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AN AERIAL RADIOLOGICAL SURVEY OF THE

BABCOCK AND WILCOX NUCLEAR FACILITIES

AND SURROUNDING AREA

LYNCHBURG, VIRGINIA

DATE OF SURVEY: JULY 1988

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ABSTRACT

An aerial radiological survey was conducted from July 18 through July 25, 1988, over a 41-square-kilometer (16-square-mile) area surrounding the Babcock and Wilcox nuclear facilities located near Lynchburg, Virginia. 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. The terrestrial exposure rates varied from 8 to 12 microroentgens per hour (μR/h). A search of the data for man-made radiation sources revealed the presence of three areas of high count rates in the survey area.

Spectra accumulated over the main plant showed the presence of cobalt-60 (^{60}Co) and cesium-137 (^{137}Cs). A second area near the main plant indicated the presence of uranium-235 (^{235}U). Protactinium-234m (^{234m}Pa) and ^{60}Co were detected over a building to the east of the main plant.

Soil samples and pressurized ion chamber measurements were obtained at four locations within the survey boundaries in support of the aerial data.

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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 for the DOE by EG&G Energy Measurements, Inc. (EG&G/EM), a contractor of the DOE. 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-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 18 through July 25, 1988, over the Babcock and Wilcox facilities and surrounding area. The survey covered a 41-square-kilometer (16-square-mile) area around the plant. The purpose of the survey was to map the gamma radiation environment of the area surrounding the Babcock and Wilcox facilities.

2.0 SITE DESCRIPTION

The Babcock and Wilcox facilities are located just outside of the city of Lynchburg, Virginia, and the land surrounding the plant is hilly, wooded terrain. Elevations in the survey area range from a minimum of 500 feet along the James River to a high of about 900 feet at the top of Mount Athos in the eastern portion of the survey area.

Large-area aerial photographic imagery of the plant, taken by EG&G/EM aircraft, was used in preparing this report. In addition, 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.[1] Within cities, the levels are also dependent on the nature 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 130 mrem/y).[2] Some areas with high uranium and/or thorium concentrations in the surface minerals exhibit even higher radiation levels, especially in the western states.

Radon, a radioactive noble gas, is a member of both the uranium and thorium radioactive 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 of background radiation, 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.[3]

4.0 SURVEY PLAN

The survey was designed to cover approximately 41 square kilometers (16 square miles) surrounding the Babcock and Wilcox facilities (Figure 1). The gamma ray spectral data were processed to provide both a qualitative and a quantitative analysis, where applicable, of the radionuclides in the survey area. The steering computer was programmed to set up a series of parallel flight lines to cover the area surrounding the site. For this survey, all lines were flown in an approximately north-south direction at a nominal altitude

FIGURE 1. *GENERAL VIEW OF THE BABCOCK AND WILCOX FACILITIES AND SURROUNDING AREA SHOWING THE FACILITIES, SURVEY BOUNDARY, AND GROUND SAMPLE SITES FOR THE 1988 AERIAL SURVEY*

of 61 meters (200 feet) above ground level, 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 four 4-in × 4-in × 16-in log-type, thallium-activated sodium iodide, NaI(Tl), gamma detectors as well as one 2-in × 4-in × 4-in 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.

The signal from each detector was calibrated with a sodium-22 (^{22}Na) source. Normalized outputs from each detector were combined in a four-way summing amplifier for each array. The 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 postmission analysis on minicomputer systems.

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

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 compressed into 256 channels. Table 1 summarizes the spectral data compression performed by REDAR IV.

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 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 (^{241}Am). The spectral compression technique reduces by a factor of four the amount of data storage required.

