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AN AERIAL RADIOLOGICAL SURVEY OF THE

SAXTON NUCLEAR EXPERIMENTAL CORPORATION FACILITY

AND SURROUNDING AREA

SAXTON, PENNSYLVANIA

DATE OF SURVEY: JULY 1989

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ABSTRACT

An aerial radiological survey was conducted during the period July 5 to 22, 1989, over an 83-square-kilometer (32-square-mile) area surrounding the Saxton Nuclear Experimental Corporation (SNEC) facility which is owned by General Public Utilities and located near Saxton, Pennsylvania. The survey was conducted at a nominal altitude of 61 meters (200 feet) with line spacings of 91 meters (300 feet). A contour map of the terrestrial gamma exposure rate extrapolated to 1 meter above ground level (AGL) was prepared and overlaid on an aerial photograph and a set of United States Geological Survey (USGS) topographic maps of the area. The terrestrial exposure rates varied from about 9 to 11 microroentgens per hour (μR/h) over most of the survey area. The levels over the SNEC facility did not differ from the exposure rates seen over the entire survey area. Cesium-137 (Cs-137) levels typical of worldwide fallout deposition were detected throughout the surveyed area. No other trends of Cs-137 were observed.

Soil samples and pressurized ion chamber measurements were obtained at six locations within the survey boundaries to support the aerial data.

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Tables

1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains the Remote Sensing Laboratory (RSL) in Las Vegas, Nevada, and an extension facility in Washington, D.C. The RSL is operated under contract to the DOE by EG&G Energy Measurements, Inc. (EG&G/EM). One of the major functions of the RSL is to manage an aerial surveillance program called the Aerial Measuring System (AMS).

Since its inception in 1958, the AMS has continued a nationwide effort to document baseline radiological conditions surrounding nuclear energy-related sites of interest. These sites include power plants, manufacturing and processing plants, and research laboratories employing nuclear materials. At the request of federal or state agencies and by direction of the DOE, the AMS is deployed for various aerial survey operations.

An aerial radiological survey, performed at the request of the United States Nuclear Regulatory Commission (NRC), was conducted from July 5-22, 1989, over the Saxton Nuclear Experimental Corporation (SNEC) facility and surrounding area (Figure 1). The survey covered an 83-square-kilometer (32-square-mile) area around the plant. The purpose of the survey was to map the gamma environment of the area surrounding the SNEC Facility. Particular attention was to be paid to the possible presence of cesium-137 (Cs-137) in the areas surveyed.

2.0 SITE DESCRIPTION

The SNEC facility is located in Saxton, Pennsylvania, about 32 kilometers (20 miles) southeast of Altoona, Pennsylvania. The plant is located in a narrow, deep valley whose sides rise up 152 meters (500 feet) from the valley floor. Elevations in the survey area range from a minimum of 213 meters (700 feet) in the central portion of the survey area (along the banks of the reservoir which runs down the center of the survey area) to over 610 meters (over 2,000 feet) in several parts of the survey area.

Large-area aerial photographic imagery of the plant, taken by EG&G aircraft, were used in preparing this report. In addition, many oblique aerial photographs of the site were taken during the survey.

3.0 NATURAL BACKGROUND

Natural background radiation originates from radioactive elements present in the earth, airborne radon, and cosmic rays entering the earth's atmosphere from space.

The natural terrestrial radiation levels depend upon the type of soil and bedrock immediately below and surrounding the point of measurement. Within cities, the radiation levels are also dependent on the elemental composition of street and building materials. The gamma radiation originates primarily from the uranium decay chain, the thorium decay chain, and radioactive potassium. Local concentrations of these nuclides produce radiation levels at the surface of the earth typically ranging from 1 to 15 μR/h (9 to 1,3[illegible] mrem/y).[1] Areas with especially high uranium and/or thorium concentrations in the surface minerals exhibit even higher radiation levels.

Cesium-137 is another radioactive element which is found in many parts of the world.[2] It is a product of nuclear fission. Generally, Cs-137 is due to worldwide fallout resulting from the atmospheric testing of nuclear weapons. Values of less than 1 picocurie per gram of soil (pCi/g) are considered normal, although higher values have been reported.[3]

Radon, a radioactive noble gas, is a member of both the uranium and thorium decay chains. It can both diffuse through the soil and travel through the air to other locations. Therefore, the level of airborne radiation due to these radon isotopes and their daughter products at any specific location depends on a variety of factors including the meteorological conditions, mineral content of the soil, and soil permeability. Typically, airborne radiation contributes from 1 to 10 percent of the natural background radiation levels.

