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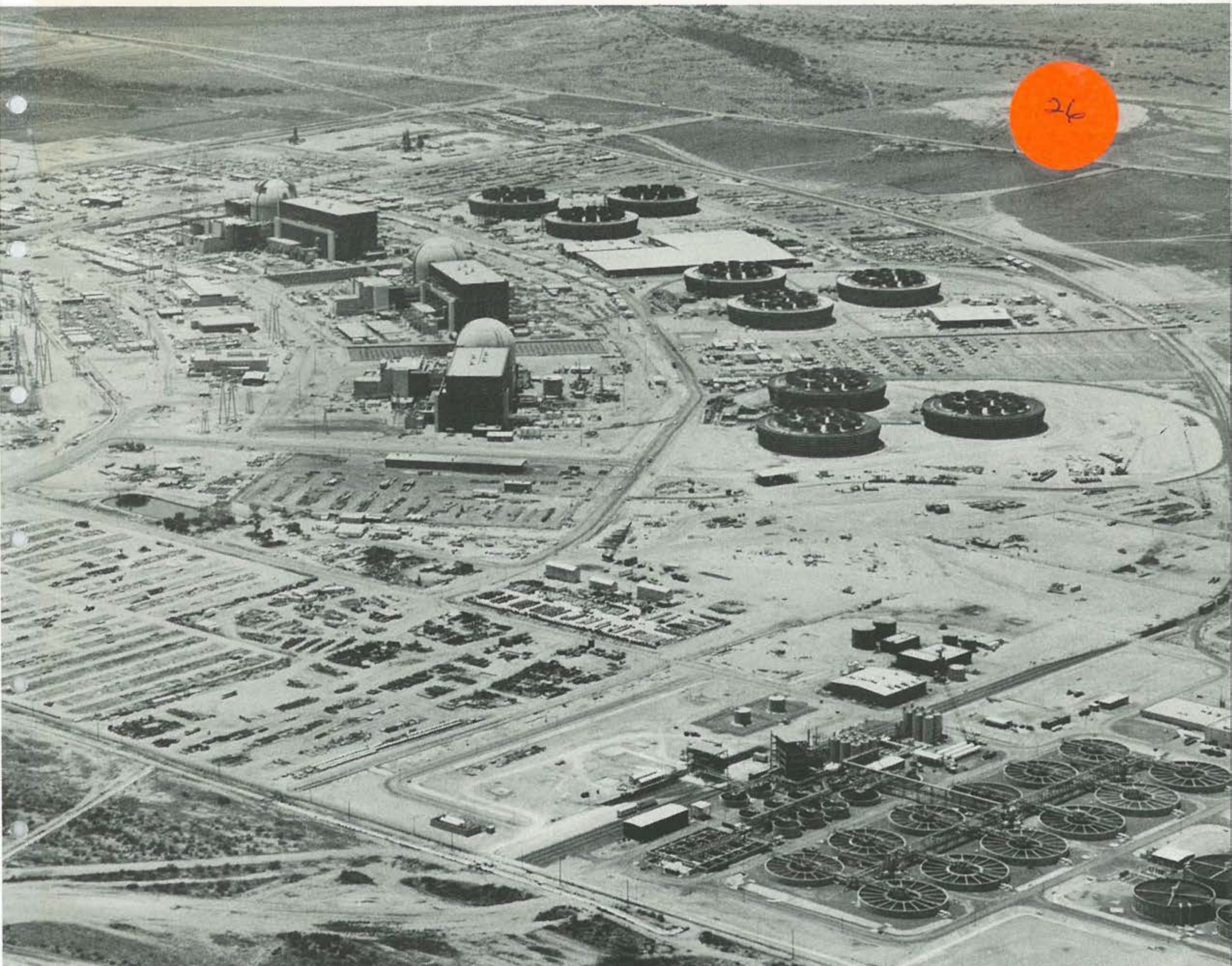