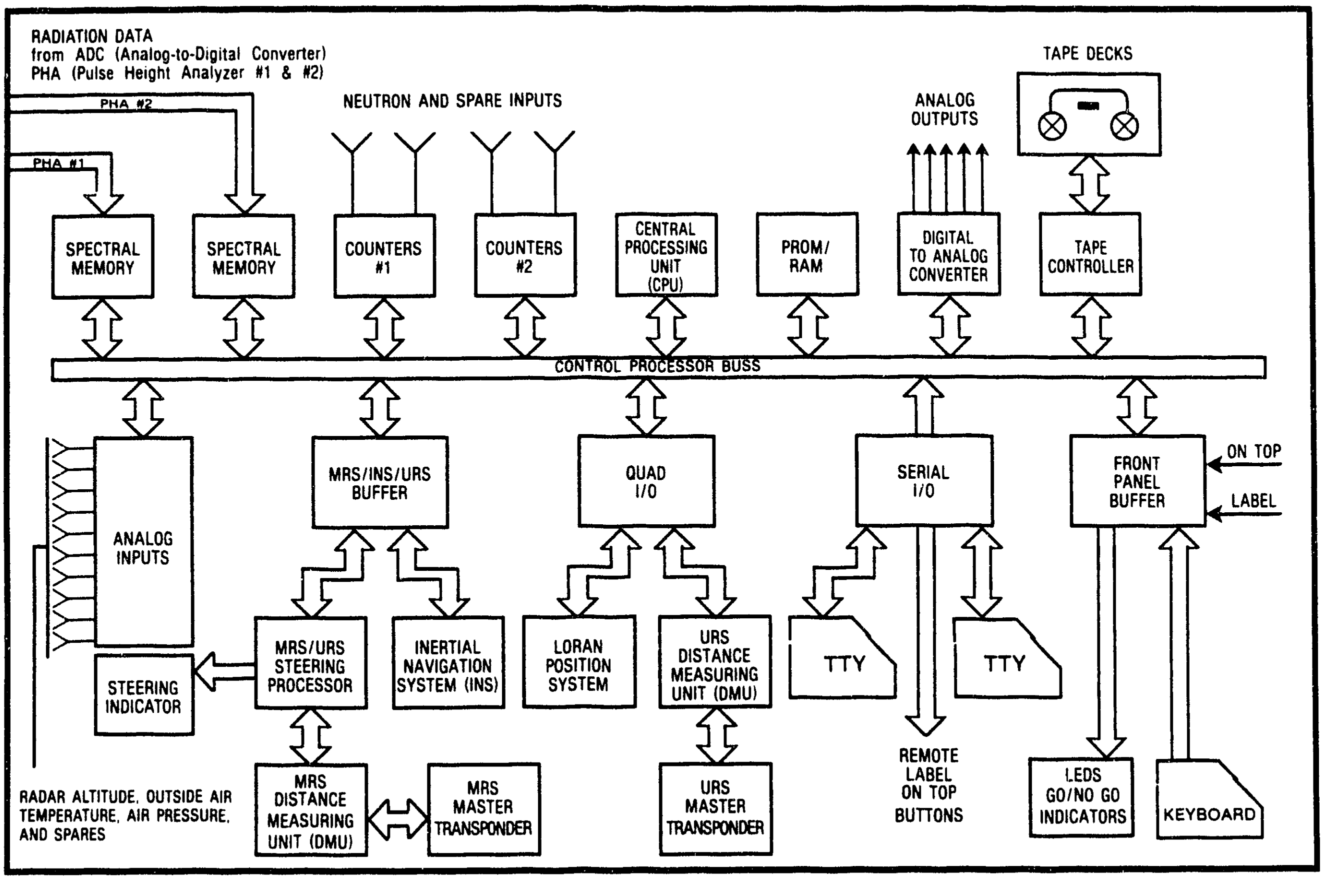


FIGURE 3. ***REDAR IV PROCESSOR SYSTEM BLOCK DIAGRAM***

Table 1. REDAR IV Spectral Data Compression

$E\gamma$ (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 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.

