25-9208①
1-3

EGG 10617-1192
UC-702
SEPTEMBER 1993

THE
**REMOTE
SENSING
LABORATORY**
OPERATED FOR THE U.S.
DEPARTMENT OF ENERGY BY EG&G/EM

AERIAL RADIOLOGICAL SURVEYS OF STEED POND SAVANNAH RIVER SITE

DATES OF SURVEYS: 1984-1989

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, Tennessee 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

AERIAL RADIOLOGICAL SURVEYS OF STEED POND SAVANNAH RIVER SITE

DATES OF SURVEYS: 1984-1989

A. E. Fritzsche
J. E. Jobst
Project Scientists

Reviewed By

H. W. Clark, Jr., Manager
Nuclear Radiation Department

Z. G. Burson
SRS Project Manager

This Document is UNCLASSIFIED

C. K. Mitchell
Classification Officer

This work was performed by EG&G/EM under Contract Number DE-AC08-88NV10617 with joint funding provided by the United States Department of Energy and E.I. du Pont de Nemours & Company, Inc., operators of the Savannah River Site and Savannah River Laboratory at the time of the surveys. The Savannah River Site and Savannah River Technology Center are currently operated by Westinghouse Savannah River Company, Inc.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

From June 1984 to August 1985, three aerial radiological surveys were conducted over Steed Pond at the Savannah River Site in South Carolina. In addition, Steed Pond was included in larger-area surveys of the Savannah River Site in subsequent years. The surveys were conducted by the Remote Sensing Laboratory of EG&G Energy Measurements, Inc., Las Vegas, Nevada, for the U.S. Department of Energy.

Airborne measurements were obtained for both natural and man-made gamma radiation over Steed Pond and surrounding areas. The first survey (June 1984) was conducted when the pond was filled to normal capacity for the time of the year. On September 1, 1984, the Steed Pond dam spillway failed causing the pond to drain. The four subsequent surveys were conducted with the pond drained. The second survey (mid-September 1984) and the third (August 1985) were conducted to study silt deposits exposed by the drop in water level after the spillway's opening. Steed Pond data from the February 1987 and April 1989 Savannah River Site surveys have been included to bring this study up to date.

CONTENTS

Abstract	ii
--------------------	----

Sections

1.0 Introduction	1
2.0 Site Description	1
3.0 Survey Plans	3
4.0 Survey Equipment	3
5.0 Data Processing	4
6.0 Data Analysis	5
6.1 Radiation Contours	5
6.2 Gamma Energy Spectra	8
7.0 Results	8
7.1 Regions of Interest	9
7.2 Man-Made Gross Count Contour Maps	9
7.3 Protactinium-234m Contour Maps	11
7.4 Total Terrestrial Gamma Count Rate Contour Maps	17
8.0 Conclusion	17

Figures

1 Steed Pond Location on the Savannah River Site	2
2 MBB BO-105 Helicopter with Detector Pods	4
3 Block Diagram of the REDAR IV System	5
4 Typical Operational Equipment Arrangement	6
5 Mobile Computer Processing Laboratory	7
6 Block Diagram of the REDAC System	7
7 Regions of Interest in the Tim's Branch and Upper Three Runs Creek Area	10
8 Man-Made Gross Count Rate Contour Map for the Tim's Branch and Upper Three Runs Creek Area, June 1984	12
9 Man-Made Gross Count Rate Contour Map for the Tim's Branch and Upper Three Runs Creek Area, September 1984	13

10	Man-Made Gross Count Rate Contour Map for the Steed Pond Area, August 1985	14
11	Man-Made Gross Count Rate Contour Map for the Steed Pond Area, February 1987	15
12	Man-Made Gross Count Rate Contour Map for the Steed Pond Area, April 1989	16
13	Protactinium-234m Dose Rate Contour Map for the Tim's Branch and Upper Three Runs Creek Area, June 1984	19
14	Protactinium-234m Dose Rate Contour Map for the Tim's Branch and Upper Three Runs Creek Area, September 1984	20
15	Protactinium-234m Dose Rate Contour Map for the Steed Pond Area, August 1985	21
16	Protactinium-234m Dose Rate Contour Map for the Steed Pond Area, February 1987	22
17	Protactinium-234m Dose Rate Contour Map for the Steed Pond Area, April 1989	23
18	Total Terrestrial Gamma Count Rate Contour Map for the Tim's Branch and Upper Three Runs Creek Area, June 1984	24
19	Total Terrestrial Gamma Count Rate Contour Map for the Tim's Branch and Upper Three Runs Creek Area, September 1984	25
20	Total Terrestrial Gamma Count Rate Contour Map for the Steed Pond Area, August 1985	26
21	Total Terrestrial Gamma Count Rate Contour Map for the Steed Pond Area, February 1987	27
22	Total Terrestrial Gamma Count Rate Contour Map for the Steed Pond Area, April 1989	28
C-1	Net Gamma Energy Spectrum over ROI 1, September 1984	33
C-2	Net Gamma Energy Spectrum over ROI 2, September 1984	33
C-3	Net Gamma Energy Spectrum over ROI 3, September 1984	34
C-4	Net Gamma Energy Spectrum over ROI 4, August 1985	34
C-5	Net Gamma Energy Spectrum over ROI 5, June 1984	35
C-6	Net Gamma Energy Spectrum over ROI 6, June 1984	35
C-7	Net Gamma Energy Spectrum over ROI 7, June 1984	36
C-8	Net Gamma Energy Spectrum over ROI 8, August 1985	36
C-9	Net Gamma Energy Spectrum over ROI 9, September 1984	37
C-10	Net Gamma Energy Spectrum over ROI 10, September 1984	37
C-11	Net Gamma Energy Spectrum over ROI 11, September 1984	38
C-12	Net Gamma Energy Spectrum over ROI 12, September 1984	38

C-13	Net Gamma Energy Spectrum over ROI 13, September 1984	39
C-14	Net Gamma Energy Spectrum over ROI 14, April 1989	39
E-1	Protactinium-234m Estimated Activity Versus Rainfall	42

Tables

1	Description of Regions of Interest in the Tim’s Branch Area	11
D-1	Conversions and Parameters	40
D-2	Dose Rates at 1 Meter Due to Sources in the Soil	41

Appendices

A	Survey Equipment and Specifications	29
B	Computer Algorithms	30
C	Gamma Energy Spectra	32
D	Conversion Coefficients	40
E	Rainfall Effects on Terrestrial Activity Measurements	42
	References	43

1.0 INTRODUCTION

Three aerial radiological surveys were conducted by the Remote Sensing Laboratory of EG&G Energy Measurements, Inc. (EG&G/EM) over Steed Pond at the Savannah River Site (SRS) for the U.S. Department of Energy. These surveys were part of the Comprehensive Integrated Remote Sensing program, a continuing series of aerial surveys designed to provide a technical database for studying the impact of site operations on the environment encompassing the SRS and the surrounding area.