Cosmic rays, the space component, interact with elements of the earth's atmosphere and soil. These interactions produce an additional natural source of gamma radiation. Radiation levels due to cosmic rays vary with altitude and geomagnetic latitude. Typically, values range from 3.3 μR/h at sea level in Florida to 12 μR/h at an altitude of 3 kilometers (1.9 miles) in Colorado.[4]

FIGURE 1. GENERAL VIEW OF THE SAXTON NUCLEAR EXPERIMENTAL CORPORATION FACILITY AND SURROUNDING AREA SHOWING THE FACILITIES, SURVEY BOUNDARY, AND GROUND SAMPLE SITES FOR THE 1989 AERIAL SURVEY

4.0 SURVEY PLAN

The survey was designed to cover approximately 83 square kilometers (32 square miles) surrounding the SNEC facility (Figure 1). The gamma ray spectral data were processed to provide both a qualitative and quantitative analysis, where applicable, of the radionuclides in the survey area. The helicopter steering computer was programmed to guide the aircraft through a series of parallel flight lines which would emcompass the area surrounding the site. For this survey, all lines were flown in an approximately north-south direction at a nominal altitude of 61 meters (200 feet) above ground level (AGL), a line spacing of 91 meters (300 feet), and a speed of 36 meters/second (70 knots).

5.0 SURVEY EQUIPMENT

A Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter (Figure 2) was used for the low altitude survey. The aircraft carried a crew of two and a lightweight data acquisition system called the Radiation and Environmental Data Acquisition and Recorder system, Model IV (REDAR IV). Two pods—each containing an array of four 10.2-cm × 10.2-cm × 40.6-cm (4-in × 4-in × 16-in) log-type, thallium-activated, sodium iodide, NaI(Tl), gamma detectors as well as one 10.2-cm × 10.2-cm cylindrical gamma detector of the same material—were mounted on the sides of the helicopter. The smaller detector extends the effective dynamic range of the REDAR IV system, which is useful in examining areas exhibiting enhanced levels of radiation.

FIGURE 2. *MBB BO-105 HELICOPTER WITH DETECTOR PODS*

The signal from each detector was calibrated with a sodium-22 (Na-22) source. Normalized outputs from each detector were combined in a four-way summing amplifier for each array. Then outputs of each array were matched and combined in a two-way summing amplifier. Finally, the signal was adjusted in the analog-to-digital converter (ADC) so that the calibration peaks appeared in preselected channels of the multichannel analyzer of the REDAR IV system.

5.1 REDAR IV System

The REDAR IV is a multimicroprocessor, portable data acquisition and real-time analysis system. It has been designed to operate in the severe environments associated with platforms such as helicopters, fixed-wing aircraft, and various ground-based vehicles. The system displays to the operator all required radiation and system information, in real time, via CRT displays and multiple LED readouts. All pertinent data are recorded on magnetic cartridge tapes for post-mission analysis on minicomputer systems.

The system employs five Z-80 microprocessors with AM9511 arithmetic processing chips to perform data collection and display, real-time data analysis, navigational calculations, and data recording, all of which are under operator control. The system allows access to the main processor bus through both serial and parallel data ports under control of the central processor.

The system consists of the following subsystems:

1. Two independent radiation data collection systems
2. A general purpose data I/O system
3. A digital magnetic tape recording system
4. A CRT display system
5. A real-time data analysis system
6. A ranging system with steering calculation and display

The REDAR IV processing system block diagram is shown in Figure 3.

Each radiation data collection system consists of a multichannel analyzer which collects 1,024 channels of gamma ray spectral data (4.0 keV/channel) once every second during the survey operation. The 1,024 channels of data are sent to the single-channel processor, then compressed into 256 channels. Table 1 summarizes the spectral data compression performed by REDAR IV.