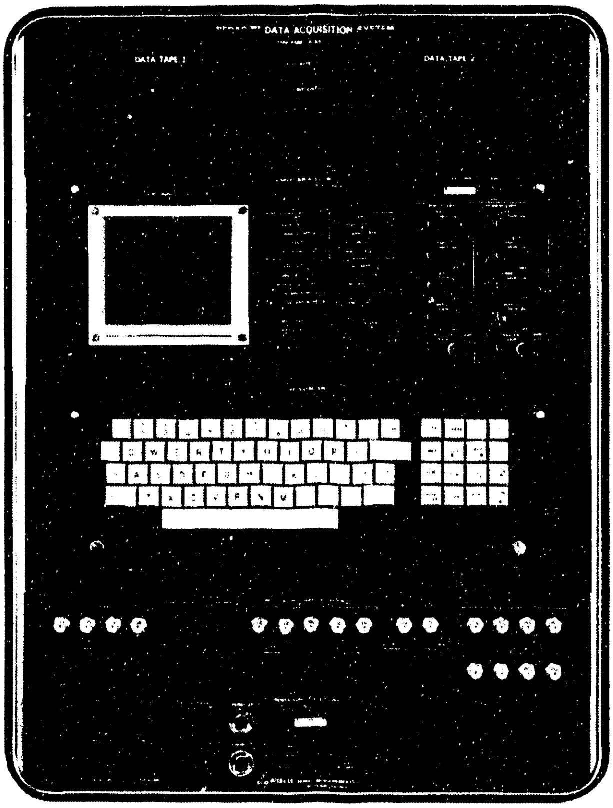


FIGURE 4. ***REDAR IV DATA ACQUISITION SYSTEM***

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 transponder slaves 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 detectors and electronics systems which accumulated and recorded the data are described in considerable detail in a separate publication.[4]

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 Lynchburg Municipal Airport in Lynchburg, Virginia.

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

The REDAC system consists primarily of a 32-bit CPU with 4 megabytes 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 IV tapes; a 34-inch-wide incremental plotter; a multispeed printer; a system CRT display; and three alpha/graphics CRT displays with hardcopy units. A block diagram of the system is shown in Figure 6. This system has an extensive series of software routines available for complete data processing in the field.

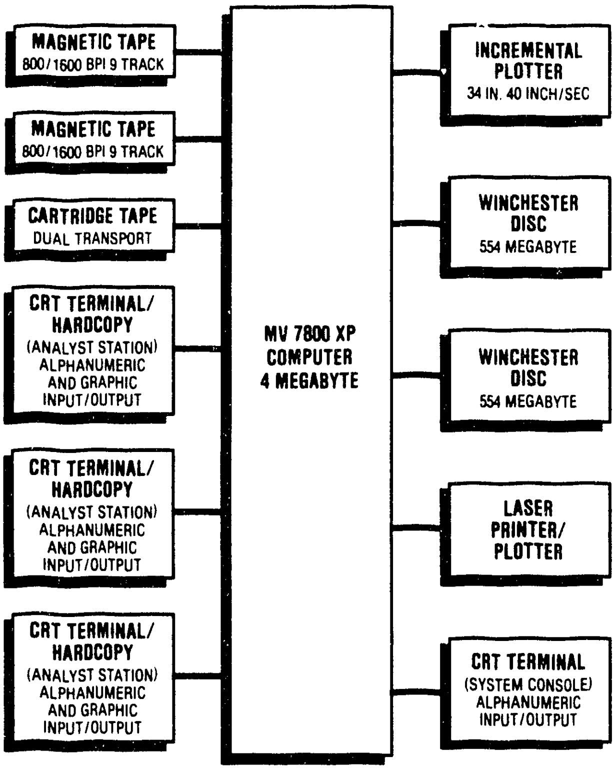


FIGURE 6. ***BLOCK DIAGRAM OF THE REDAC SYSTEM***

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 the photopeak count rates for radioisotopes deposited on the terrain by human activity. Such isotopes disturb the spectral shape due to natural soil radioactivity. These photopeak count rates can then be converted to isotope concentrations or exposure rates. Spectral data can be summed over any portion of a survey flight line.

The spectral data can also be decompressed into a linear plot. The REDAC can display the spectral data or plot it on the incremental plotter for isotopic identification and documentation.

7.0 DATA ANALYSIS

In general, the aerial radiation data consisted of contributions from the 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 existing sources of man-made radiation. Isopleth maps were produced by processing the data, using two different computer procedures: the gross count procedure and the man-made gross count extraction procedure.