AN AERIAL RADIOLOGICAL SURVEY OF THE

PALO VERDE NUCLEAR GENERATING STATION

AND SURROUNDING AREA

WINTERSBURG, ARIZONA

DATE OF SURVEY: NOVEMBER 1982

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Project Scientist

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ABSTRACT

An aerial survey of terrestrial gamma radiation was performed during the period 4 November through 15 November 1982 over a 16-kilometer by 16-kilometer (10-mile by 10-mile) area approximately centered on the Palo Verde Nuclear Generating Station near Wintersburg, Arizona. Gamma radiation spectral data were collected while flying a helicopter over a regular pattern of parallel lines spaced 150 meters (500 feet) apart at an altitude of 90 meters (300 feet). All radiation measurements taken at the nominal flight altitude were corrected for altitude variations, cosmic radiation, and helicopter background to generate exposure rates from terrestrial sources extrapolated to 1 meter above ground level. The data are presented as isoradiation contour maps. The average terrestrial radiation levels fall between 8 and 14 microroentgens per hour (μR/h). All gamma radiation detected within the survey area was associated with naturally occurring radionuclides. Direct ground-based measurements at 1 meter height were also taken at four scattered sites within the survey area. These values agree with the contour intervals determined from the aerial measurements and differ from the mean value of adjacent contours by no more than 10%.

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1.0 INTRODUCTION

An aerial radiological survey of the Palo Verde Nuclear Generating Station and surrounding area near Wintersburg, Arizona was performed at the request of the U.S. Nuclear Regulatory Commission from 4 November through 15 November 1982. The purpose of the survey was to characterize the intensity and identity of natural background radiation from terrestrial sources prior to the startup of the Palo Verde Unit 1 nuclear reactor, which was under construction at the time of the survey.

The survey utilized the Aerial Measuring System (AMS)[1] which is maintained by the U.S. Department of Energy's Remote Sensing Laboratory (RSL), operated for the DOE by EG&G Energy Measurements, Inc.

2.0 SURVEY SITE DESCRIPTION

The Palo Verde Nuclear Generating Station is located in the Buckeye Valley in Maricopa County, Arizona, approximately 3 kilometers (2 miles) south of Wintersburg, Arizona and 72 kilometers (45 miles) west of Phoenix, Arizona. At present, three units are under construction. Each unit is a 1270 net megawatt (electric) pressurized water reactor. No nuclear fuel was present on the site at the time of the survey.

The survey area was a 16-kilometer by 16-kilometer (10-mile by 10-mile) square with edges oriented in approximately a north-south and east-west direction. The survey area is outlined in Figure 1, which shows a general view of the Buckeye Valley.

3.0 NATURAL BACKGROUND RADIATION

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 levels are also dependent on the nature of the 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 surface minerals exhibit even higher radiation levels, especially in the western states.

One member of both the uranium and thorium radioactive decay chains is an isotope of radon, a noble gas, which 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 meteorological conditions, mineral content of the soil, and soil permeability. Typically, airborne radiation contributes from 1 to 10% 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. Typical values range from 3.3 μR/h at sea level in Florida to 12 μR/h at an altitude of 3 km (1.9 miles) in Colorado.[3]

4.0 SURVEY EQUIPMENT AND PROCEDURES

The primary instrument used for detection of terrestrial gamma radiation is a cluster of thallium-activated sodium iodide, NaI(Tl), detectors mounted on a helicopter platform. Flight lines are flown in a regular pattern over the entire site. In addition, scattered measurements are taken at the 1 meter level with a portable survey instrument. Soil samples are collected at the same locations. The number of ground level samples is insufficient to represent the entire site. Their primary purpose is for spot verification of the aerial survey data. The physical equipment utilized during the survey is described briefly in the following sections.

4.1 Aerial Measurements

The aerial data acquisition system consists of a detector package and a sophisticated data acquisition system (REDAR IV)* on board a

* Radiation and Environmental Data Acquisition and Recorder system, Model IV.

