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EG&G/EM SURVEY REPORT
AMO-8809
JUNE 1989

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

AN AERIAL RADIOLOGICAL SURVEY OF THE

WASTE ISOLATION PILOT PLANT

AND SURROUNDING AREA

CARLSBAD, NEW MEXICO

DATE OF SURVEY: APRIL 1988

DISCLAIMER

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ABSTRACT

An aerial radiological survey was conducted during the period 8 April to 19 April 1988 over a 404-square-kilometer (156-square-mile) area covering the Waste Isolation Pilot Plant (WIPP) located near Carlsbad, New Mexico, and the surrounding area. The survey was conducted at a nominal altitude of 91 meters (300 feet) with a line spacing of 152 meters (500 feet). A contour map of the terrestrial exposure rates plus the cosmic exposure rate extrapolated to 1 meter above ground level was prepared and overlaid on an aerial photograph of the area. The average terrestrial exposure rates ranged from approximately 6.0 to 9.0 microroentgens per hour (μR/h). Two areas of increased exposure rate were evident. Both areas indicated higher than normal concentrations of naturally occurring radionuclides. A machine-aided search of the data for man-made sources of radiation indicated the presence of Cs-137 at the Gnome Site, which was expected from previous survey work done in the area. No other sources of man-made radiation were found.

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1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains an aerial surveillance system, the Aerial Measuring System (AMS), which is maintained and operated for DOE by EG&G Energy Measurements, Inc. (EG&G/EM), an independent contractor. Since its inception in 1958, this continuing nationwide program has included radiological surveys of nuclear power plants, processing plants for nuclear materials, and research laboratories. AMS aircraft have been deployed to nuclear accident sites and used in searches for lost radioisotopes. They were routinely used during launch operations for Apollo, Viking, and other space vehicles which contained radiosiotope thermal generators. They are also slated to be used for the Galileo Mission. AMS aircraft are also equipped with mapping cameras and multispectral camera arrays for aerial photography, a thermal mapper for infrared imagery, a broad array of meteorological sensors, and air sampling systems for particulate and whole gas measurements. All of the survey operations are conducted at the request of federal or state agencies and by the direction of DOE.

An aerial gamma survey was conducted from 8 April through 19 April 1988 over the Waste Isolation Pilot Plant (WIPP) and the surrounding area (Figure 1). The survey covered a 404-square-kilometer (156-square-mile) area covering the WIPP site, the north and south access roads, the Gnome site, and the surrounding area. The purpose of the survey was to map the gamma environment in the vicinity of the WIPP site. The survey was performed at the request of the DOE Albuquerque Operations Office.

2.0 SITE DESCRIPTION

The Waste Isolation Pilot Plant (WIPP), located 26 miles east of Carlsbad, New Mexico, is a 10,240-acre research and development project of the Department of Energy that is designed to demonstrate the safe disposal of transuranic (TRU) radioactive waste. The TRU waste will be stored some 2,150 feet below the surface, close to the middle of the underlying salt bed.

Large-area aerial photographic imagery of the plant was obtained in May 1988, and many oblique photographs of the site were taken during the survey.

3.0 NATURAL BACKGROUND

Natural background radiation originates from radioactive elements present in the earth (terrestrial radiation) and radiation entering the earth's atmosphere from space (cosmic radiation).

Natural terrestrial gamma radiation originates primarily from the uranium and thorium decay chains and radioactive potassium. The natural terrestrial radiation levels depend upon the type of soil and bedrock immediately below and surrounding the point of measurement. Within cities, the levels are also dependent on the nature of street and building materials. Local concentrations of the naturally occurring nuclides produce exposure rate levels at the surface of the earth generally ranging from 1 to 20 μR/h.[1] The highest levels within the United States are normally found in the western states, primarily on the Colorado Plateau, as a result of higher uranium and thorium concentrations in surface minerals.

The uranium and thorium decay chains include radon (a radioactive, chemically inert gas) which diffuses through the soil into the atmosphere. The rate of diffusion is highly variable, and the atmospheric distribution of radon can be complex due to a variety of factors. Thus, the magnitude of the background radiation contributed by airborne radon and its daughters depends on the meteorological conditions and the mineral composition and permeability of the soil as well as other physical conditions existing at each location at a particular time. Typically, radon contributes from 1 to 10 percent of the natural external background radiation exposure.

Cosmic rays, the space component, interact in a complex manner with elements of the earth's atmosphere and the soil. These interactions produce an additional natural source of ionizing radiation. Radiation levels due to cosmic rays vary with elevation (altitude) and slightly with geomagnetic latitude. Typically values range from 3 μR/h at sea level in Florida to 12 μR/h at an altitude of 3 kilometers (10,000 feet) in Colorado.[2]

4.0 SURVEY PLAN

The survey was designed to cover approximately 404 square kilometers (156 square miles) surrounding the Waste Isolation Pilot Plant (Figure 1). The gamma ray spectral data were processed to provide both a qualitative and quantitative