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. This count rate (measured at survey altitude) was converted to exposure rate (microroentgens/hour) at 1 meter above ground level by application of a predetermined conversion factor (1,450 counts/ sec = μR/h at 1 meter). 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 meters at the survey altitude of 61 meters). The exposure rate values could be one or two orders of magnitude higher for a source localized in a small area.

7.2 Man-Made Gross Count Extraction Procedure

The man-made gross count (MMGC) extraction algorithm is designed to sense the presence of changes in spectral shape. Large changes in gross counting rates from natural radiation usually produce only small changes in spectral shape because the change in the spectral shape for natural emitters is more or less a constant as the detector moves from one location to another. The algorithm senses counts in the low-energy portion of the spectrum in excess of those predicted on the premise that these counts bear a constant ratio to counts in the higher energy portion. Since 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 in keV as:

$$\mathrm{MMGC} = \sum_{E=38}^{1394} (\mathrm{counts})_E - K \sum_{E=1394}^{3026} (\mathrm{counts})_E$$

The counts in the high-energy window (1,394 to 3,026 keV) are multiplied by a constant, K. This makes the high-energy window approximately equal to the average counts in the low-energy window (38 to 1,394 keV). Hence, the resultant MMGC is approximately equal to zero for areas containing normal background radiation and is significantly different from zero in those areas which do not contain normal background radiation.

8.0 GROUND-BASED MEASUREMENT PROCEDURES

Exposure rates were measured and soil samples were obtained at four locations during the Babcock and Wilcox survey to support the integrity of the aerial results. The locations for the ground-based measurements 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 at a 1-meter height at the center of a 200-meter (660-foot) diameter measurement area. Soil samples, to a depth of 15.0 cm, were also obtained at the center and at the four points of the compass on the circumference of the 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.[4,5]

9.0 DISCUSSION OF RESULTS

9.1 Terrestrial Gamma Exposure Rate Contour Map

The principal result obtained from the gamma survey of the Babcock and Wilcox facilities is the terrestrial gamma exposure rate contour map (Figure 7) of the 41-square-kilometer (16-square-mile) area surrounding the plant. The map represents the measured terrestrial gamma exposure rate plus an estimated cosmic component (3.7 μR/h) at 1 meter above the earth's surface. The highly variable, airborne radon daughter component is not included.

The exposures at 1 meter above the ground, shown on the map in Figure 7, range from a low of 4 to 6 μR/h over the river to a high in excess of 150 μR/h over the main facility. The average exposure rate is approximately 10 μR/h for most of the survey area. Figure 8 shows a typical gamma ray spectrum for the survey area. The spectrum shows the presence of the naturally-occurring radioisotopes bismuth-214 (^{214}Bi), thallium-208 (^{208}Tl), actinium-228 (^{228}Ac), and potassium-40 (^{40}K).

9.2 Man-Made Gross Count Contour Analysis

The MMGC algorithm (discussed in Section 7.2) was used to search the Babcock and Wilcox aerial survey data for man-made gamma emitters. The results of this analysis do not greatly differ from those of the gross count contour. For that reason, the MMGC plot is not included.