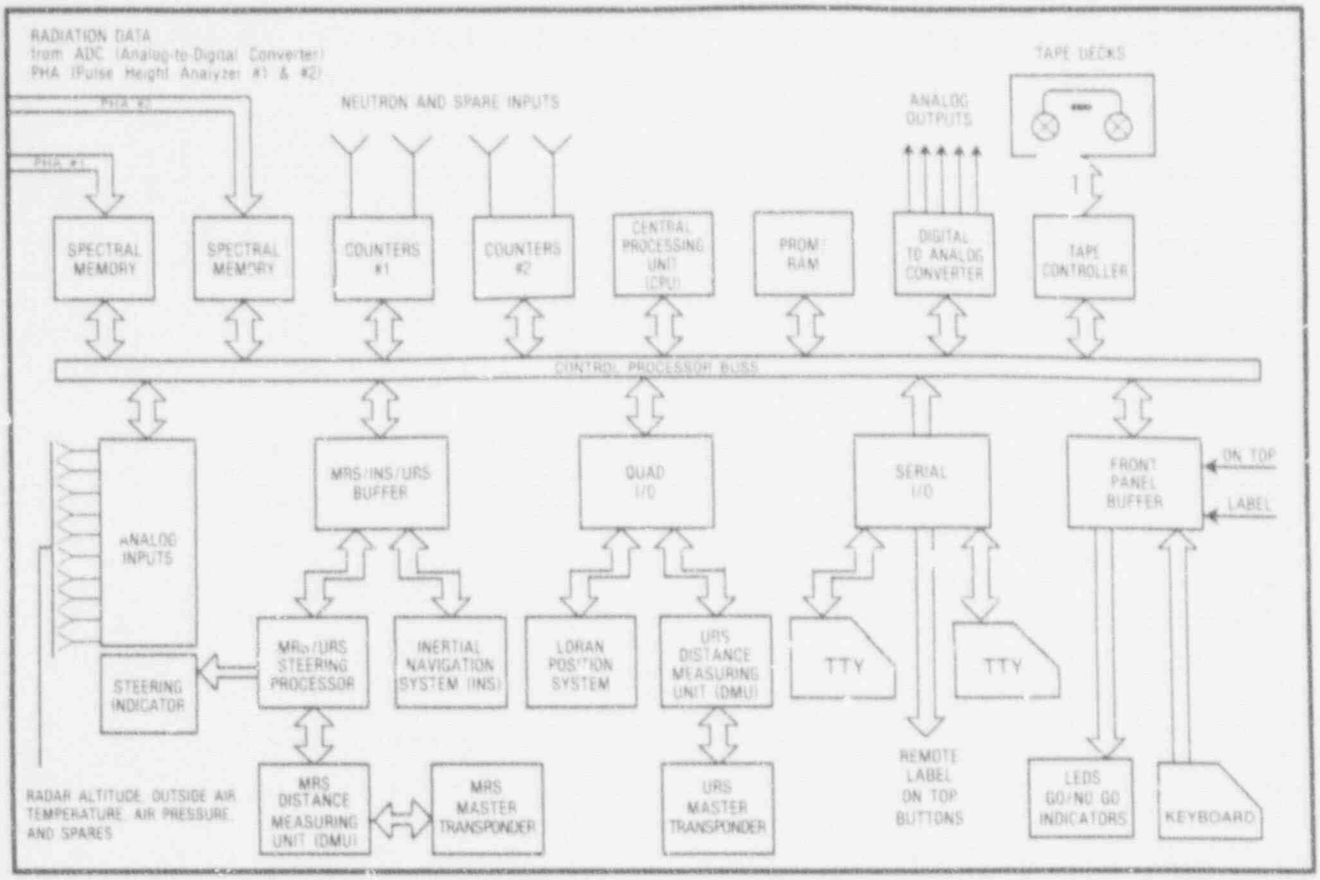

FIGURE 3. *REDAR IV PROCESSOR SYSTEM BLOCK DIAGRAM*

Table 1. REDAR IV Spectral Data Compression

Eγ (keV) At Input Channel Center	Input Channel (linear @ 4 keV/channel)	Output Channel (compressed)	Output Channel Energy Coefficient ΔE (keV/channel)
0 - 300	0 - 75	0 - 75	4
304 - 1,620	76 - 405	76 - 185	12
1,624 - 4,068	406 - 1,017	186 - 253	36
4,072 - Cutoff	1,018 - 1,023	254	N/A
		255 (always zero)	

The spectrum is divided into three partitions with the appropriate energy coefficient to make the width of the photopeaks approximately the same in each partition. The resolution of NaI(Tl) crystals varies with energy, permitting the compression of the spectral data without compromising photopeak identification and peak stripping techniques. In the first partition (Channels 0-75), the data are not compressed to permit stripping of low-energy photopeaks, such as the 60-keV photopeak from americium-241 (Am-241). The spectral compression technique reduces the amount of data storage required by a factor of four.