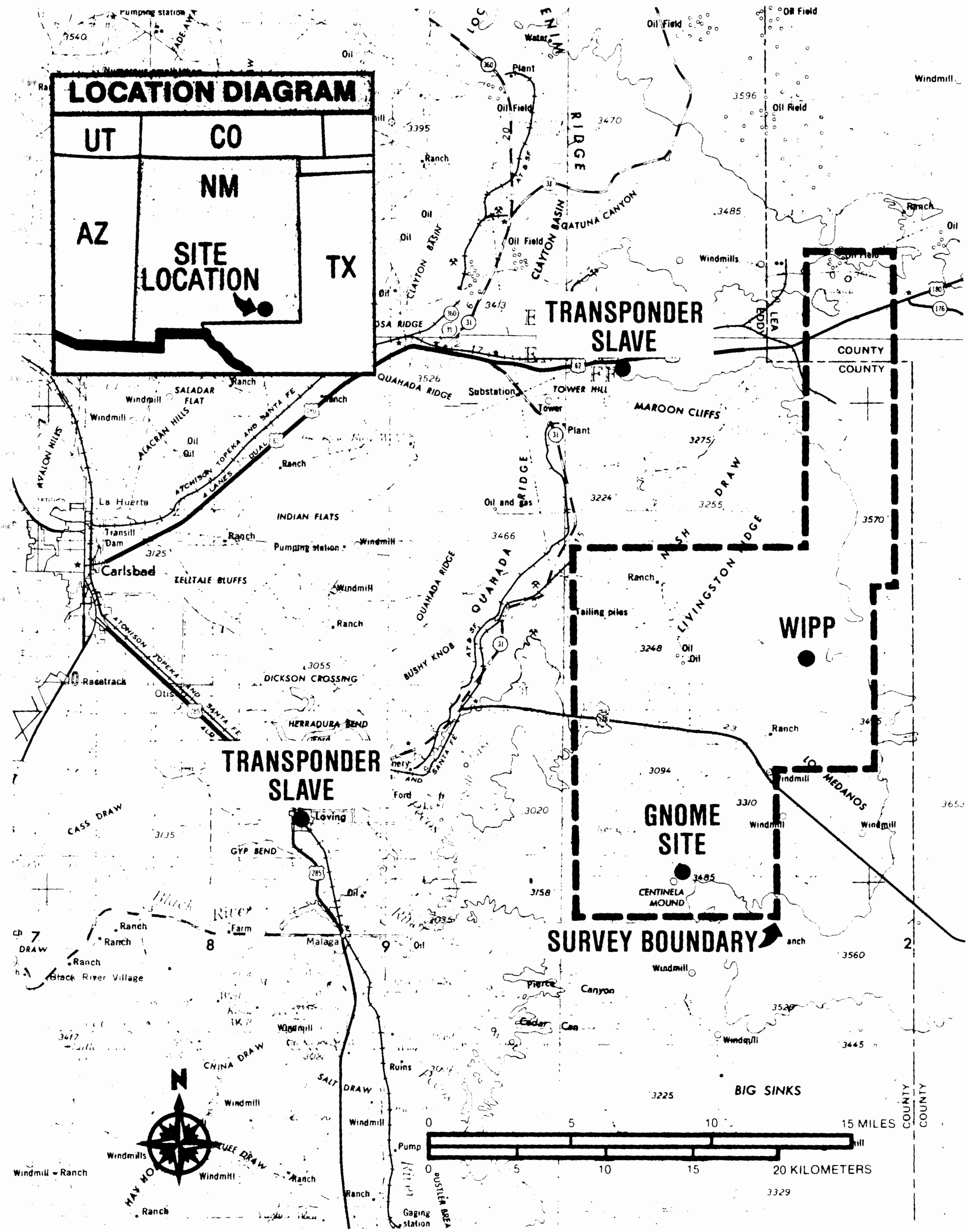


FIGURE 1. *GENERAL VIEW OF THE WASTE ISOLATION PILOT PLANT (WIPP), SURVEY BOUNDARY, AND URS TRANSPONDER LOCATIONS FOR THE APRIL 1988 AERIAL RADIOLOGICAL SURVEY*

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 a north-south direction at a nominal altitude of 91 meters (300 feet) above ground level (AGL), a line spacing of 152 meters (500 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 version of the Radiation and Environmental Data Acquisition and Recorder system, Model IV (REDAR IV). Two pods—each containing four 5.1-cm × 10.2-cm × 40.6-cm (2-in × 4-in × 16-in) log-type thallium-activated sodium iodide, NaI(Tℓ), gamma detectors as well as one 5.1-cm × 10.2-cm × 10.2-cm (2-in × 4-in × 4-in) gamma detector of the same material—were mounted on the sides of the helicopter. The smaller detector extended the effective dynamic range of the REDAR IV system, which is useful in areas exhibiting enhanced levels of radiation.

The preamplifier signal from each detector was calibrated with a Na-22 source. Normalized outputs of 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 system is a multi-microprocessor, 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 all required radiation and system information to the operator in real time via CRT displays and multiple LED readouts. All pertinent data are recorded on magnetic cartridge tapes for post-mission analysis on a minicomputer system.

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

The system employs five Z-80 microprocessors with AM9511 arithmetic processing chips to perform the data collection and display, real-time 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 control 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 UHF ranging system with steering calculation and display

The REDAR 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 and then compressed to 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