Airborne measurements were made of both natural and man-made gamma radiation emanating from Steed Pond and the surrounding terrain. Created by a man-made dam, Steed Pond was a small, shallow impoundment of Tim's Branch, located in the northwest portion of SRS, approximately 2 km southeast of the 300/700 Area (Figure 1). The first survey was conducted in June 1984. The spillway failed on September 1, 1984, exposing sediment as the pond drained. Subsequent surveys in mid-September 1984 and August 1985¹ were conducted to evaluate the extent and intensity of any man-made radioisotopes in the sediment. The presence of uranium and uranium daughters was suspected. February 1987² and April 1989³ data were also used to obtain a current estimate of any uranium distribution.

The measurement platform used for this survey was a twin-engine Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter equipped with an array of sodium iodide detectors which respond to gamma radiation. Flight lines spaced 76 meters (250 feet) apart were flown at an altitude of 46 meters (150 feet) or 61 meters (200 feet). Radiation data and aircraft position were recorded simultaneously. Computer algorithms were used to determine the gamma gross count and analyze the data for the presence of various isotopes such as cesium-137 (¹³⁷Cs), cobalt-60 (⁶⁰Co), and protactinium-234m (^{234m}Pa). The data were processed during each survey in a mobile computer laboratory at Bush Field near Augusta, Georgia. Gamma radiation signal intensities as a function of position were plotted on map overlays of Tim's Branch and Steed Pond. Three map overlays are shown for each survey: gamma gross count, man-made gross count, and ^{234m}Pa, a daughter of uranium which effectively shows the presence of its parent, uranium-238 (²³⁸U). Each ^{234m}Pa map shows the annual dose equivalent (expressed in millirems) due to a given radionuclide or a combination of radionuclides. Although the data were analyzed for both ¹³⁷Cs and ⁶⁰Co, no maps are shown for these radionuclides because no ⁶⁰Co was detected, and ¹³⁷Cs was found in only one location at a barely detectable level. The location of the ¹³⁷Cs is shown on a man-made gross count (MMGC) contour map.

Natural soil contains several dozen radioactive isotopes which have been slowly decaying since their formation. The data show the average radiation dose, measured in millirems (mrem), which a person would receive if he remained at a given location for an entire year. The results are applicable to a 1-meter elevation above ground, only as an average over several hectares because the measurements were made at 46 or 61 meters above ground. An annual cosmic ray dose of 33 mrem, typical of the Savannah River area, is not included in any of the data plots in this report.

2.0 SITE DESCRIPTION

The SRS is an irregularly shaped, 777-square-kilometer (300-square-mile) facility formerly operated by E.I. du Pont de Nemours and Company, Inc. and currently operated by its successor, the Westinghouse Savannah River Company, for the U.S. Department of Energy. The facility is located in southcentral South Carolina, approximately 24 kilometers (15 miles)

FIGURE 1. STEED POND LOCATION ON THE SAVANNAH RIVER SITE

south of Aiken. Figure 1 shows a map of Steed Pond and a portion of the Savannah River Site. The Location Diagram indicates with a dashed line the approximate area covered by the Steed Pond surveys. Actual survey boundaries differed for all five surveys; they are indicated in subsequent figures. Steed Pond is 2 kilometers southeast of the 300/700 Area complex where uranium metal fabrication is conducted.

3.0 SURVEY PLANS

The first Steed Pond survey was flown over a 3-day period, June 12-14, 1984. The survey altitude was 46 meters (150 feet) with a line spacing of 76 meters (250 feet). At that time, the man-made dam which created Steed Pond was intact, and the pond was filled to normal capacity for the time of year.

After the spillway failed on September 1, 1984, and the water drained from the pond, it was decided to conduct a second survey of the pond along with the Tim's Branch drainage basin above and below the dam. Sediment that was normally covered by impounded water was exposed after the water drainage. It was suspected that uranium residues from the 300/700 Area operations might be detectable, not only in pond sediment, but in the drainage basin below the dam. The second, third, fourth, and fifth surveys were conducted with the pond drained.

The second survey was also conducted at a survey altitude of 46 meters with lines spaced 76 meters apart. Most of the data were obtained on September 15, 1984; three lines on the east border of the survey area were obtained on September 21, 1984.

A third survey was conducted during August 21-22, 1985, in conjunction with other survey work being done at the same time at SRS.¹ The spillway had not been repaired, and exposed sediment beds were potentially drier than in September of 1984. Therefore, it was decided to resurvey a small area including the former Steed Pond area and the Tim's Branch drainage basin above it. Although the line spacing was the same (76 meters), the survey altitude was increased to 61 meters because the helicopter could not consistently lock onto transponder beacons at the previous 46-meter altitude.

The fourth survey, during February 10-23, 1987,² was part of a much larger aerial survey over the northwestern portion of the Savannah River Site. A portion of that survey has been used here to show possible changes in radiologic measurements around Steed Pond. The fifth survey, from April 13-26, 1989,³ was also a portion of a larger survey. With the addition of these data, a radiologic record from just prior to the drainage of Steed Pond to 1989 was prepared.

4.0 SURVEY EQUIPMENT

The MBB BO-105 helicopter, Figure 2, was used to obtain the gamma radiation data in these surveys. For the 1984 surveys, the equipment pods, mounted below the left and right sides of the fuselage, each contained ten sodium iodide (NaI) crystals, each 5 inches in diameter by 2 inches thick. However, by August 1985, the detector arrays had been improved. In the new configuration, each pod contained four large NaI log detectors measuring $4 \times 4 \times 16$ in. The new arrays are not only more sensitive to gamma radiation, but they are also less sensitive to both thermal and mechanical shock.