The 256 channels of spectral data are continuously recorded every second. The REDAR IV system has two sets of spectral memories; each memory can accumulate four individual spectra. The two memories are operated in a flip-flop mode, every 4 seconds, for continuous data accumulation. While one memory is being used to store data, the data in the other memory are being transferred to magnetic tape.

The REDAR IV data acquisition system is shown in Figure 4.

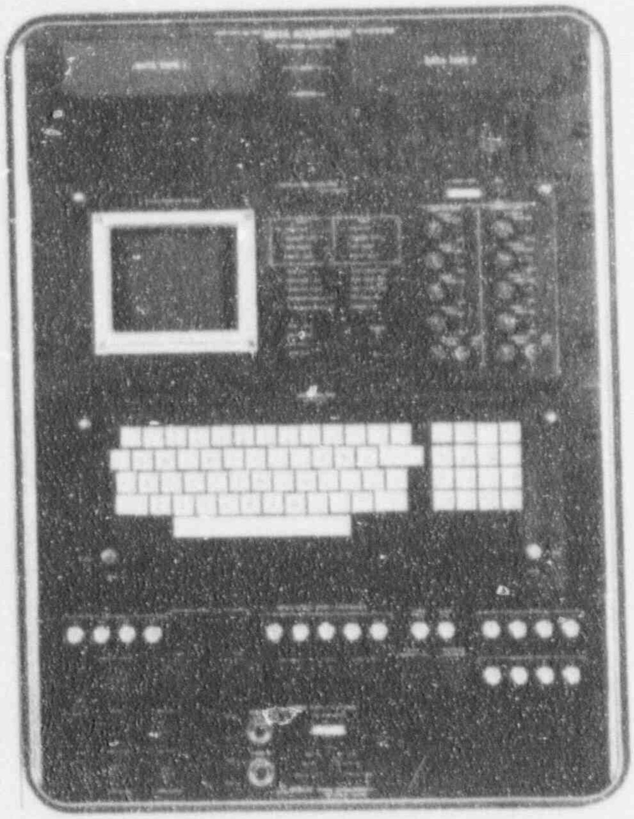

FIGURE 4. *REDAR IV DATA ACQUISITION SYSTEM*

5.2 Helicopter Positioning Method

The helicopter position was established by two systems: an ultrahigh-frequency ranging system (URS) and a radar altimeter.

The URS master station, mounted in the helicopter, interrogated two remote transponders located outside the survey area. By measuring the roundtrip propagation time between the master and remote stations, the master unit computed the distance to each. The distances were recorded on magnetic tape with the radiation data, once each second. Simultaneously, these distances were converted to position coordinates for the steering indicator to direct the aircraft along the predetermined flight lines.

The radar altimeter similarly measured the time lag for the return of a pulsed signal and converted this delay to aircraft altitudes. For altitudes up to 610 meters (2,000 feet), the accuracy was ±0.6 meter or ±2 percent, whichever was greater. These data were also recorded on magnetic tape so that any variation in gamma signal strength caused by altitude fluctuations could be compensated.

The detector and electronic systems which were used to record the data are described in considerable detail in a separate publication.[5]

6.0 DATA PROCESSING EQUIPMENT

Data processing was begun in the field with the Radiation and Environmental Data Analyzer and Computer (REDAC) system. This system consists of a computer analysis laboratory mounted in a mobile van (Figure 5). During the survey operations, the van and aircraft were based at the Blair County-Altoona Airport.

FIGURE 5. *INTERIOR OF THE MOBILE DATA ANALYSIS LABORATORY*

The REDAC system has a 16-bit CPU with 512 kilobytes of memory and floating point processor; two discs with a total of 1.1 gigabytes of storage; two 800/1,600-byte-per-inch, 9-track, 1/2-inch tape drives; two 4-track, 1/4-inch cartridge tape drives for reading REDAR IV tapes; a 36-inch-wide carriage incremental plotter; a multispeed printer; a system CRT display; and three alpha/graphics CRT displays and hard-copy units (Figure 6). An extensive library of software is available for data processing.