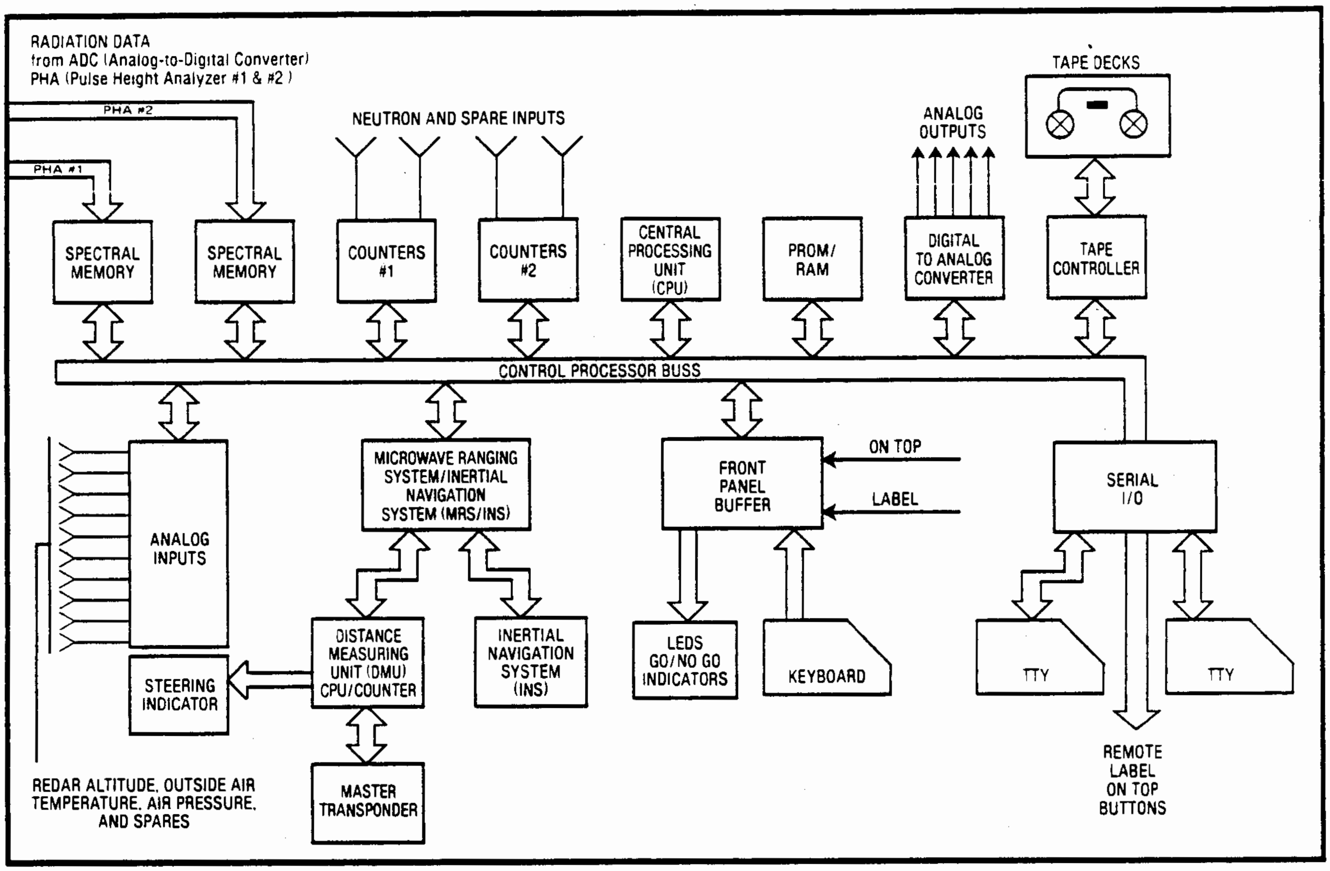


FIGURE 3. ***REDAR PROCESSOR SYSTEM BLOCK DIAGRAM***

photopeaks such as the 60 keV photopeak from 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.

Table 1. REDAR IV Spectral Data Compression

Eγ (keV)	Channel Input	Energy Coefficient ΔE (keV/channel)	Compressed Channel Output
0 - 300	0 - 75	4	0 - 75
304 - 1620	76 - 405	12	76 - 185
1624 - 4068	406 - 1017	36	186 - 253
4072 - 4088	1018 - 1022	N/A	254
>4088 - Analog Cutoff	1023	N/A	255
	1024	Unused	256

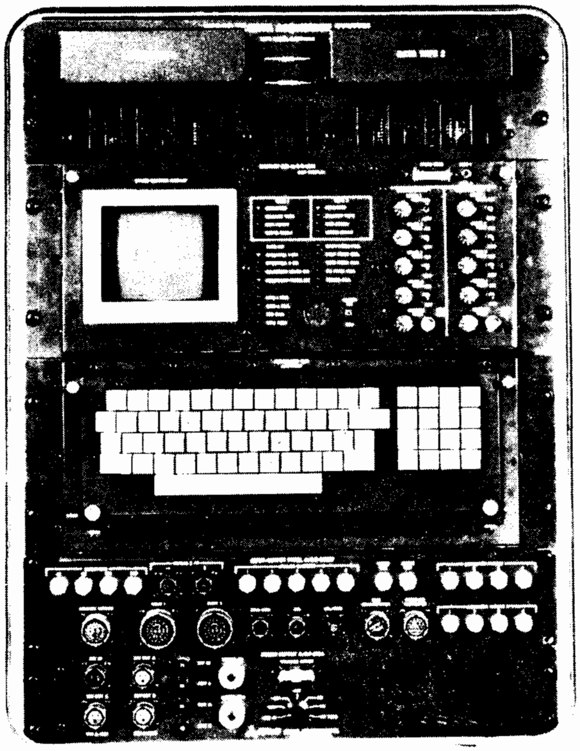


FIGURE 4. ***REDAR DATA ACQUISITION SYSTEM***

5.2 Helicopter Positioning Method

The helicopter position was established using two systems: an ultrahigh frequency ranging system (URS) and an AL-101 radar altimeter.

The URS master station, mounted in the helicopter, interrogated the remote transponder slaves located outside the survey area (the locations of the transponder slaves relative to the survey area are indicated in Figure 1). 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 altitude. 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.

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 operation, the van and aircraft were based at McCausland Aviation at the Cavern City Airport located in Carlsbad, New Mexico.