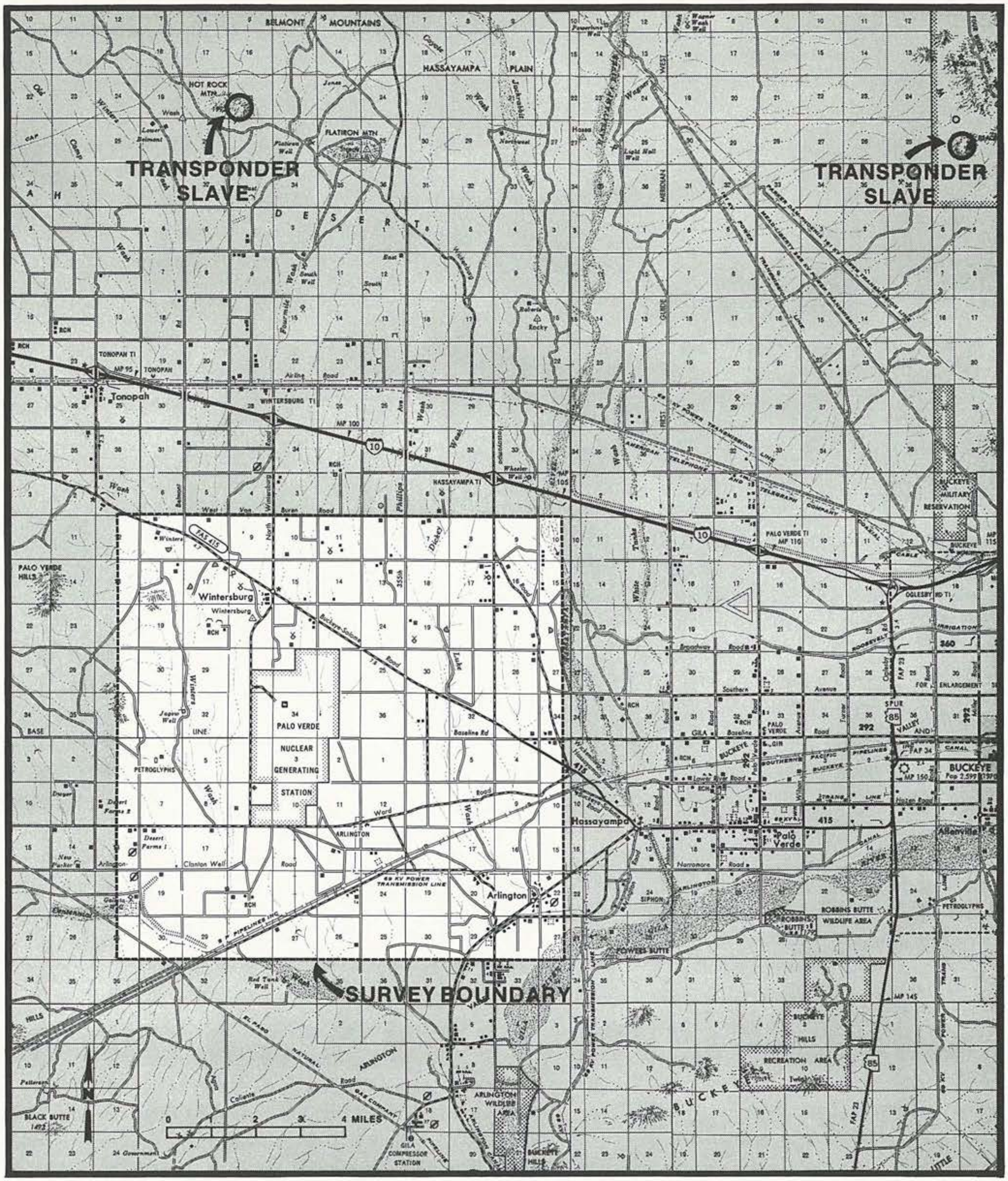

Figure 1. *GENERAL VIEW OF THE WINTERSBURG, ARIZONA AREA SHOWING THE PALO VERDE NUCLEAR GENERATING STATION, SURVEY BOUNDARY, AND MRS TRANSPONDER LOCATIONS FOR THE NOVEMBER 1982 SURVEY*

Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter (Figure 2).

The detector package contains an array of twenty 12.7-cm diameter by 5-cm thick (5 in. by 2 in.) NaI(Tl) scintillation detectors distributed equally between two cargo pods, which are mounted on the exterior of the helicopter and are visible in Figure 2. Each crystal is shielded on the sides with 0.1 cm (0.04 in.) of cadmium. Signals from 19 of the detectors are summed to produce a single spectrum with high intensity. The remaining single tube is used alone to provide a separate spectrum with lower sensitivity appropriate for monitoring high levels of radiation. Both spectra are simultaneously acquired and recorded providing a data acquisition system with extended dynamic range. The dual spectral capability also provides redundancy which improves system reliability.

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

The REDAR IV system acquires, monitors, displays, and records all survey data at least once each second of real time. The data stored on magnetic tape consist of the dual spectral data mentioned above, position data, and environmental data such as outside air temperature and absolute air pressure.