FIGURE 2. MBB BO-105 HELICOPTER WITH DETECTOR PODS

Gamma signals from 19 of the NaI crystals or (in the new array) from seven of the eight logs were accumulated and digitized in analog-to-digital converter Number 1 (ADC1), then routed to pulse-height analyzer Number 1 (PHA1). Figure 3 is a schematic diagram of the Radiation and Environmental Data Acquisition and Recorder (REDAR) system and auxiliary electronic equipment aboard the helicopter. Gamma signals from the remaining log detector were routed to PHA2. These data are useful in regions of high level activity, when count rates exceed the capacity of PHA1 (about 40,000 counts per second). Spectra from both PHAs were simultaneously acquired and recorded. This scheme extends the dynamic range of count rates for the data acquisition system.

REDAR acquired, displayed, and recorded all survey data for each second of survey time. Data stored on magnetic tape cartridges included: dual gamma spectra, outside air temperature, absolute barometric pressure, radar altimeter measurements, and position data from the ultrahigh-frequency ranging system (URS).

To provide flight lines 76 meters apart at an altitude of 46 meters or 61 meters, the REDAR was programmed to provide appropriate navigation guidance from the URS data for the pilot. A typical operational setup for an aerial radiation survey is shown in Figure 4. Appendix A contains more detailed information regarding the survey equipment and its use.

5.0 DATA PROCESSING

Data accumulated over the SRS were processed by the Radiation and Environmental Data Analyzer and Computer (REDAC) system. Preliminary processing was begun in the field by a

FIGURE 3. BLOCK DIAGRAM OF THE REDAR IV SYSTEM

mobile REDAC system mounted in a van (Figure 5). During the survey, the van and the survey helicopter were based at Bush Field in Augusta, Georgia.

The mobile REDAC consists primarily of a Data General Eclipse S280 computer which has a 16-bit CPU, 512 kilobytes of memory, and a floating point processor; two discs with a total of 1.1 gigabytes of storage; two 800/1600-byte-per-inch, 9-track, 1/2-inch tape drives; two 4-track, 1/4-inch, cartridge tape drives for reading REDAR tapes; a 36-inch-wide carriage incremental plotter; a dot matrix line printer; and three CRT terminals with alphanumeric, graphic, and hardcopy printout capabilities. A block diagram of the system is shown in Figure 6. This system has an extensive library of software routines for data processing in the field. Analysis is refined and completed at the EG&G/EM's Remote Sensing Laboratory in Las Vegas, Nevada, using a larger and faster Data General MV-8000 II system.

6.0 DATA ANALYSIS

6.1 Radiation Contours

Computer algorithms have been developed to extract gammas of a specific source from the gamma energy spectrum using various combinations of windows in the spectrum (Appendix B).

Natural background and contaminants are subtracted from the spectrum to observe photo-peaks of interest. The resulting count rates, together with position data, are plotted as constant

FIGURE 4. TYPICAL OPERATIONAL EQUIPMENT ARRANGEMENT

FIGURE 5. MOBILE COMPUTER PROCESSING LABORATORY

FIGURE 6. BLOCK DIAGRAM OF THE REDAC SYSTEM

count rate contours, and a pattern of contour lines is superimposed on a vertical aerial photograph of the Savannah River Site.

Isoradiation contour plots were prepared for gross count, man-made gross count, ^{137}Cs , ^{60}Co , and $^{234\text{m}}\text{Pa}$ (a daughter of ^{238}U with prominent gamma photopeaks at 765 and 1,001 keV). The

lines become prominent in gamma spectra obtained over land containing above-normal concentrations of ^{238}U . Only 0.30 percent of $^{234\text{m}}\text{Pa}$ disintegrations result in the emission of a 765 keV gamma; 0.60 percent generate a 1,001 keV gamma. The ^{137}Cs and ^{60}Co plots are not shown in this report because no ^{60}Co was detected; ^{137}Cs was detected at only one location and only at a very low level. The location of the ^{137}Cs is adequately shown on the MMGC map as Region of Interest (ROI) 8, in Figure 19.

The algorithms applied are the same as those for the 1982 survey report,⁴ with the exception of that devised to extract $^{234\text{m}}\text{Pa}$. Details regarding the radiation contours and the computer algorithms used to generate them are presented in Appendix B.

One of the Forest Service towers used to support the URS transponders was relocated between the 1984 and 1985 surveys. Hence, the coordinate system for the 1985 survey had to be rotated to coincide with those used for the 1984 survey.

The most significant difference between the surveys was in the detector system. In the 1985 survey, eight 4- × 4- × 16-in NaI logs were used, as indicated in Section 4. Eight logs have greater gamma sensitivity than twenty 5- × 2-in crystals as well as superior resistance to structural damage.

The gamma gross count radiation isopleth is the most sensitive means for displaying subtle changes in the terrestrial radiation level. Experience has taught, however, that the most useful tool for detecting departures from natural activity is the MMGC algorithm. For all five of the Steed Pond surveys, we have examined the MMGC contour plot and identified ROIs in which such departures are apparent. An ROI may have gross activity above or below that of its surroundings.

6.2 Gamma Energy Spectra

To identify the source(s) of each ROI, gamma spectra were obtained from the smallest rectangle which can cover the ROI. A background spectrum was then obtained from a slightly larger rectangle surrounding the first. The two spectra were subtracted, channel by channel, to generate a net spectrum which usually shows photopeaks uniquely characterizing the isotope(s) responsible for the anomaly. When two spectra are shown on the same plot, the vertical scale factor for the upper spectrum has been divided by a factor of 10.

In the following section, analyses are provided for the isopleth contour maps which are included in the text. Frequent references are made to gamma spectra for the ROIs. All useful net spectra will be found in Appendix C. It should be noted that there are 14 ROIs, not all of which appear within each survey boundary.