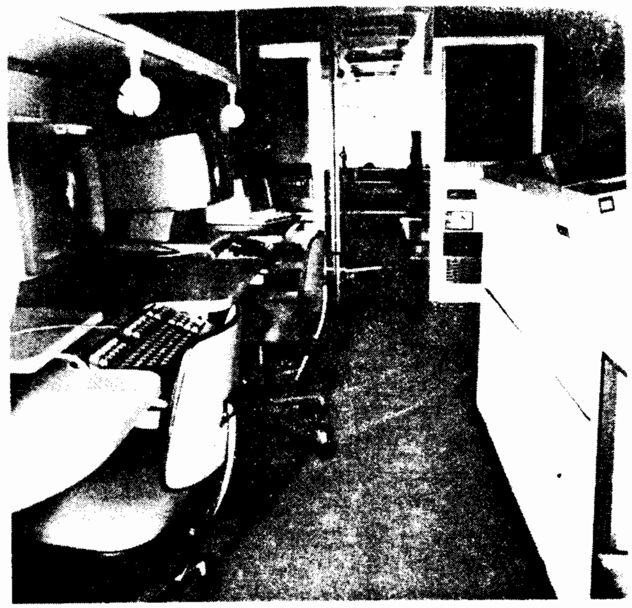


FIGURE 5. ***MOBILE COMPUTER PROCESSING LABORATORY***

The REDAC system consists primarily of 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 800/1600-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 laser printer; a system CRT display; and three alpha/graphics CRT displays and 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.

Gamma spectral windows can be selected for any portion of the spectrum. Weighted combinations

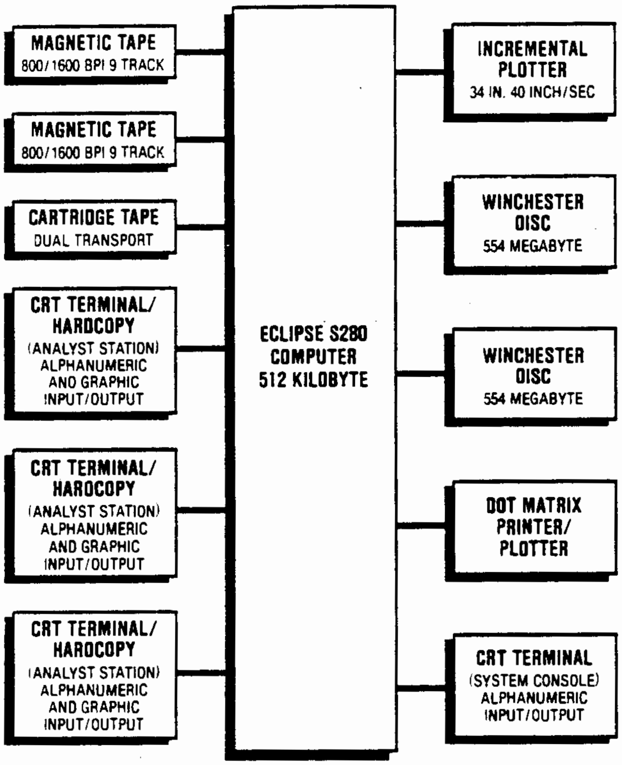


FIGURE 6. ***REDAC SYSTEM BLOCK DIAGRAM***

of such windows can be summed or subtracted and the results plotted as a function of time or distance. By proper selection of windows and weighting factors, it is possible to extract the photopeak count rates for radionuclides deposited on the terrain by human activity. Such nuclides disturb the spectral pattern of the natural soil radioactivity. These photopeak count rates can then be converted to nuclide 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

The aerial radiation data consisted, in general, of contributions from the naturally occurring radionuclides, aircraft and detector background, and cosmic rays. For this survey, the major emphasis was on mapping the terrestrial gamma radiation in the surrounding area of the WIPP site and locating and identifying any sources of anomalous and/or man-made radiation if they existed. Isopleth maps were produced by processing the data using two different procedures: gross count procedure and man-made gross count extraction procedure.

7.1 Gross Count Procedure

The gross count method was based on the integral counting rate observed in that portion of the spectrum between 0.04 and 3.0 MeV. 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. This factor assumes a uniformly distributed source covering an area which is large compared with the field-of-view of the detector (approximately 300 meters at the survey altitude of 91 meters). The exposure rate values could be one to 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 natural emitters change in a more or less constant ratio as the detector moves from one location to another. The algorithm senses counts in the lower portion of the spectrum in excess of those predicted on the premise that these counts bear a constant ratio to counts in the upper portion. Since the algorithm is designed to be most sensitive to man-made nuclides, the spectrum dividing line is chosen at an energy (1.4 MeV) above which most long-lived, man-made nuclides do not emit gamma rays. It is analytically expressed in MeV as:

$$\text{MMGC} = \sum_{E=0.04}^{1.40} (\text{counts})_E - K \sum_{E=1.40}^{3.00} (\text{counts})_E$$

The counts in the upper energy window (1.40 to 3.00 MeV) are multiplied by a constant, K, so as to equal the counts in the low energy window (0.04 to 1.40 MeV). Hence, the resultant MMGC is equal to zero for areas containing normal background radiation.

The man-made gross count algorithm is general and will respond to a wide range of nuclides. The result of using this generality is less than optimum sensitivity to specific nuclides. If the nuclide of interest is known, more sensitive algorithms can be devised.

8.0 DISCUSSION OF RESULTS

The results of the aerial radiological survey conducted over the WIPP survey area are presented as contours of terrestrial gamma exposure rates superimposed on aerial photographs of the site.

The gamma exposure rate contours report the total external exposure rate due to uniformly distributed terrestrial sources in μR/h extrapolated to 1 meter above ground level and include a cosmic ray exposure rate of 4.7 μR/h. A typical natural background gamma energy spectrum for the survey area is shown in Figure 7. It illustrates that only natural radionuclides (*e.g.*, K-40, Bi-214, Tl-208) exist in the majority of the survey area.