4.1.1 Spectral Data

The spectral data are initially collected as a 1024-channel spectrum which is compressed into 256 channels before storage on magnetic tape. The compression scheme is summarized in Table 1. Compression of the spectrum in this manner results in only a modest loss of spectral resolution since the peak widths, in energy units, from NaI(Tl) scintillators naturally become progressively wider at higher energy. The final compressed width (full width at half maximum) of the photopeaks varies from 3 to 8 channels for the major peaks within the primary range of interest from 0.060 to 2.62 MeV. A typical spectrum is shown in Figure 3.

Each of the 256-channel compressed spectra is collected for one second and then placed in a buffer. Four buffers are available to accumulate four consecutive one-second spectra before actual transfer to magnetic tape. While the data are recorded on magnetic tape (a relatively slow process), a second set of four buffers accumulates more data. The buffers then alternate between data accumulation and tape storage functions.

4.1.2 Position Data

Geographic position is determined from a microwave ranging system (MRS), consisting of a master transponder* with two slaves and navigational processors in the REDAR IV. The master transponder mounted in the helicopter interrogates two slave transponders mounted on tall structures or high terrain outside of the survey area (Figure 1). By measuring the roundtrip propagation time between master and slave stations, the distance to each can be computed. Position accuracy with this system is ±15 meters (50 ft) or better. These distances are measured and displayed each quarter-second, but recorded only once each second. The steering processor also utilizes the quarter-second position data to compute course error, which is displayed in real time to the pilot.

The helicopter altitude above ground level is determined with a radar altimeter, which measures the time delay of a microwave pulse echo and converts this delay to aircraft altitude. The altitude accuracy of this system is ±1 meter or 3%, whichever is greater. These data are recorded on magnetic tape so that variations of the observed gamma count rate caused by altitude deviations can be corrected in subsequent data processing. The steering processor compares the radar altitude to the desired survey altitude specified by the operator and presents an altitude error display to the pilot in real time.

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* Trisponder-202A, Del Norte Technology, Inc., Euless, Texas.

Table 1. Spectral Data Compression			
$E\gamma$ (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 - Cutoff	1018 - 1023	N/A	254
> Cutoff	Forced to Zero	N/A	255

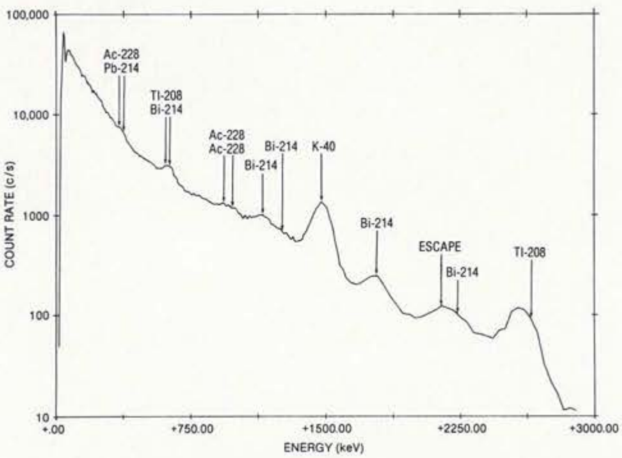


Figure 3. *TYPICAL GAMMA SPECTRUM OBSERVED AT 90 m (300 ft) WITH A SODIUM IODIDE DETECTOR ARRAY IN THE VICINITY OF THE PALO VERDE NUCLEAR GENERATING STATION*

4.1.3 Field Computer Equipment

Recorded data are initially examined immediately after each flight using a mobile computer. The mobile computer system consists of a Data General NOVA 840 Computer; a 2.4-megabyte hard disk; two dual density, nine-track magnetic tape drives; two digital cartridge drives; two digital cassette drives; two incremental plotters; and two terminals (CRT and thermal printer). Generally, the initial analysis performed on the mobile computer system is only sufficient to verify that valid data are being collected. This typically involves both a pre-flight test of the system and a post-flight test of the data. A complete analysis is performed in the EG&G/EM laboratory in Las Vegas, Nevada using a larger and faster Data General Eclipse System. The mobile data analysis system is mounted in either a 5-ton truck or a 20-ft step-van, which also serves as the field operations base. Ordinarily, the "data-van," as it is called, is located near the survey site at the helicopter staging area.