7.0 RESULTS

The principal results from these surveys are contour plots of the total terrestrial gamma count rate, the MMGC, and the excess $^{234\text{m}}\text{Pa}$ dose rate at 1 meter. All of these contour plots are overlaid on an aerial photograph of the Steed Pond area dated March 2, 1987.

Specific ROIs have been selected and their energy spectra examined especially for man-made isotope signatures. Some of these spectra are given in Appendix C. In addition, an estimate of

the man-made activity inventory has been computed for ^{234m}Pa (the principal anomalous isotope).

7.1 Regions of Interest

Fourteen ROIs have been outlined in Figure 7. These are all anomalous (positive count rate) areas on the following MMGC maps, except for ROIs 5 and 6, which are relatively low total gamma count rate areas (and low dose rate areas).

Table 1 lists the ROIs and the responsible isotope if it can be identified. Man-made isotopes were identified only in ROIs 1, 2, 3, 4 (^{234m}Pa), and ROI 8 (^{137}Cs).

Not all of the ROIs are listed on all of the contour maps. All are designated initially, but only ROIs 1, 2, 3, and 4, (which contain ^{234m}Pa) are labeled on all of the contour maps.

7.2 Man-Made Gross Count Contour Maps

Perhaps the MMGC contour maps, Figures 8 through 12, provided the greatest sensitivity for detecting man-made gamma emitters. Unfortunately this algorithm is somewhat sensitive to altitude changes, water cover, and other natural phenomena. Therefore, energy spectra from positive MMGC areas must be inspected in order to identify the anomaly.

The contour levels for each map have been selected for each survey to represent the same quantity of gamma fluence rate or exposure rate at 1 meter above ground level (AGL). Scaling is discussed in Appendix D.

The MMGC contours show the continuing presence of anomalies in ROIs 2, 3, and 4 in Tim's Branch from June 1984 through April 1989. Activity in Steed Pond (ROI 1) becomes visible in September 1984 after the water in Steed Pond was drained, and is visible thereafter. Energy spectra of these four ROIs (Appendix C) clearly show the presence of ^{234m}Pa (Figures C-1, C-2, C-3, and C-4). The thicker detectors used subsequent to September 1984 tend to map a larger area in these four ROIs than do the earlier detectors used in June and September of 1984. However, the area covered by ROIs 1, 2, 3, and 4 (mapped in February 1987) is small. A plausible explanation is that the soil was very wet or even partially water-covered during the February 1987 survey, but relatively dry during surveys other than the very first one (Appendix E).

Downstream on Tim's Branch and Upper Three Runs Creek floodplain are ROIs 14, 10, 11, 9, 12, and 13. Net gamma energy spectra from these ROIs do not show ^{234m}Pa or any other man-made isotopes. Regions of interest 9, 12, and 13 show excess bismuth-214 (^{214}Bi), a daughter of radium-226 (^{226}Ra), which may be a perturbation in the natural activity distribution. Net spectra are shown in Figures C-9, C-12 and C-13. The other ROIs (10, 11, and 14) along this drainage show only the Compton distribution in their energy spectra. No identifying photopeaks are clearly visible in Figures C-10, C-11, and C-14.

At the northern end of Tim's Branch are ROIs 7 and 8. ROI 7 does not yield any definitive photopeaks in the gamma energy spectrum, whereas ROI 8 shows ^{137}Cs (Figure C-8).

FIGURE 7. REGIONS OF INTEREST IN THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA

Table 1. Description of Regions of Interest in the Tim's Branch Area			
ROI No.	Location	Spectrum Figure No.^a	Anomalous Isotope^b
1	Steed Pond	C-1	^{234m} Pa
2	2,400 ft north of Steed Pond, Tim's Branch	C-2	^{234m} Pa
3	3,000 ft north of Steed Pond, Tim's Branch	C-3	^{234m} Pa
4	4,000 ft north of Steed Pond, Tim's Branch	C-4	^{234m} Pa
5	6,000 ft north of Steed Pond, Tim's Branch	C-5	Natural
6	Immediately southeast of Area 700	C-6	Natural
7	At Rd. No. D-1 and Tim's Branch	C-7	Unknown
8	At Rd. No. D-1 and Tim's Branch	C-8	¹³⁷ Cs
9	3,600 ft south of Hwy C, in Upper Three Runs Creek ^c	C-9	²¹⁴ Bi
10	Tim's Branch and Hwy C	C-10	Unknown
11	South of Hwy C, across from ROI 10 ^c	C-11	Unknown
12	6,000 ft south of Hwy C, in Upper Three Runs Creek ^c	C-12	²¹⁴ Bi
13	10,000 ft south of Hwy C, in Upper Three Runs Creek ^c	C-13	²¹⁴ Bi
14	5,000 ft south of Steed Pond, Tim's Branch	C-14	Unknown

^a From Appendix C.

^b An anomalous isotope may be identified from the net spectrum of the ROI. If the net spectrum contains a natural distribution of photopeaks, it is so labeled. If no photopeaks are clearly visible, the anomaly is labeled "Unknown."

^c Not in Tim's Branch drainage.

The mean ¹³⁷Cs activity in ROI 8, about 0.1 $\mu\text{Ci}/\text{m}^2$, is consistent in magnitude with worldwide fallout. The mean count rate, at 58 cps in April of 1989, is less than the minimum count rate necessary to detect it using the cesium photopeak algorithm (Appendix B). The more sensitive MMGC algorithm made it detectable here.

7.3 Protactinium-234m Contour Maps

The principal anomalous isotope identified in the Steed Pond area is ^{234m}Pa which implies concentrations of ²³⁸U, thorium-234 (²³⁴Th), and uranium-234 (²³⁴U). The 1,001-keV, ^{234m}Pa gamma photopeak has been contoured, for the five surveys, Figures 13 through 17. The method is outlined in Appendix B. The lowest contour level for each survey has been set at three times the standard deviation (3 σ) of the algorithm result over background areas, *i.e.*, regions where only natural concentrations of ²³⁸U occur. This yields few false detections. At this contour, the 1-meter dose from ^{234m}Pa is 3 or 4 mrem per year,⁵ dependent on the detector array used and the altitude flown. Other contour levels are scaled to the sensitivity of the detector array to the ^{234m}Pa activity so that each level is the same in dose rate units throughout the survey. Appendix D explains the scaling procedure.