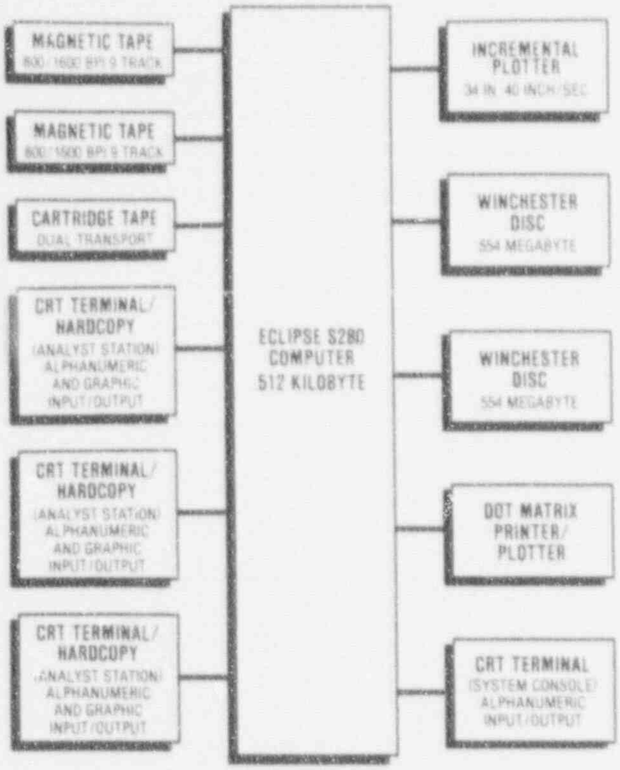

FIGURE 6. *BLOCK DIAGRAM OF THE REDAC SYSTEM*

Gamma spectral windows can be selected for any portion of the spectrum. Weighted combinations of such windows can be summed or subtracted and the results plotted as a function of time or distance. By the proper selection of windows and weighting factors, it is possible to extract photopeak count rates for radioisotopes deposited on the terrain by human activity. The photopeak count rates can then be converted to isotope concentrations or exposure rates.

The REDAC can display the spectral data on a CRT or plot it on an incremental plotter for isotopic identification and documentation.

7.0 DATA ANALYSIS

In general, the aerial radiation data consist of contributions from naturally occurring radioelements, aircraft and detector background, and cosmic rays. For this survey, the major emphasis was on mapping the terrestrial gamma radiation in the area surrounding the plant and locating and identifying any anomalous sources of man-made radiation, particularly Cs-137. Isopleth maps were produced using three different procedures: gross count procedure, man-made gross count extraction procedure, and Cs-137 count extraction procedure. Only the gross count isopleth is presented in this report.

7.1 Gross Count Procedure

The gross count (GC) method was based on the integral counting rate in that portion of the spectrum between 38 and 3,026 keV. The count rate (measured at survey altitude) was converted to exposure rate ($\mu R/h$) at 1 meter above ground level by application of a predetermined conversion factor. This factor assumes a uniformly distributed source covering an area which is large compared with the field of view of the detector (approximately 100- to 200-meter diameter circle at the survey altitude of 61 meters).

7.2 Man-Made Gross Count Extraction Procedure

The man-made gross cour. (MMGC) extraction algorithm is designed to reveal the presence of changes in spectral shape. Large changes in gross counting rates from natural radiation usually produce only small changes in spectral shape. The natural emitters will change intensity of radiation emitted, but the spectral shape will remain nearly constant. As the detector moves from one location to another, the value of the ratio of the counts in the high energy portion of the spectrum to the low energy counts remains approximately constant. The algorithm is designed to be most sensitive to man-made nuclides. The spectrum dividing line is chosen at an energy (1,394 keV) above which most long-lived, man-made nuclides do not emit gamma rays. It is analytically expressed as:

$$\text{MMGC} = \sum_{E = 38\text{ keV}}^{1{,}394\text{ keV}} \text{counts}_E - K_m \sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}} \text{counts}_E$$

Counts in the upper energy window (1,394 to 3,026 keV) are multiplied by a constant, K_m, which is the average ratio of counts in the low energy window to counts in the high energy window for areas of normal background. The resultant MMGC is approximately equal to zero for areas containing normal background radiation and significantly different from zero in those areas which have contributors in addition to background radiation. The MMGC analysis did not show any statistically significant anomalies.

7.3 Cesium-137 Gross Count Extraction Procedures

The Cs-137 extraction procedure is very similar to the man-made gross count algorithm. Two windows are used for the Cs-137 extraction procedure. The low energy window is set to encompass the Cs-137 photopeak, which occurs at 662 MeV. This window encompasses an energy range of 590 keV to 722 keV. The high energy window is used to infer the contributions of other sources to the counts in the Cs-137 window. The ranges used were 722 keV to 794 keV. Mathematically this can be expressed as:

$$\text{Cs-137} = \sum_{E = 590\ \text{keV}}^{722\ \text{keV}} \text{counts}_E - K_c \sum_{E = 722\ \text{keV}}^{794\ \text{keV}} \text{counts}_E$$

Where K_c is analogous to K_m in the previous equation.