4.1.4 Survey Pattern

The flight pattern over the survey area consisted of 106 parallel lines spaced 150 meters (500 ft) apart, and flown at a nominal altitude of 90 meters (300 ft). Repeated measurements of a land test line at the beginning and end of each survey flight were also made to provide consistency checks on the equipment.

4.2 Ground Measurements

Ground measurements were made at four different locations around the reactor site. The local radiation intensity at 1 meter height was measured with a high pressure ion chamber. In addition, 1 kilogram soil samples were taken at the same locations to a depth of 15 cm in 2.5-cm increments. These samples were analyzed at EG&G/EM's Santa Barbara Laboratory using a calibrated Ge(Li) detector to determine isotope concentrations. Further details of the ground sampling procedures are given in a separate publication.[4]

4.3 Data Analysis Procedures

The data reduction procedures are designed to reduce all field data to a standard format for final presentation. Results from different surveys with varying equipment and flight altitude can then be easily compared.

The final normalized radiation values for the entire survey area can be presented in a variety of formats, but the one found most useful is a graphical contour plot with each contour line representing a constant radiation (isoradiation) level. The levels are typically expressed in units of microroentgens per hour (μR/h) at 1 meter. These values actually represent an average over a relatively large area rather than a spot value since, for example, 55% of the photopeak response from 1 MeV gammas at an altitude of 90 meters (300 ft) is from within a circular area 90 meters in radius, i.e., the radius of the sample area is approximately the same as the altitude.

The "gross count" raw data for the contour plot is initially obtained from a single wide window from 0.04 to 3.0 MeV, which includes all photopeaks in the energy spectrum, i.e., those due to natural terrestrial sources plus any man-made contributions.

The reported external exposure rate is calculated as the sum of the observed terrestrial component and an estimate of the local cosmic radiation. The terrestrial component is the net radiation level obtained by subtracting the non-terrestrial component (due to cosmic rays, airborne radon, and the helicopter) from the gross radiation level.

4.3.1 Conversion Procedures

Conversion of gross radiation measurements at approximately 90 meters (300 ft) altitude into dose rates at 1 meter from only terrestrial sources involves three basic steps: (1) normalization of the data to standard conditions which involves adjustment of the data to remove effects of altitude variation, dead time in the multichannel analyzer, and variations in the number of detectors; (2) removal of the non-terrestrial background contribution from cosmic radiation, activity in detector and platform construction materials, and airborne radon; and (3) conversion of the normalized count rate from terrestrial sources into exposure rates in microroentgens per hour.

The actual conversion process can be represented in terms of explicitly measured parameters as follows:

$$D = (G_L t_L W_L - B)\ A_L C$$

where

D = Exposure rate at 1 meter (μR/h).

G_L = Gross count rate between 40 keV and 3 MeV over land (c/s).

t_L = Live time correction.

W_L = Weight factor normalizing response to a standard 20 tube detector array.

B = Background count rate between 40 keV and 3 MeV (c/s). (See Section 4.3.2.)

A_L = Altitude correction factor. (See Section 4.3.4.)

C = Calibration factor converting counts per second to microroentgen per hour. (See Section 4.3.3.)

4.3.2 Background

The background count rate is normally determined by integration of the background radiation spectrum between 40 keV and 3 MeV. The raw background spectrum is determined by flying over nearby water to eliminate any terrestrial component. If no water is available for a background spectrum (as at Palo Verde), reliance is placed on the fact that intensity data which are properly corrected for background will vary exponentially with altitude. A multi-altitude flight was made at Palo Verde to specifically measure the deviation from exponential behavior and, therefore, determine the effective local background, B_0. Subsequent variations in background caused by fluctuations in atmospheric radon are detected by monitoring repeated radiation measurements (before and after each flight) over a reference line. Changes in the response over the reference line are used to adjust the initially measured background. This forces the reference line response to be constant for the entire survey. The daily background, B, was calculated using

$$B = B_0 \pm \Delta R$$

where

ΔR = Change in reference line gross count after correcting for altitude, deadtime, and tube count.