LEGEND	
Note A.	ROI 9 is due to Bi-214, a daughter of Ra-226 and may not be man-made.
Note B.	ROI 10 is due to low energy gammas only and may not be man-made.

CONVERSION SCALE	
LETTER LABEL	MAN-MADE GROSS COUNT RATE* (cps)
A	0 - 750
B	750 - 1,160
C	1,160 - 2,510
D	2,510 - 5,400
E	5,400 - 11,600

* The man-made count rate is generally due to long-lived, man-made gamma emitters only. Count rates presented are from the survey altitude of 46 meters.

FIGURE 8. MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA, JUNE 1984

FIGURE 9. MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA, SEPTEMBER 1984

FIGURE 10. MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE STEED POND AREA, AUGUST 1985

FIGURE 11. MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE STEED POND AREA, FEBRUARY 1987

FIGURE 12. MAN-MADE GROSS COUNT RATE CONTOUR MAP FOR THE STEED POND AREA, APRIL 1989

During the June 1984 survey (Figure 13), only ROIs 2, 3, and 4 are visible. Steed Pond contained significant water. In September of 1984 (Figure 14), ROI 1 on Steed Pond also indicated ^{234m}Pa after the water had been drained. In subsequent surveys during August 1985, February 1987, and April 1989 (Figures 15, 16, and 17), these four ROIs are always clearly indicated. No other indications of ^{234m}Pa are indicated downstream or upstream from these contiguous areas in Tim's Branch. It is notable that these four ROIs of interest show weakly in the first four surveys, but quite strongly in the April 1989 survey. There are several possible reasons:

1. The two 1984 surveys were flown with detectors less sensitive to the 1,001-keV gamma ray of ^{234m}Pa than those used during the later surveys.
2. The 1985 survey was flown at a higher altitude (200 ft rather 150 ft) than the other surveys.
3. The soil moisture may have been greater during the 1987 survey. Appendix E discusses rainfall effects.

7.4 Total Terrestrial Gamma Count Rate Contour Maps

The total terrestrial gamma count rate maps (Figures 18, 19, 20, 21, and 22) are usually correlated with the gamma dose rate at 1 meter above the ground. The correlation coefficient has been obtained for a natural mixture of thorium-232 (^{232}Th), uranium-238 (^{238}U), and potassium-40 (^{40}K) only in background areas, *i.e.*, where there are no anomalies. The correlation coefficient or conversion from total count rate to the 1-meter dose rate is listed on each map.

The contour levels have been normalized so that each level on one map represents the same natural dose rate at the same level on each of the other maps. However, the normalization is less accurate for the four ^{234m}Pa anomalous areas.

These total count rate maps show the four ^{234m}Pa anomalous areas in Tim's Branch only weakly until the April 1989 survey. In that survey, the total count rate over the anomalies became 40 percent greater than the prevailing local background. Note that Steed Pond (ROI 1) shows a very low count rate in June 1984 (Figure 18) because it was then covered with water.

The low dose rate areas, ROIs 5 and 6, have been qualified as natural from their net spectra (Figures C-5 and C-6, respectively).

The highest count rate area, ROI 9, shows clearly in Figures 18 and 19. The dose rate here goes to 19 $\mu\text{R/h}$ or about 170 mrem/yr and is due to an excess of ^{226}Ra daughters in the uranium chain. From the location, this anomaly appears natural rather than man-made.

Finally, note that the contours have not changed significantly from map to map or from year to year. Their locations are nearly identical.

8.0 CONCLUSION

The five-year period included in these five surveys shows a stable, natural terrestrial radioactive environment. The implied yearly dose rates at 1 meter remain nearly constant in Tim's Branch and surroundings. Terrestrial dose rate levels are mostly in the 30 to 50 mrem/yr interval. Some mild concentrations of uranium daughters (*e.g.*, ^{214}Bi) show along Upper Three Runs Creek, but appear to be natural in origin.

Excess ^{234m}Pa was detectable in Steed Pond after the water was drained in 1984 and was still plainly detectable in 1989. The protactinium implies the presence of ^{238}U , ^{234}Th , ^{234m}Pa , and ^{234}U , none of which are as conveniently detectable from their gamma emissions as ^{234m}Pa .

A redistribution of protactinium has not been detected downstream from Steed Pond subsequent to 1984 when Steed Pond was drained. If protactinium and its parent uranium have been transported downstream, they exist at levels less than $9\ \mu\text{Ci}/\text{m}^2$, the minimum detectable activity (for large areas) with this detector array. A 40-mCi, localized source (*i.e.*, a pocket of material in the stream bed) would be at the aerial minimum detectable activity level.

There may be as much as 10 mCi of ^{137}Cs 1.5 miles north of Steed Pond, distributed over as much as 8 hectares (20 acres). Such a low level suggests it may be associated with worldwide fallout.

Further gamma surveys related to SRS activities may be found in References 12 through 16.

FIGURE 13. PROTACTINIUM-234m DOSE RATE CONTOUR MAP FOR THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA, JUNE 1984

FIGURE 14. PROTACTINIUM-234m DOSE RATE CONTOUR MAP FOR THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA, SEPTEMBER 1984

FIGURE 15. PROTACTINIUM-234m DOSE RATE CONTOUR MAP FOR THE STEED POND AREA, AUGUST 1985

FIGURE 16. PROTACTINIUM-234m DOSE RATE CONTOUR MAP FOR THE STEED POND AREA, FEBRUARY 1987

FIGURE 17. PROTACTINIUM-234m DOSE RATE CONTOUR MAP FOR THE STEED POND AREA, APRIL 1989

FIGURE 18. TOTAL TERRESTRIAL GAMMA COUNT RATE CONTOUR MAP FOR THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA, JUNE 1984

FIGURE 19. TOTAL TERRESTRIAL GAMMA COUNT RATE CONTOUR MAP FOR THE TIM'S BRANCH AND UPPER THREE RUNS CREEK AREA, SEPTEMBER 1984