8.0 GROUND-BASED MEASUREMENT PROCEDURES

Exposure rates were measured and soil samples obtained at five locations during the SNEC survey to support the integrity of the aerial results. The locations of the ground-based measurements (see Figure 1) were chosen on the basis of assumed normal background radiation levels and were away from any obvious anomalies. A Reuter-Stokes pressurized ionization chamber was used for each exposure measurement. Measurements were made at a height of 1 meter above ground level (AGL). Soil samples, to a depth of 15.0 cm, were also obtained at the center and at four points of the compass on the circumference of a 200-meter (660-foot) diameter circular area. The soil samples were dried and their gamma activities measured using a germanium-based detector system located at EG&G/EM's Santa Barbara laboratory. Detailed descriptions of the systems and procedures used for soil sample data collection and analysis are outlined in separate publications.[6,7]

9.0 DISCUSSION OF RESULTS

9.1 Terrestrial Gamma Exposure Rate Contour Map

The principal result obtained from the gamma survey of the SNEC facility is the terrestrial gamma exposure rate contour map (Figure 7) of the 83-square-kilometer (32-square-mile) area surrounding the plant. The map represents the measured terrestrial gamma exposure rate plus an estimated cosmic component (3.8 μR/h) at 1 meter above the earth's surface. The highly variable airborne radon daughter component is not included.

The exposure rates at 1 meter AGL, shown on the map in Figure 7, range from less than 7 μR/h over the Rayestown reservoir to 11 to 15 μR/h over other portions of the survey area. No areas of exposure rates greater than 15 μR/h were observed.

Aerial systems integrate radiation levels over an area whose diameter may be several times the height of the platform above ground. This is a function of gamma ray energy, their birth within the soil matrix, and the response characteristics of the detector package. For activity fairly uniformly distributed over large areas (typical of natural background radiation), the agreement between ground-based readings and those inferred from aerial data is generally quite good. However, for nonuniform areas, the averaging inherent in aerial measurements will underestimate activity directly over anomalies and will overestimate activity immediately surrounding these anomalies. For such conditions, ground and aerial measurements will not agree. While the aerial data serve to locate such anomalies, ground measurements are required to better define the activity and spatial extent of the anomalies.

Figure 8 is a typical background spectrum for the area surrounding the SNEC facility.