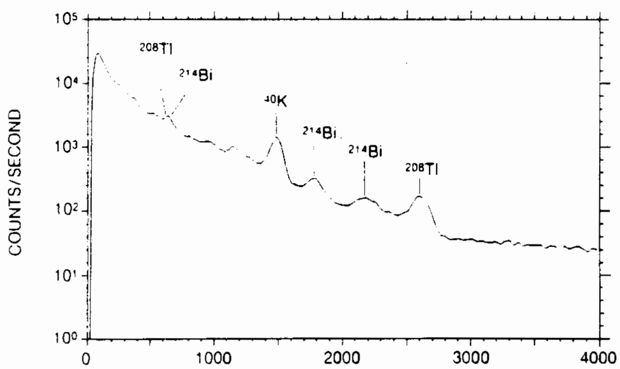


FIGURE 7. *GAMMA RAY ENERGY SPECTRUM TYPICAL OF THE NATURAL BACKGROUND IN THE SURVEY AREA*

For better resolution in presenting the data, the survey area has been divided into two figures. Figure 8 is the northern-most portion of the survey area covering the North Access Road and the WIPP site. The total terrestrial gamma background ranged from approximately 6.0 to 7.5 μR/h in the general vicinity of the WIPP site and 9.0 to 12.0 μR/h to the north of the site. There is an area, indicated on the contour map as Area 1, where the exposure rate values are slightly higher than the general background (12.0 to 13.5 μR/h). Figure 9 is the net (source minus background) spectrum taken from Area 1, and it indicates that higher levels of K-40 (a naturally occurring nuclide) are present in this area. Figure 10 is the southern portion of the survey area covering the WIPP site, the South Access Road, and the Gnome Site. The general terrestrial gamma background of this portion of the survey area generally ranged from 6.0 to 9.0 μR/h. There is an area, indicated on the contour map as Area 2, where the exposure rate values are higher than the general background (15.0 to 20.0 μR/h). Figure 11, the net spectrum taken from Area 2, indicates that higher levels of Bi-214 (a naturally occurring nuclide) are present in this area.

The MMGC algorithm (discussed in Section 7.2) was used to search the WIPP aerial survey data for man-made gamma emitters. The Gnome Site indicated in Figure 10 as Area 3 in the southern portion of the survey area had the only man-made anomaly found, which was expected. The Gnome Site was the location of the first scientific experiment in the Plowshare Program established in 1960. Project Gnome was the first attempt to develop nuclear devices exclusively for peaceful uses. The final decontamination and decommissioning (D/D) of the site was completed in September 1979. EG&G/EM has previously surveyed this particular area in both the pre- and post-operational phases of the D/D. References 3 through 7 describe in detail the results of previous survey work conducted in this area. Figure 12 is a net spectrum taken from Area 3; Cs-137 is the predominant nuclide and represents the residual levels of cesium left on the surface after cleanup operations.

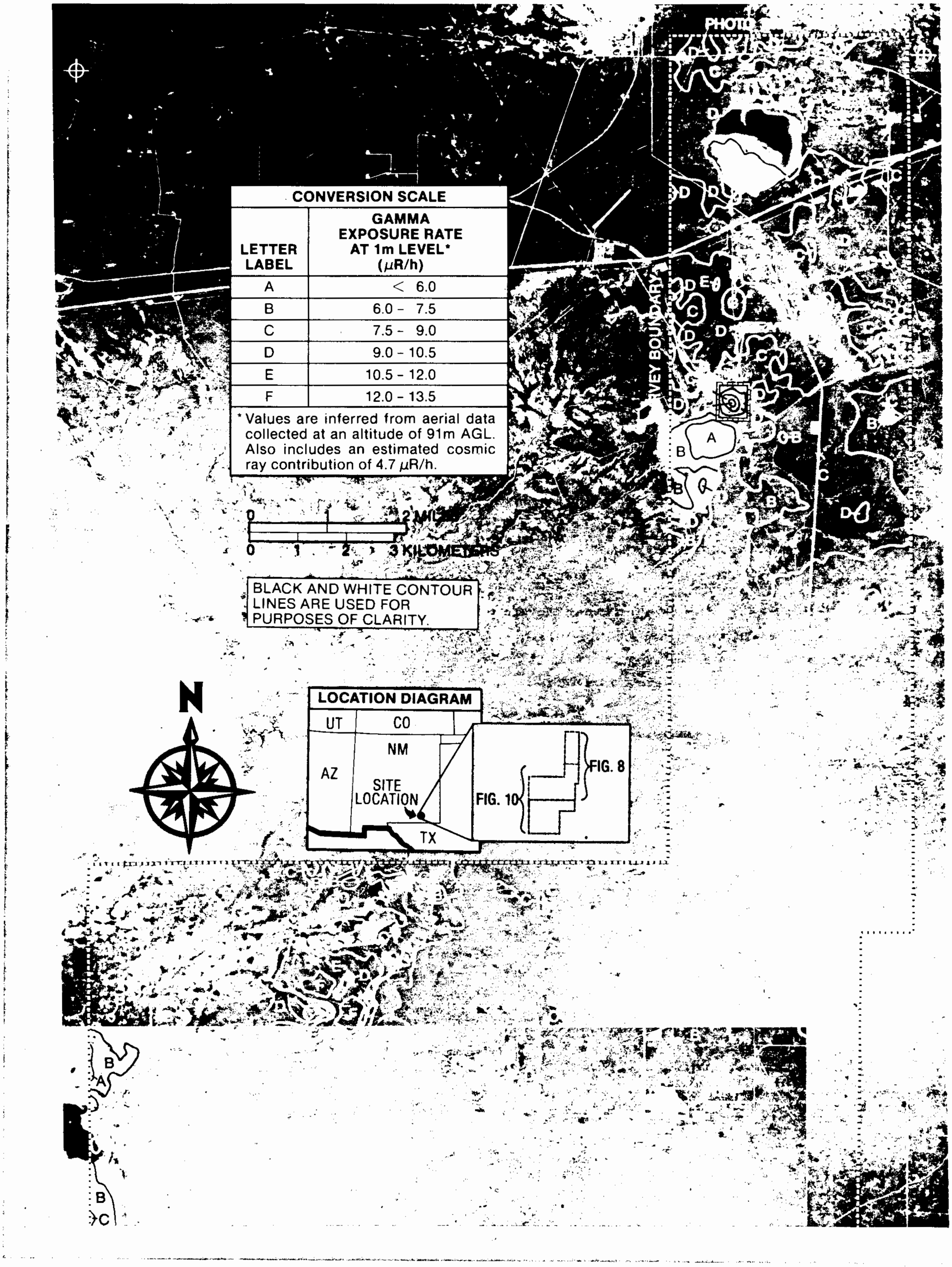


FIGURE 8. *GAMMA RADIATION EXPOSURE RATE (TERRESTRIAL PLUS COSMIC) CONTOURS DERIVED FROM AERIAL DATA OBTAINED IN APRIL 1988 OVER THE WASTE ISOLATION PILOT PLANT AND NORTH ACCESS ROAD CORRIDOR*