FIGURE 20. TOTAL TERRESTRIAL GAMMA COUNT RATE CONTOUR MAP FOR THE STEED POND AREA, AUGUST 1985

FIGURE 21. TOTAL TERRESTRIAL GAMMA COUNT RATE CONTOUR MAP FOR THE STEED POND AREA, FEBRUARY 1987

FIGURE 22. TOTAL TERRESTRIAL GAMMA COUNT RATE CONTOUR MAP FOR THE STEED POND AREA, APRIL 1989

APPENDIX A

SURVEY EQUIPMENT AND SPECIFICATIONS

The MBB BO-105 helicopter (Figure 2) used to obtain gamma radiation data in these surveys carried two equipment pods on the left and right sides of the fuselage. Each contained ten 5 × 2-in, sodium iodide (NaI[Tl]) detectors. This arrangement was used in both 1984 surveys. For the 1985, 1987, and 1989 surveys, the pods had been reconfigured: each contained four large, NaI log detectors measuring 4 × 4 × 16 in. Gamma signals from all twenty crystals or all eight logs were accumulated and recorded by the REDAR system. Figure 3 shows a schematic diagram of the REDAR system and auxiliary electronic equipment aboard the helicopter.

The preamplifier signal from each detector was recalibrated daily with sodium-22 (^{22}Na) and americium-241 (^{241}Am) radiation sources, and normalized outputs from each detector were combined. The summed signal was adjusted in the analog-to-digital converter so that calibration peaks appeared in appropriate channels of the multichannel analyzer of the REDAR.

The REDAR recorded each gamma signal with the energy, time, and helicopter position. The latter was established with two systems: an ultrahigh-frequency ranging system called the URS and an AL-101 radar altimeter. The master URS transceiver, mounted in the helicopter, interrogated two remote transceivers mounted on towers outside the survey area. These transmitted a return signal with a different sequence of frequencies. By measuring the round-trip propagation time between the master and remote units, the master unit computed the distance to each. These distances were recorded on magnetic tape each second. In subsequent computer processing, these inputs were converted to position coordinates over the SRS site. All of the surveys were flown at an altitude of 46 meters except the third which was flown at 61 meters. All line spacing was 76 meters.

The radar altimeter simultaneously measured the time lag for the return of a pulsed signal and converted this to aircraft altitude with an accuracy of ± 0.9 meter. These measurements were also recorded on magnetic tape so that the computer could compensate for variations in gamma signal strength caused by altitude fluctuations.

The REDAR operator navigated the aircraft over two preselected site landmarks which determined the first survey line. The system computer was then programmed to align all subsequent flight lines parallel to the first, spaced 76 meters apart (see Figure 4). Appropriate signals were fed by REDAR to an aircraft guidance system on the instrument panel. By centering a horizontal and a vertical needle, the pilot could fly a line at the 46-meter or 61-meter altitude, spaced precisely 76 meters from the previous line. In practice, the guidance system has been extremely reliable. Properly spaced, accurately flown lines provide the needed assurance that small radiation sources will not be undetected because of accidental gaps between lines.

APPENDIX B

COMPUTER ALGORITHMS

Three computer algorithms were used to generate the gamma radiation isopleth contours for this report:

1. Gross count = $A(38; 3,026) - B$
2. Man-made gross count = $C(38; 1,394) - D(1,394; 3,026)$
3. Pa-234m = $E(926; 1,094) - F(1,094; 3,026)$

The numbers in parentheses are the initial and final energies of the window, expressed in kilovolts (keV). Parentheses denote counts in this energy window for a specified number of computer records.

The letter A is a normalization constant. It normalizes the count rate to a full array of detectors, *i.e.*, to twenty 5- × 2-in crystals or eight 4- × 4- × 16-in logs.

The letter B is a constant which includes gamma radiation background from many different sources: cosmic radiation, radon, thoron, or sources within the aircraft. A flight is made over a nearby body of water, in this case Par Pond, to determine the background each day. The background varies from day to day primarily because radon and thoron levels vary considerably with atmospheric pressure.

Possible counts from airborne argon-41 (⁴¹Ar), which is released during reactor operations, are not included. The data from all five surveys were examined carefully for ⁴¹Ar activity. Since none was found, the algorithms contain no explicit term for argon subtraction.

Constant C is a normalization constant, like A. The man-made gross count algorithm is highly sensitive to spectral shape deformation which generally occurs below the ⁴⁰K peak. Most man-made radioisotopes produce a strong contribution below 1,394 keV and little or no contribution above that energy. We determine a constant

$$P = \frac{(38; 1,394)}{(1,394; 3,026)}$$

for data acquired over a portion of SRS unaffected by site operations such as production, fabrication, storage, or the experimental areas and effluent pathways downstream from these operations.

P, properly normalized, is the constant D which zeroes the algorithm for all background areas, *i.e.*, all regions without man-made contributions. D is a sensitive function of the survey area and is determined for the specific area overflown on each flight.

Constant E is also a normalization constant, like A. It affects only the upper photopeak window (926; 1,094). Not only is the 1,001 keV photopeak twice as intense as the 765 keV photopeak (0.60 percent vs. 0.30 percent), but it is further from the Compton buildup and easier to count cleanly.

In a manner similar to the gross-count constant D , F is set so the algorithm vanishes in the absence of protactinium contamination. Data on either side of the streambed provide background regions. This constant is also determined for each flight. Values of F differ only very slightly from day to day, *i.e.*, from one part of the Tim's Branch basin to another.

APPENDIX C

GAMMA ENERGY SPECTRA

A total of 14 Regions of Interest (ROIs) were identified on the Steed Pond data. Since the survey boundaries were different for each survey, some ROIs were not overflowed for each survey. However, for all available ROIs, spectra were obtained to confirm the evidence of protactinium contamination and to determine whether other radionuclides were contributing to observed anomalies.

The data for all five surveys were processed with both a ^{137}Cs and a ^{60}Co algorithm. None of the ten contour plots showed measurable concentrations of these fission products. It was a surprise, then, to find evidence of ^{137}Cs in ROI 8.