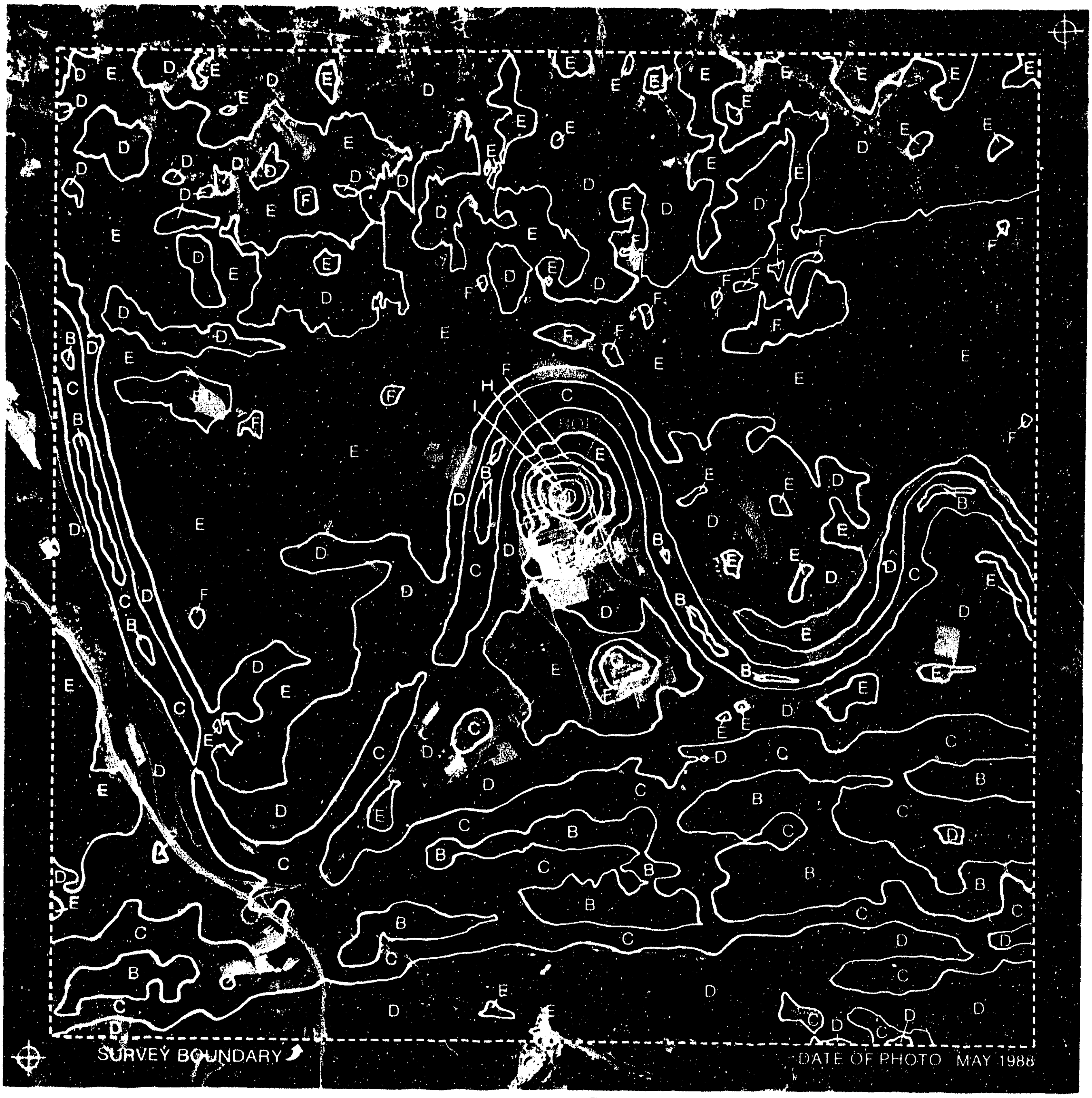
Two areas of anomalies are seen over the main plant (ROI 1 and ROI 2 in Figure 7). The net spectrum of the first of these (Figure 9) shows the presence of cobalt-60 (^{60}Co) and cesium-137 (^{137}Cs). The net spectrum of the second anomaly (Figure 10) shows the presence of uranium-235 (^{235}U).

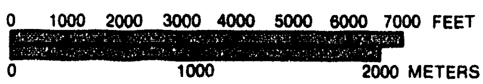
A third anomalous count area is seen in Figure 7 (ROI 3). The net gamma ray spectrum of this site (Figure 11) shows the presence of ^{60}Co and protactinium-234m (^{234m}Pa).