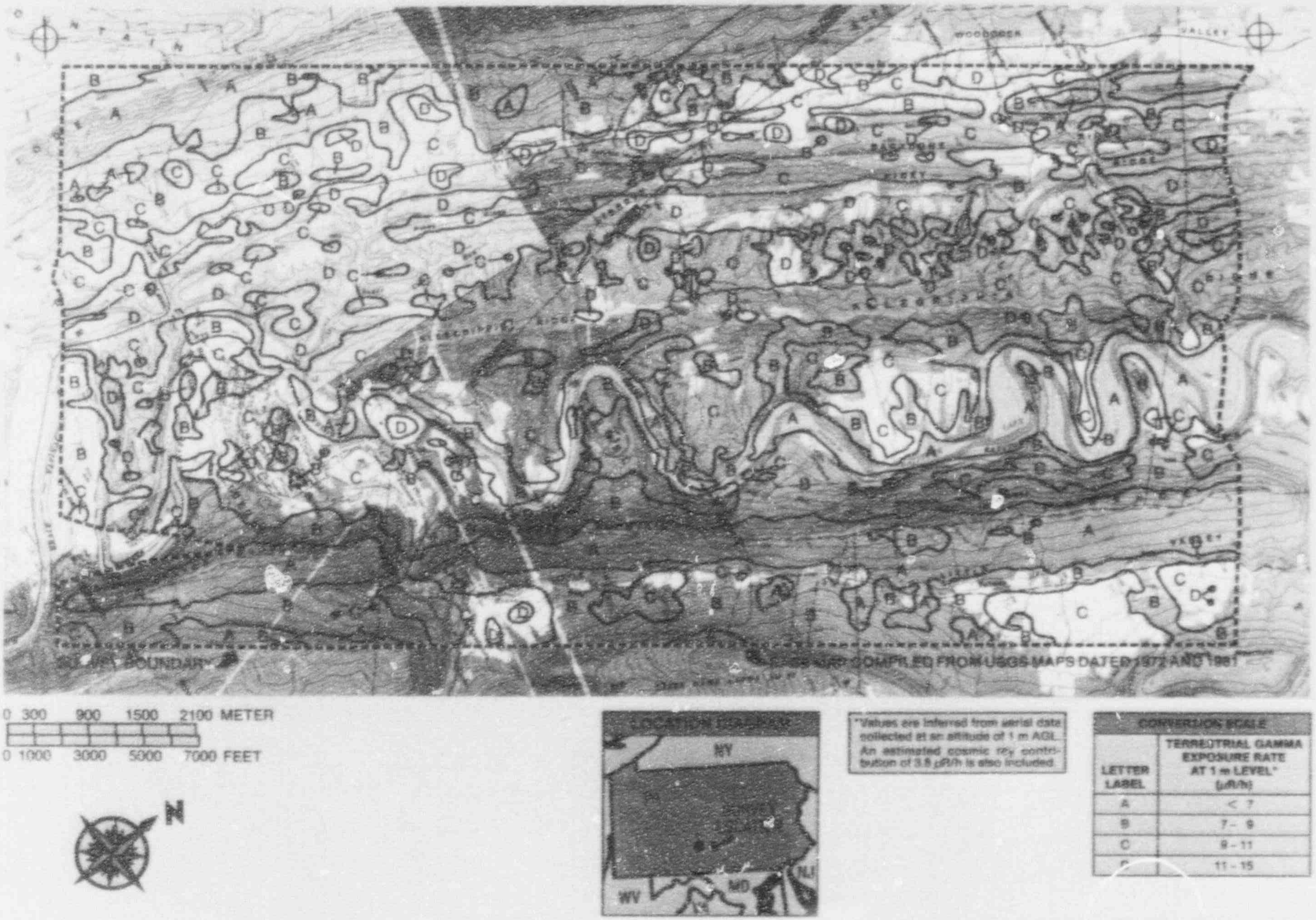

FIGURE 7. TERRESTRIAL GAMMA RADIATION EXPOSURE RATE CONTOURS DERIVED FROM AERIAL DATA OBTAINED DURING JULY 5-22, 1989, OVER THE SAXTON NUCLEAR EXPERIMENTAL CORPORATION FACILITY AND SURROUNDING AREA

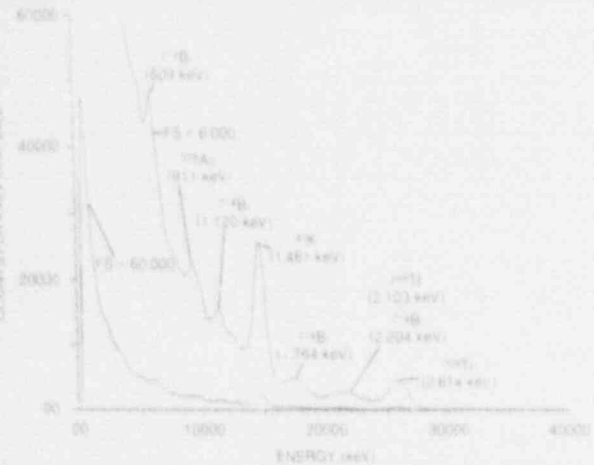

FIGURE 8. ***GAMMA RAY ENERGY SPECTRUM TYPICAL OF THE NATURAL BACKGROUND IN THE SURVEY AREA***

9.2 Cesium-137 Count Contour Analysis

A computer-aided search of the data for man-made sources, particularly the gamma-emitting radionuclide Cs-137, indicated the presence and distribution of Cs-137 activity typical of world-wide fallout. None of the investigations revealed trends that suggest dispersal of Cs-137 via particulate transport during contaminated waste burning, hauling, or storing. The Cs-137 activity inferred from aerial data was well within that expected from the deposition of woldwide fallout, which is approximately 1 pCi/gram of soil or less. No other man-made contaminates were detected in this area.

9.3 Ground-Based Measurements

Pressurized ion chamber measurements and soil samples were collected during the survey at six sites within the survey boundaries. The site locations (Numbers 1 through 6) are labeled in Figure 1. The soil samples were dried and counted on a calibrated gamma spectrometer in the laboratory. The soil analysis exposure rates were computed from the primary isotopic concentrations in the soil samples and included the effect of soil moisture (see Table 2). The measured soil exposure rate values are compared with the ion chamber measurements and the aerial measurements in Table 3. These exposure values represent the terrestrial plus the cosmic components only.