To obtain these spectra, a small rectangle was established around a given ROI or around the most intense portion of the ROI if it was a large one. All data points within the rectangle were then summed; a spectrum was obtained for the combined data. Then a somewhat larger rectangle was drawn around the first; all data points between the two rectangles were summed, and a second (background) spectrum was obtained. A normalized background spectrum was then subtracted from the first to obtain a net spectrum for the given ROI. Only net spectra are shown here. For this reason, the higher energy photopeaks (^{40}K , ^{214}Bi , ^{208}Tl) are usually absent. In theory, only man-made peaks remain; most naturally occurring radionuclides are subtracted. In practice, the process works quite well and is a sensitive indicator of man-made contaminants.

The spectra which follow (C-1 through C-14) are labelled by the ROI to which they correspond and the month and year in which they were obtained. The sharp, narrow "photopeaks" are the result of statistical fluctuations in the count rates in the energy channels.

FIGURE C-1. NET GAMMA ENERGY SPECTRUM OVER ROI 1, STEED POND, SEPTEMBER 1984

FIGURE C-2. NET GAMMA ENERGY SPECTRUM OVER ROI 2, SEPTEMBER 1984

FIGURE C-3. NET GAMMA ENERGY SPECTRUM OVER ROI 3, SEPTEMBER 1984

FIGURE C-4. NET GAMMA ENERGY SPECTRUM OVER ROI 4, AUGUST 1985

FIGURE C-5. NET GAMMA ENERGY SPECTRUM OVER ROI 5, JUNE 1984

FIGURE C-6. NET GAMMA ENERGY SPECTRUM OVER ROI 6, JUNE 1984

FIGURE C-7. NET GAMMA ENERGY SPECTRUM OVER ROI 7, JUNE 1984

FIGURE C-8. NET GAMMA ENERGY SPECTRUM OVER ROI 8, AUGUST 1985

FIGURE C-9. NET GAMMA ENERGY SPECTRUM OVER ROI 9, SEPTEMBER 1984

FIGURE C-10. NET GAMMA ENERGY SPECTRUM OVER ROI 10, SEPTEMBER 1984

FIGURE C-11. NET GAMMA ENERGY SPECTRUM OVER ROI 11, SEPTEMBER 1984

FIGURE C-12. NET GAMMA ENERGY SPECTRUM OVER ROI 12, SEPTEMBER 1984

FIGURE C-13. NET GAMMA ENERGY SPECTRUM OVER ROI 13, SEPTEMBER 1984

FIGURE C-14. NET GAMMA ENERGY SPECTRUM OVER ROI 14, APRIL 1989

APPENDIX D

CONVERSION COEFFICIENTS

CONVERSIONS

A number of count rate conversion coefficients and associated parameters may be useful to support the interpretation of the contour plots. These are given in Table D-1.

Table D-1 Conversions and Parameters			
Date of survey	June 1984 Sept. 1984	Aug. 1985	Feb. 1987 April 1989
Detector configuration, NaI(Tl)	Twenty 5×2 in	Eight 4×4×16 in	Eight 4×4×16 in
Flight altitude (ft)	150	200	150
Detector effective area ^a to ^{234m} Pa (cm ²)	730	1,900	1,900
Total count, dose conversion (cps/μrem/h)	990	1,000	1,100
Pa-234m, 1-MeV count rate conversion to a surface source (μCi/m ² /cps)	0.202	0.100	0.078
Pa-234m, 1-MeV count rate conversion to a volume ^b source $\alpha = 0.1 \text{ cm}^{-1}$ (pCi/g/cps)	3.74	1.77	1.44
Pa-234m, 1-MeV count rate conversion to uniform volume source (pCi/g/cps)	2.24	1.05	0.86
Pa-234m, 1-MeV count rate to 1-meter dose rate, surface source (μrem/h/cps)	0.030	0.015	0.011
Pa-234m, 1-MeV count rate to 1-meter dose rate, volume source, $\alpha = 0.1 \text{ cm}^{-1}$ (μrem/h/cps)	0.018	0.0087	0.0077
Pa-234m, 1-MeV count rate to 1-meter dose rate, uniform volume source (μrem/h/cps)	0.021	0.0096	0.0080

^a Effective area is the probability that a 1-MeV photon incident on the detectors will be totally absorbed.

^b Vertical soil concentrations, C, of the form $C = C_0 e^{-\text{depth}/10 \text{ cm}}$ are assumed.

NOTE: Air density = 0.0012 g/cm³; soil density = 1.5 g/cm³; mass absorption coefficient of soil = mass absorption coefficient of air = 0.0636 cm²/g. These parameters are used to determine the above conversions.

A few conversions from Beck⁵ have been used to obtain dose rates at 1 m AGL due to concentrations of ^{234m}Pa in the ground. Table D-2 lists these conversions.

CONTOUR LEVEL SCALING

The contour levels of the total count rate, man-made count rate (MMGC), or ^{234m}Pa are set at the same dose levels throughout the five surveys. The exceptions are the lowest level for the

Table D-2. Dose Rates at 1 Meter Due to Sources in the Soil			
Gamma Energy (keV)	Uniform Volume Source $\frac{\mu\text{R/h}}{\gamma/\text{s/g}}$	Volume Source $\alpha = 0.1 \text{ cm}^{-1}$ $\frac{\mu\text{R/h}}{\gamma/\text{s/cm}^2}$	Surface Source $\frac{\mu\text{R/h}}{\gamma/\text{s/cm}^2}$
1,001	30.4	1.15	4.86
765	22.6	0.90	3.86

NOTE: Roentgen, R, has been equated to rem throughout this report.

MMGC and for the $^{234\text{m}}\text{Pa}$ dose rate. These lowest levels are set to three times the standard deviation of the algorithm's output.

First, the 1984 levels for the total count rate, the MMGC, and the $^{234\text{m}}\text{Pa}$ dose rate were set as baseline levels. Then the contour levels for the other survey dates were set from the product of the 1984 levels and the ratio of the respective conversion factors (cps to $\mu\text{rem/h}$). Table D-1 lists relevant conversion factors. As an example, the levels for total count rate in either 1987 or 1989 are the 1984 levels times 1,100/990 (1984 levels $\times$ 1.11).

The MMGC levels were set with the same ratios as were the total count rate levels, because this quantity is nearly proportional to the total count rate. Inverse ratios to the order applied to total count rate and MMGC levels were used to obtain $^{234\text{m}}\text{Pa}$ levels because these conversion factors are inverted (the units are inverted - $\mu\text{rem/h/cps}$ rather than $\text{cps}/\mu\text{rem/h}$).