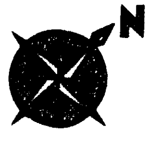
9.3 Ground-Based Measurements

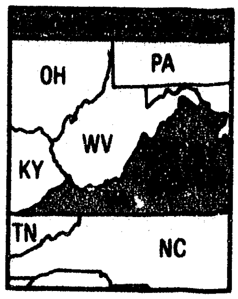
Pressurized ion chamber measurements and soil samples were collected at four sites within the survey boundaries during the aerial survey. The site locations (Numbers 1 through 4) are labeled in Figure 1. The soil samples were dried and counted on a calibrated gamma spectrometer in the laboratory. The 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 calculated 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 results for each site. There are several contributors to









LETTER LABEL	TERRESTRIAL GAMMA EXPOSURE RATE AT 1 m LEVEL (μR/h)*
A	< 4
B	4 - 6
C	6 - 7.5
D	7.5 - 9.5
E	9.5 - 11.5
F	11.5 - 15
G	15 - 29
H	29 - 72
I	72 - 190
J	190 - 280

*Values are inferred from aerial data collected at an altitude of 61 m AGL. An estimated cosmic ray contribution of 3.7 μR/h is also included.

FIGURE 7. *TERRESTRIAL GAMMA RADIATION EXPOSURE RATE CONTOURS DERIVED FROM AERIAL DATA OBTAINED JULY 18-25, 1988 OVER THE BABCOCK AND WILCOX FACILITIES AND SURROUNDING AREA*