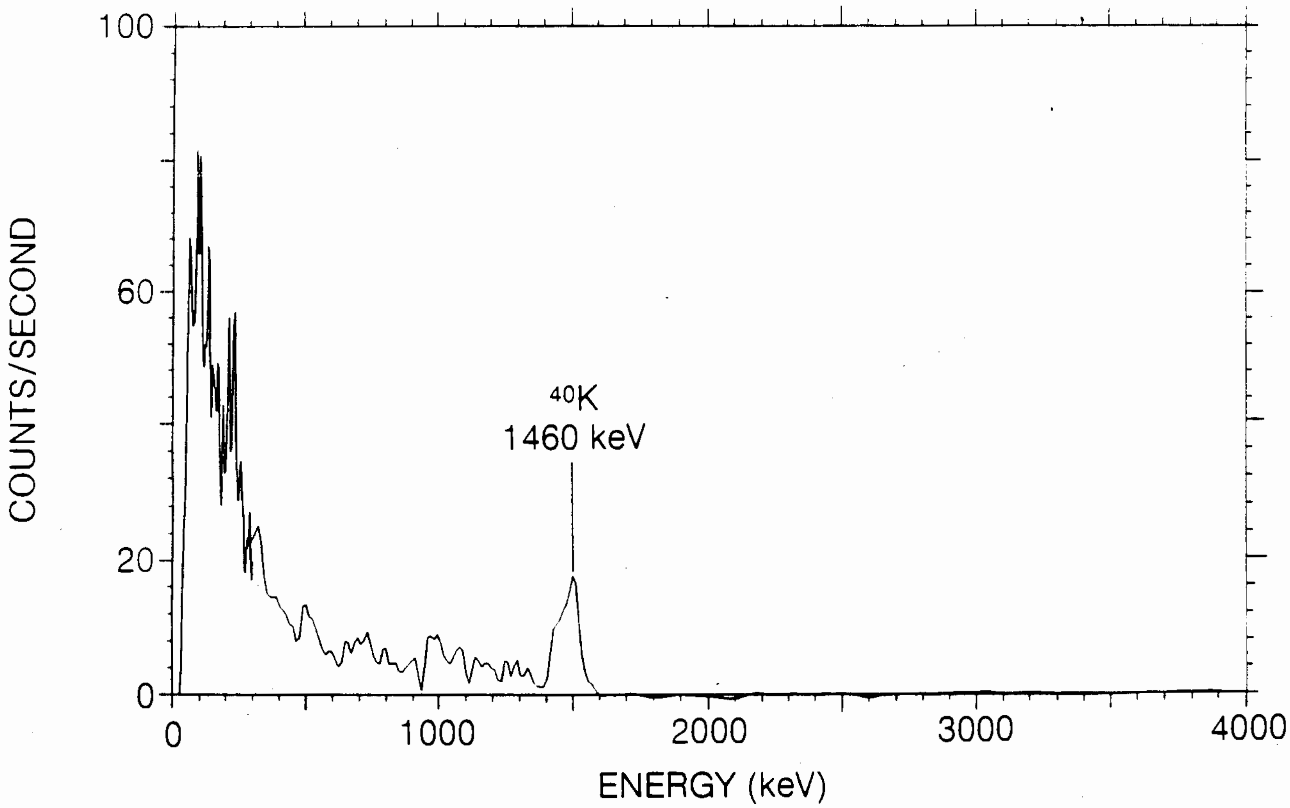
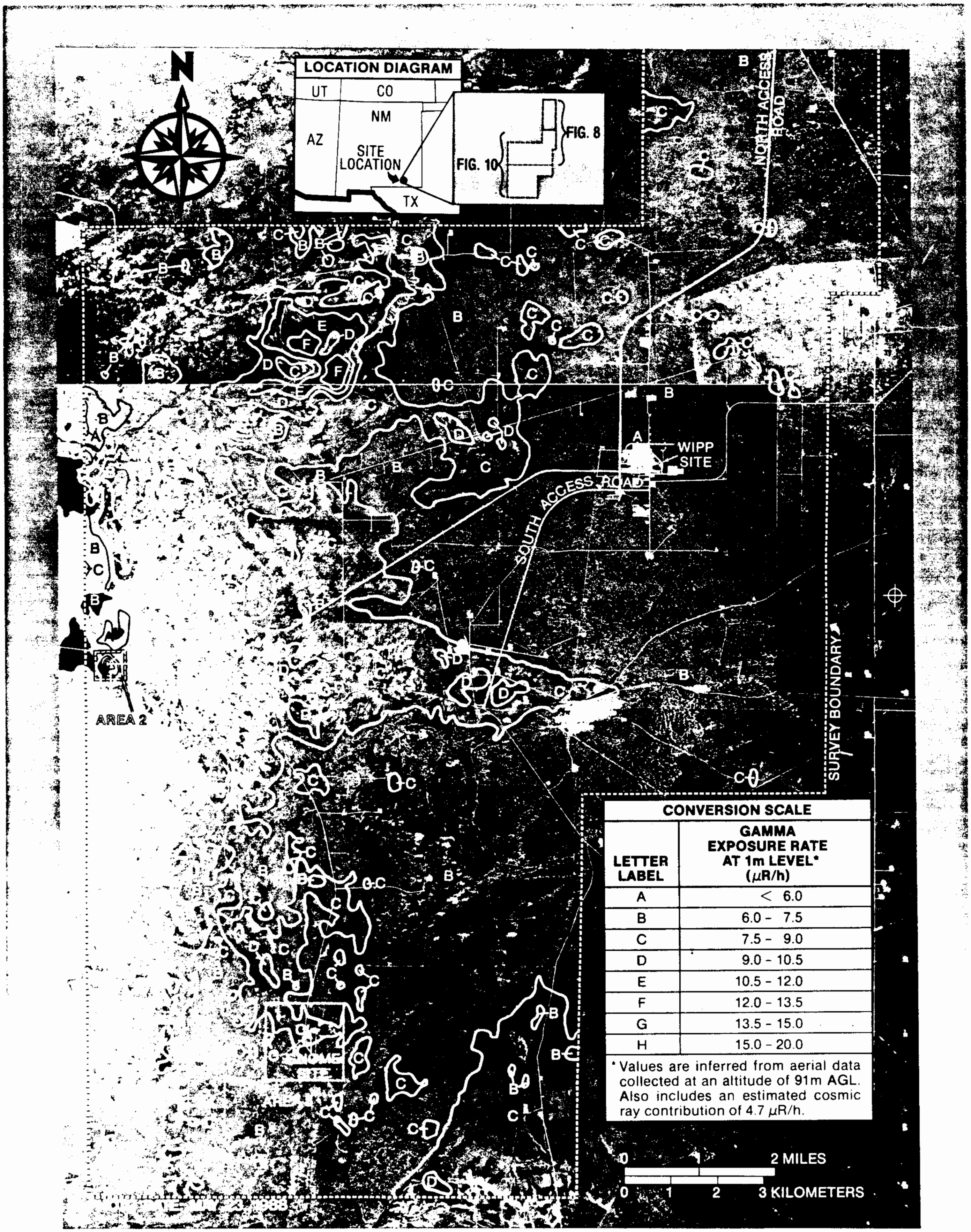