The isotopic and ion chamber measurements generally agree with the inferred aerial data for each site. There are several contributors to differences among the measurement methods:

1. The aerial data were not taken at exactly the same places and times as the ground data.

2. Each 1-second data point obtained with the airborne system covers an area several thousand times as large as a measurement made at 1 meter, such as with a portable ion chamber.

3. Since only a limited number of soil samples were taken, statistical deviations are significant.

Table 2. Results of Soil Sample Analysis (Average Values)

Site[1]	Soil Moisture (%)	U-238 (ppm)	Th-232 (ppm)	Cs-137 (pCi/g)	K-40 (pCi/g)
1	20 ± 6	3.4 ± 0.7	11 ± 2	0.3 ± 0.1	12 ± 2
2	23 ± 6	2.9 ± 0.3	8 ± 1	0.3 ± 0.1	8 ± 2
3	19 ± 3	3.1 ± 0.2	11.9 ± 0.6	0.4 ± 0.3	18 ± 4
4	16 ± 4	3.1 ± 0.2	12 ± 1	0.18 ± 0.05	20 ± 4
5	[2]	[2]	[2]	[2]	[2]
6	25 ± 1	3.5 ± 0.7	11 ± 1	0.27 ± 0.02	14 ± 1

[1] Site Description
Site 1: Field, 6 inches of grass, playground
Site 2: Fallow corn field, 1-2 inches of weeds and grass
Site 3: Cemetery, west side
Site 4: Field, 6 inches of grass, limed 4 years ago
Site 5: End of wood pier over Juniata River
Site 6: Field, 3 inches of grass and weeds

[2] No soil samples taken.

Table 2. Comparison of Aerial and Ground-Based Measurements			
	Exposure Rate (μR/h at 1 Meter Above Ground Level)		
Sample Location[1]	Soil Analysis[2,3]	Ion Chamber[4]	Inferred Aerial Data[2]
G-1	10 ± 1.6	9.8 ± 0.5	7 - 9
G-2	9 ± 1.3	8.0 ± 0.5	9 - 11
G-3	11 ± 1.3	11.0 ± 0.5	9 - 11
G-4	12 ± 1.6	11.7 ± 0.5	9 - 11
G-5	[5]	5.4 ± 0.5	7 - 9
G-6	10.3 ± 0.8	11.0 ± 0.5	9 - 11

[1] Site locations are shown in Figure 1.

[2] Calculation includes cosmic ray contribution of 3.8 μR/h.

[3] Calculation includes a moisture correction of the Form 1/(1 + m).

[4] Reuter-Stokes Model No. RSS-111, Serial No. R3588.

[5] No soil samples taken.

4. The ground cover may reduce the computed isotopic exposure by as much as 5 percent.
5. Site S-1 was located in an area where conditions were changing, hence the aerial system did not measure a homogeneous sample.
6. Site S-5 was on the banks of the reservoir. The aerial system measured both the conditions over the reservoir and the surrounding terrain.

Differences in Cs-137 concentrations reported in this survey and a previously conducted ground survey[8] are not great. Some higher readings were reported in the ground survey. This can be attributed to a number of factors:

1. The ground survey intentionally chose survey sites which were most likely to have retained Cs-137 fallout.
2. The previous survey measured the samples *in situ*; soil samples for this survey were removed from the field and then analyzed in a laboratory. The *in situ* technique assumes an exponential distribution of Cs-137 which is dependent on the soil depth. Any deviations in the soil profile would result in different measured concentrations of Cs-137.
3. Cesium-137 is not necessarily homogeneously distributed.

10.0 SUMMARY

An aerial radiological survey was conducted between July 5 and 22, 1989, over an 83-square-kilometer (32-square-mile) area surrounding the Saxton Nuclear Experimental Corporation facility located near Saxton, Pennsylvania. The survey was conducted at a nominal altitude of 61 meters (200 feet) with line spacings of 91 meters (300 feet). A contour map of the terrestrial gamma exposure rate (extrapolated to 1 meter above ground) was prepared. The Cs-137 activity inferred from aerial data was within the limits of the deposition from worldwide fallout. No other man-made contaminates were detected in the survey area.

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