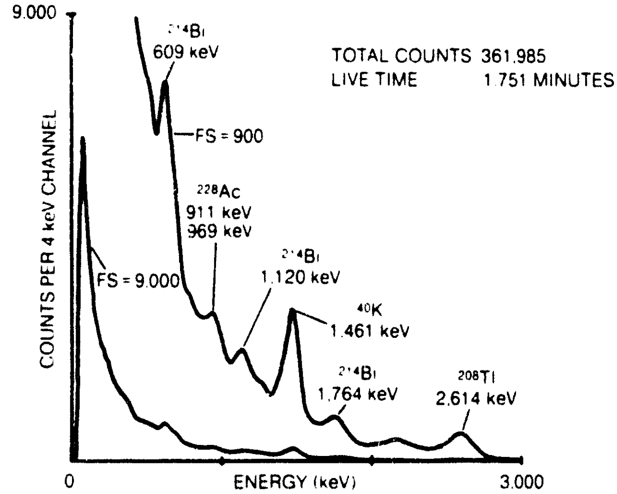


FIGURE 8. *GAMMA RAY ENERGY SPECTRUM TYPICAL OF THE NATURAL BACKGROUND IN THE SURVEY AREA*

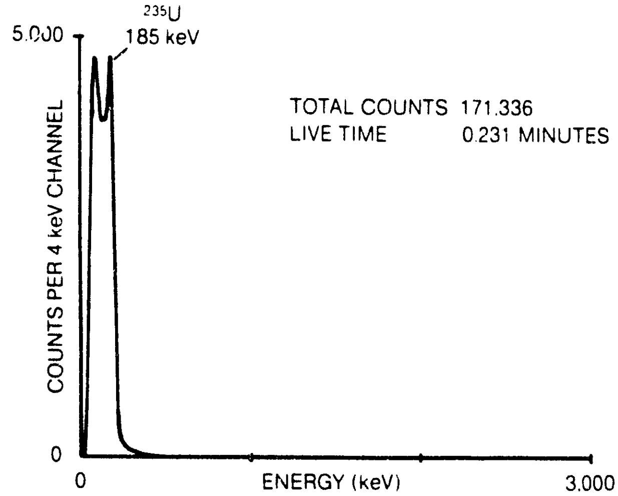


FIGURE 10. *NET GAMMA RAY SPECTRUM OVER THE BABCOCK AND WILCOX FACILITIES (ROI 2)*

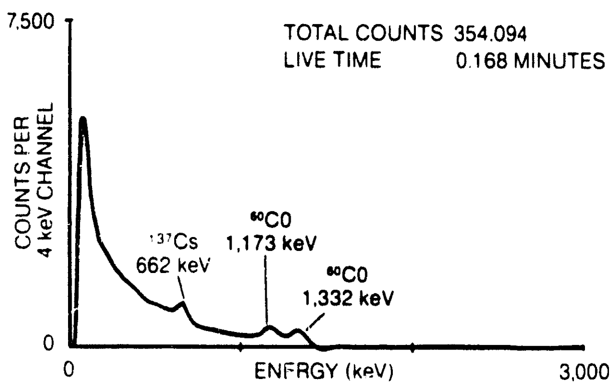


FIGURE 9. *NET GAMMA RAY SPECTRUM OVER THE BABCOCK AND WILCOX FACILITIES (ROI 1)*

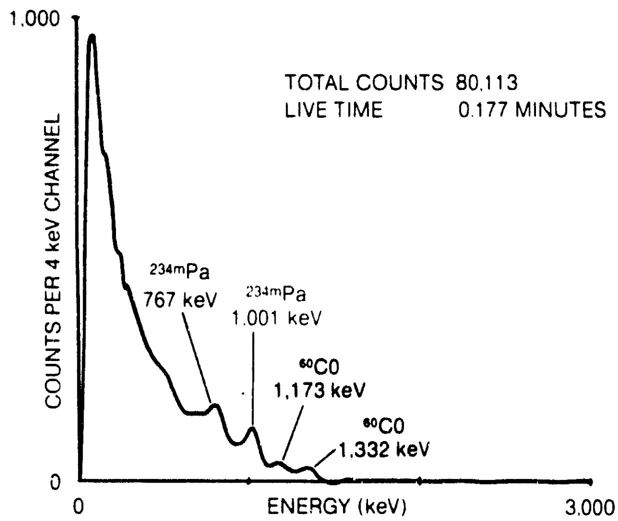


FIGURE 11. *NET GAMMA RAY SPECTRUM OVER THE BABCOCK AND WILCOX FACILITIES (ROI 3)*

Table 2. Results of Soil Sample Analysis[1]

Site[2]	Soil Moisture (%)	^{238}U (ppm)	^{232}Th (ppm)	^{137}Cs (pCi/g)	^{40}K (pCi/g)
1	15 ± 2	2.7 ± 0.2	9.4 ± 0.8	0.04 ± 0.04	10.5 ± 0.9
2	17 ± 2	3.0 ± 0.2	10.8 ± 0.9	0.27 ± 0.03	11 ± 2
3	18 ± 2	2.7 ± 0.2	9 ± 2	0.15 ± 0.12	17 ± 1
4	18 ± 2	3.3 ± 0.3	13 ± 1	0.26 ± 0.12	20 ± 2

[1] Average values

[2] See site locations in Figure 1.

Table 3. Comparison of Aerial and Ground-Based Measurements			
	Exposure Rate (μR/h at 1 Meter Above Ground Level)		
Sample Location[a]	Soil Analysis[b]	Ion Chamber[c]	Inferred Aerial Data[b]
1	9.2 ± 0.7	8.7 ± 0.5	7.5 - 9.5
2	9.7 ± 0.7	9.1 ± 0.5	7.5 - 9.5
3	10.0 ± 0.9	9.0 ± 0.5	7.5 - 9.5
4	11.7 ± 0.7	11 ± 1[d]	9.5 - 11.5

[a] The aerial data were not taken at exactly the same places and times as the ground data.
[b] 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 survey meter, and several million times as large as a typical soil sample.
[c] Since only a limited number of soil samples were taken, statistical deviations are significant.
[d] The ground cover reduces the computed isotopic exposure by as much as 5 percent.

the differences between the two methods, and they are noted in the table footnotes.

10.0 SUMMARY

A 41-square-kilometer (16-square-mile) aerial survey of the Babcock and Wilcox nuclear facilities and surrounding area, located near Lynchburg, Virginia, was conducted between July 18 and 25, 1988. 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 exposure rates extrapolated to 1 meter (3 feet) above the ground was prepared. The contour map showed exposure levels varying from 5 μR/h to greater than 150 μR/h above one of the facility buildings. Average exposure rates were about 10 μR/h.

Three areas of elevated exposure rates were identified. The first of these was shown to be due to the presence of ^{60}Co and ^{137}Cs. The second area was shown to contain ^{235}U, and the third site was shown to contain ^{234m}Pa and ^{60}Co.

Neither the man-made gross count nor the gross count contour plots of the area showed the presence of off-site locations in the survey area which had detectable levels of radioisotopes.

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