FIGURE 9. ***NET GAMMA RAY SPECTRUM OF AREA 1***



CONVERSION SCALE	
LETTER LABEL	GAMMA EXPOSURE RATE AT 1m LEVEL* (μR/h)
A	< 6.0
B	6.0 - 7.5
C	7.5 - 9.0
D	9.0 - 10.5
E	10.5 - 12.0
F	12.0 - 13.5
G	13.5 - 15.0
H	15.0 - 20.0

*Values are inferred from aerial data collected at an altitude of 91m AGL. Also includes an estimated cosmic ray contribution of 4.7 μR/h.

FIGURE 10. *GAMMA RADIATION EXPOSURE RATE (TERRESTRIAL PLUS COSMIC) CONTOURS DERIVED FROM AERIAL DATA OBTAINED IN APRIL 1988 OVER THE WASTE ISOLATION PILOT PLANT AND THE SURROUNDING AREA*

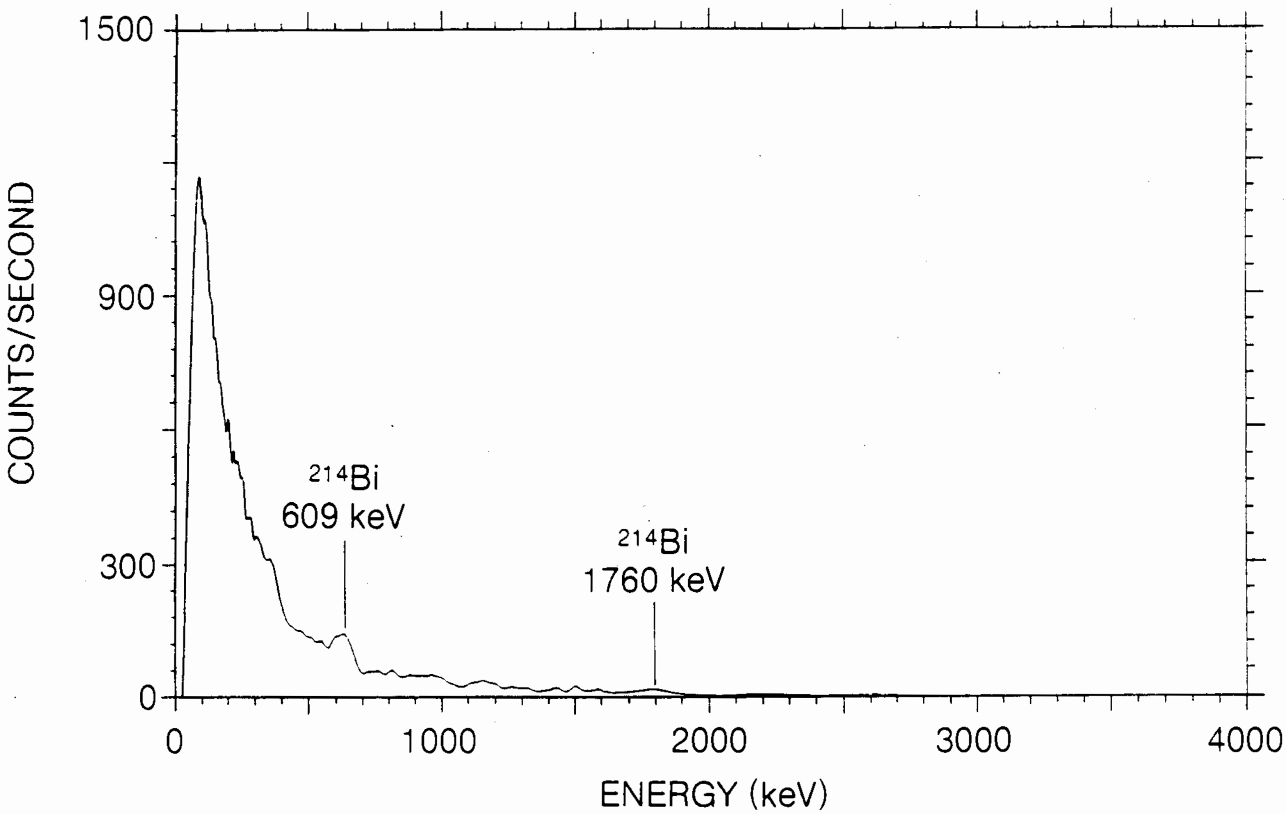


FIGURE 11. ***NET GAMMA RAY SPECTRUM OF AREA 2***

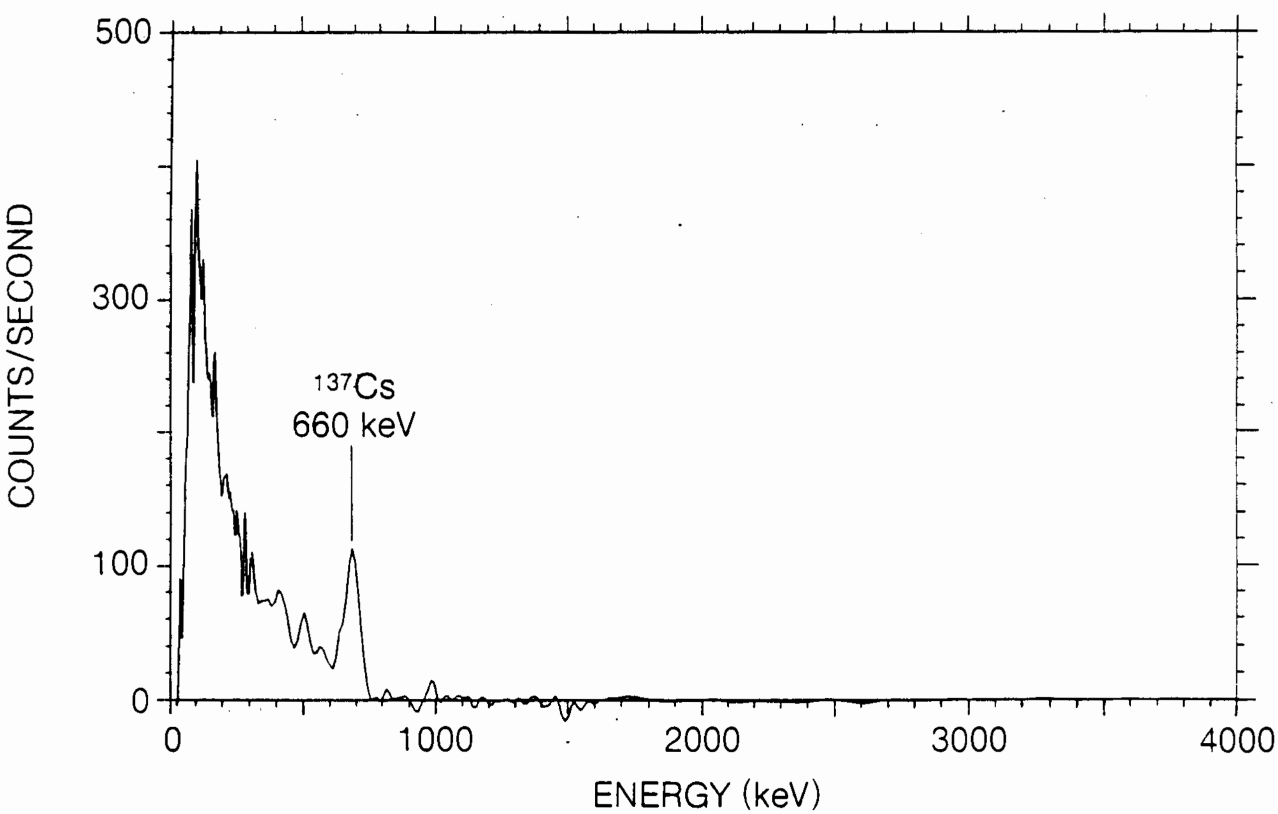


FIGURE 12. ***NET GAMMA RAY SPECTRUM OF AREA 3***

APPENDIX A

SURVEY PARAMETERS

Survey Site:	Waste Isolation Pilot Plant Carlsbad, New Mexico
Survey Coverage:	404 square kilometers (156 square miles)
Survey Date:	8 April through 19 April 1988
Survey Altitude:	91 meters (300 feet)
Aircraft Speed:	36 meters/second (70 knots)
Line Spacing:	152 meters (500 feet)
Line Length:	Variable length lines 29.3 kilometers (18.2 miles) max length 12.2 Kilometers (7.6 miles) min length
Line Direction:	North-South
Number of Lines:	109
Total Flight Line Miles:	1,455 flight line miles
Detector Array:	Eight 5.1-cm × 10.2-cm × 40.6-cm (2-in × 4-in × 16-in) NaI(Tl) detectors Two 5.1-cm × 10.2-cm × 10.2-cm (2-in × 4-in × 4-in) NaI(Tl) detectors
Acquisition System:	REDAR IV (Serial Number: A-49)
Aircraft:	MBB BO-105 Helicopter (Tail Number: N50EG)
Survey Crew:	H. Berry, N. Alcorn, J. Brown, D. Korthanke, R. Chavez, D. South, M. Lukens, R. Richmond, D. Rehm, K. Beardall, and D. Wines

Data Processing:

1. Gross Count Window: 0.04 to 3.00 MeV
2. Conversion Factor: 730 cps/μR/h
3. Cosmic Contribution: 4.7 μR/h

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