APPENDIX E

RAINFALL EFFECTS ON TERRESTRIAL ACTIVITY MEASUREMENTS

Soil moisture is known to affect the terrestrial gamma fluence rates both in theory and in practice.⁶ Though soil moisture data have not been collected routinely during aerial gamma surveys, monthly rainfall data were collected at the 300/700 Area near Steed Pond. Some correlation between measured radiation levels and monthly rainfall might be expected, though perhaps not strongly.

The soil moisture effect is demonstrated in Figure E-1. The mean estimated ^{234m}Pa concentration ($\mu\text{Ci}/\text{m}^2$) is plotted against the monthly rainfall,⁷⁻¹¹ assuming the same depth distribution, during the five surveys in the Steed Pond area. The plot indicates that the estimated activity in the Steed Pond area decreases as the rainfall (and presumably the soil moisture) increases. The apparent decrease in estimated activity is an artifact of the increase in attenuation due to the density increase of the soil water mix.

The activity concentration versus rainfall plot is not expected to be accurate. Rather, it is intended to show only the trend. This trend suggests that soil moisture measurements, obtained during an aerial survey, would probably aid the interpretation of aerial data.

Figure E-1. PROTACTINIUM-234m ESTIMATED ACTIVITY VERSUS RAINFALL

REFERENCES

1. Jobst, J.E. *An Aerial Radiological Survey of L Lake and Steel Creek, Savannah River Site*, Survey Date: August 1985, Report No. DOE(ONS-SRL)-8611. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1988.
2. Feimster, E.L. *An Aerial Radiological Survey of the Central Savannah River Site, Aiken, South Carolina*, Survey Date: February 1987, Report No. DOE(ONS-SRL)-8810. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1991.
3. Feimster, E.L. *An Aerial Radiological Survey of the Northern Region of the Savannah River Site*, Aiken, South Carolina. Survey Date: April 1989. EG&G Energy Measurements, Inc., Las Vegas, Nevada, (to be published).
4. Jobst, J.E. *An Aerial Radiological Survey of the Savannah River Plant Drainage Basins*, Date of Survey: August 1982, DOE/ONS-8312, Rev. 1. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1987.
5. Beck, H.L., *et al.* *In Situ Ge(Li) and NaI(Tl) Gamma-Ray Spectrometry*, Report No. HASL-258. Health and Safety Laboratory (AEC), New York, New York, 1972.
6. Carroll, T.R. "Airborne Soil Moisture Measurement Using Natural Terrestrial Gamma Radiation." *Soil Science*, Vol. 132, No. 5, 1981.
7. Mackey, H.E., Jr. Personal Communication, 1984, 1987, and 1989.
8. Bennett, C.S., *et al.* *Water Resources Data South Carolina: Water Year 1984*, Water-Data Report SC-84-1. U.S. Geological Survey, 1985.
9. Bennett, C.S., *et al.* *Water Resources Data South Carolina: Water Year 1985*, Water-Data Report SC-85-1. U.S. Geological Survey, 1986.
10. Bennett, C.S., *et al.* *Water Resources Data South Carolina: Water Year 1987*, Water-Data Report SC-87-1. U.S. Geological Survey, 1988.
11. Bennett, C.S., *et al.* *Water Resources Data South Carolina: Water Year 1989*, Water-Data Report SC-89-1. U.S. Geological Survey, 1990.
12. Boyns, P.K. *Aerial Radiological Survey of the Savannah River Plant, Aiken, South Carolina*, Date of Survey: June 1974, Report No. EGG-1183-1665. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1975.
13. Boyns, P.K., and D.B. Smith. *An Aerial Radiological Survey of the Savannah River Plant and Surrounding Area, Aiken, South Carolina*, Date of Survey: June 1979, Report No. EGG-1183-1816. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1982.
14. Boyns, P.K. *An Aerial Radiological Survey of the Savannah River Floodplain*, Date of Survey: July-October 1983, Report No. EGG-10282-1049. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1984.
15. Jobst, J.E. *An Aerial Radiological Survey of L Lake and Steel Creek, Savannah River Plant*, Date of Survey: August 1985. Report No. DOE(ONS-SRL)-8611, EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1988.
16. Feimster, E.L. *An Aerial Radiological Survey of L Lake and Steel Creek, Savannah River Plant*, Date of Survey: July 1986, Report No. EGG-10617-1146. EG&G Energy Measurements, Inc., Las Vegas, Nevada, 1992.

DISTRIBUTION

DOE/DP

J. E. Rudolph (3)

DOE/HQ

OSTI (25)

DOE/NV

C. A. Cox (1)

M. R. Dockter (1)

S. C. Ronshaugen (2)

DOE/SR

J. D. Arnett (2)

A. C. Doswell (4)

E. C. Goodson (4)

K. L. Hooker (4)

S. R. Wright (2)

SRS/SRTC (continued)

D. W. Hayes (5)

H. E. Mackey (10)

D. B. Moore-Shedrow (2)

W. L. Specht (2)

EG&G/EM

Z. G. Burson LVAO (1)

H. W. Clark LVAO (1)

J. F. Doyle LVAO (1)

E. L. Feimster LVAO (1)

A. E. Fritzsche LVAO (1)

P. P. Guss WAMD (1)

T. J. Hendricks LVAO (1)

J. E. Jobst LVAO (1)

R. A. Melbaum LVAO (1)

C. K. Mitchell LVAO (1)

G. R. Shipman WAMD (1)

L. R. Tinney LVAO (1)

W. J. Tipton LVAO (1)

P. H. Zavattaro LVAO (1)

SRS/SRTC

A. L. Boni (2)

T. S. DeHart (5)

J. B. Gladden (5)

LIBRARIES

RSL (30)

SBO (1)

TIC (1)

AERIAL RADIOLOGICAL SURVEYS OF
STEED POND
SAVANNAH RIVER SITE
EGG 10617-1192

DATES OF SURVEYS: 1984-1989
DATE OF REPORT: SEPTEMBER 1993

**DATE
FILMED**

5/20/94

END