ±66	1720 ±20
#17, Sector P 1.9 miles	505 ±39	169 ±5	503 ±45	479 ±16
#18, Sector P 5.5 miles	836 ±18	297 ±2	1018 ±15	825 ±5
#19, Sector Q 5.2 miles	503 ±33	153 ±4	568 ±40	439 ±13
#20, Sector M 2.7 miles	606 ±24	262 ±3	855 ±23	697 ±9
#21, Sector L 2.8 miles	1240 ±80	223 ±8	678 ±68	696 ±27
#22, Sector L 1.6 miles	487 ±33	188 ±4	658 ±35	537 ±13
#23, Sector K 3.5 miles	379 ±39	167 ±5	571 ±49	451 ±17
#24, Sector K 4.5 miles	392 ±28	154 ±4	506 ±33	425 ±11
#25, Sector S 4.5 miles	239 ±22	135 ±3	439 ±27	364 ±9
#26, Sector H 6.5 miles	941 ±63	269 ±8	767 ±65	753 ±25
#27, Sector G 4.3 miles	450 ±30	226 ±4	818 ±38	623 ±13

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site descriptions.

Table C.13. Natural Activities in Soil^a (Concentrations in pCi/kg) Continued

Site	⁴⁰ K	²³² Th Decay Chain		
		²⁰⁸ Tl	²¹² Bi	²²⁸ Ac
#28, Sector F 1.75 miles	15400 ±100	421 ±7	1498 ±66	1170 ±20
#29, Sector H 5.2 miles	576 ±3	202 ±4	682 ±36	538 ±13
#30, Sector F 7.0 miles	12200 ±200	471 ±10	1585 ±87	1350 ±30

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site descriptions.

Table C.14. Natural Activities in Soil^a (Concentrations in pCi/g)

Site	²³⁸ U Decay Chain		
	²¹⁴ Bi	²¹⁴ Pb	²²⁶ Ra
#01, Sector A 5.5 miles	582 ±5	575 ±4	1180 ±30
#02, Sector A 4.0 miles	475 ±8	473 ±20	976 ±52
#03, Sector A 5.5 miles	672 ±10	679 ±9	1350 ±60
#04, Sector A 5.25 miles	987 ±13	990 ±11	2020 ±80
#05, Sector B 1.9 miles	1930 ±20	1980 ±10	4270 ±90
#06, Sector C 4.5 miles	776 ±14	784 ±13	1640 ±100
#07, Sector B 3.2 miles	1780 ±10	1810 ±10	4030 ±70
#08, Sector C 3.5 miles	487 ±9	468 ±8	1010 ±60
#09, Sector C 2.5 miles	557 ±13	562 ±12	1360 ±90
#10, Sector D 3.0 miles	371 ±7	366 ±6	857 ±52
#11, Sector E 4.0 miles	566 ±15	537 ±13	1080 ±90
#12, Sector D 5.5 miles	1380 ±10	1320 ±10	2740 ±90
#13, Sector E 4.5 miles	345 ±12	326 ±11	914 ±90

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site descriptions.

Table C.14. Natural Activities in Soil^a (Concentrations in pCi/g) Continued

Site	²³⁸ U Decay Chain		
	²¹⁴ Bi	²¹⁴ Pb	²²⁶ Ra
#14, Sector R 6.75 miles	593 ±9	600 ±8	1450 ±70
#15, Sector Q 6.75 miles	729 ±17	763 ±16	1750 ±120
#16, Sector Q 1.75 miles	1310 ±10	1290 ±10	2740 ±100
#17, Sector P 1.9 miles	438 ±11	438 ±10	795 ±71
#18, Sector P 5.5 miles	737 ±4	746 ±3	1510 ±30
#19, Sector Q 5.2 miles	414 ±9	408 ±9	854 ±65
#20, Sector M 2.7 miles	609 ±6	613 ±5	1260 ±40
#21, Sector L 2.8 miles	501 ±17	521 ±16	1160 ±110
#22, Sector L 1.6 miles	464 ±9	446 ±8	972 ±60
#23, Sector K 3.5 miles	398 ±11	372 ±10	791 ±83
#24, Sector K 4.5 miles	399 ±8	391 ±7	867 ±57
#25, Sector S 4.5 miles	297 ±6	289 ±6	575 ±44
#26, Sector H 6.5 miles	678 ±17	682 ±15	1470 ±120

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site descriptions.C-18

Table C.14. Natural Activities in Soil^a (Concentrations in pCi/g) Continued

Site	²³⁸ U Decay Chain		
	²¹⁴ Bi	²¹⁴ Pb	²²⁶ Ra
#27, Sector G 4.3 miles	554 ±9	542 ±8	1160 ±60
#28, Sector F 1.75 miles	1380 ±20	1390 ±10	2900 ±90
#29, Sector H 5.2 miles	504 ±9	511 ±8	931 ±63
#30, Sector F 7 miles	1510 ±20	1520 ±20	3180 ±130

(a) All errors are 1-sigma counting uncertainties. Refer to Table B.2. for complete site descriptions.C-18

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