4.3.3 Calibration

Conversion of the net radiation intensity in counts per second into microroentgens per hour is based on measurements made over known radiation fields near Lake Mead, Arizona. Checks on the equivalence of the measuring system in the field to the system calibrated at Lake Mead involve preflight spectral tests for gamma energy calibration, noise discriminator setting, and radar altimeter calibration. Absolute intensity checks with calibrated radiation sources are normally not made in the field except in the sense that corroborative ground measurements are made within the survey area and compared with the helicopter measurements.

The detector response function determined from the Lake Mead calibration measurements[5] and used to convert data in this report is as follows:

$$R(A_e) = 1324\ e^{-0.001957 A_e} \text{ cps per } \mu R/h$$
$$= 753.8 \text{ cps per } \mu R/h$$

where

$R(A_e)$ = Counts per second (cps) in the energy range 0.040 MeV to 3.0 MeV at altitude A_e per microroentgen/hour at 1 meter from terrestrial sources only for 20 NaI(Tl) detectors (each 12.7 cm in diameter by 5.1 cm thick) with cadmium side covers.

A_e = Effective air layer thickness at the reference temperature and pressure = (true altitude in feet) [293/(273 + T)] (P/760) where P and T are the actual pressure and temperature in mm Hg and Celsius degrees.

4.3.4 Air Attenuation Correction

The empirical calibration equation above clearly shows that air attenuates the ground radiation in an approximately exponential manner, and altitude variations must be considered for accurate interpretation of the data. The effects of altitude changes can be made explicit by rewriting the calibration equation as:

$$\begin{pmatrix}\text{Response}\\ \text{at Alt. A}\end{pmatrix} = \begin{pmatrix}\text{Response}\\ \text{at Alt. } A_0\end{pmatrix} e^{-\alpha\left(\frac{293}{273+T}\right)\left(\frac{P}{760}\right)\Delta A}$$

where

α = Atmospheric absorption correction factor.

= 0.001957/ft at 20° C and 760 mm Hg.

T = Temperature (° C).

P = Pressure (mm Hg).

ΔA = Change in altitude (ft).

Actually, the attenuation is dependent on the exact energy spectrum and the above represents a response to a spectrum with an average energy of about 1.0 MeV. If the average energy in the field differs significantly from this average energy, the correction factor, α, can be determined in the field by flying at different altitudes over the same test line.

The average pressure and temperature during the Palo Verde survey were 735 mm Hg and 22.2° C. The adjusted α factor is, therefore,

$$\alpha_{\text{local}} = \alpha_{\text{REF}} \left(\frac{293}{273+T}\right)\left(\frac{P}{760}\right) = 0.00188\ \frac{1}{\text{ft}}$$

This fixed average value was used to make all corrections for altitude deviations in the Palo Verde survey.

4.4 Calibration Accuracy and Errors

Accuracy of the two calibration constants, 1324 and 0.001957, in the response function is estimated at 5% and 2%, respectively. The conversion factor, R, therefore has an estimated error of about 6% for an altitude of 90 meters (300 ft). Errors introduced by counting statistics in the final results are generally less important since typical gross count rates are about 4500 cps and the normal 5-second averaging effectively gives a total count large enough to keep errors under 1%. The adjustment for the number of operating detectors introduces an uncertainty of about 2% per photomultiplier tube or 2.0% total for the single tube shut down during the survey. Fluctuation in radon background and other variables difficult to monitor probably contribute another 5%. The final values quoted on the contour plots in microroentgens per hour are estimated to have an error of 10%.

It should be pointed out, however, that the aerial data represents an average value over the field-of-view of the detector array (an area of several hectares). Variations in radiation levels within a given area can lead to significant differences between the average value given by the aerial system and the spot readings obtained in a ground measurement. In the present survey, comparisons between ground measurements and the average value of adjacent contours generally agreed to within 10%.

5.0 SURVEY RESULTS AND DISCUSSION

5.1 Aerial Survey Results

A contour map displaying the external radiation exposure rate at 1 meter height from terrestrial sources and cosmic radiation is shown in Figure 4. The average values ranged from 8 to 14 μR/h, which is well within the range of typical background radiation levels.

In addition to the primary area shown in Figure 4, a small aerial survey was made in the vicinity of the natural hot springs at Tonopah, Arizona. This site is about 8 miles NNW of the reactor site. A 1-mile by 0.4-mile area centered over the hot springs was surveyed at the same altitude and line spacing as the primary site. No significant deviations from the natural background values were observed.

5.2 Ground-Based Measurements

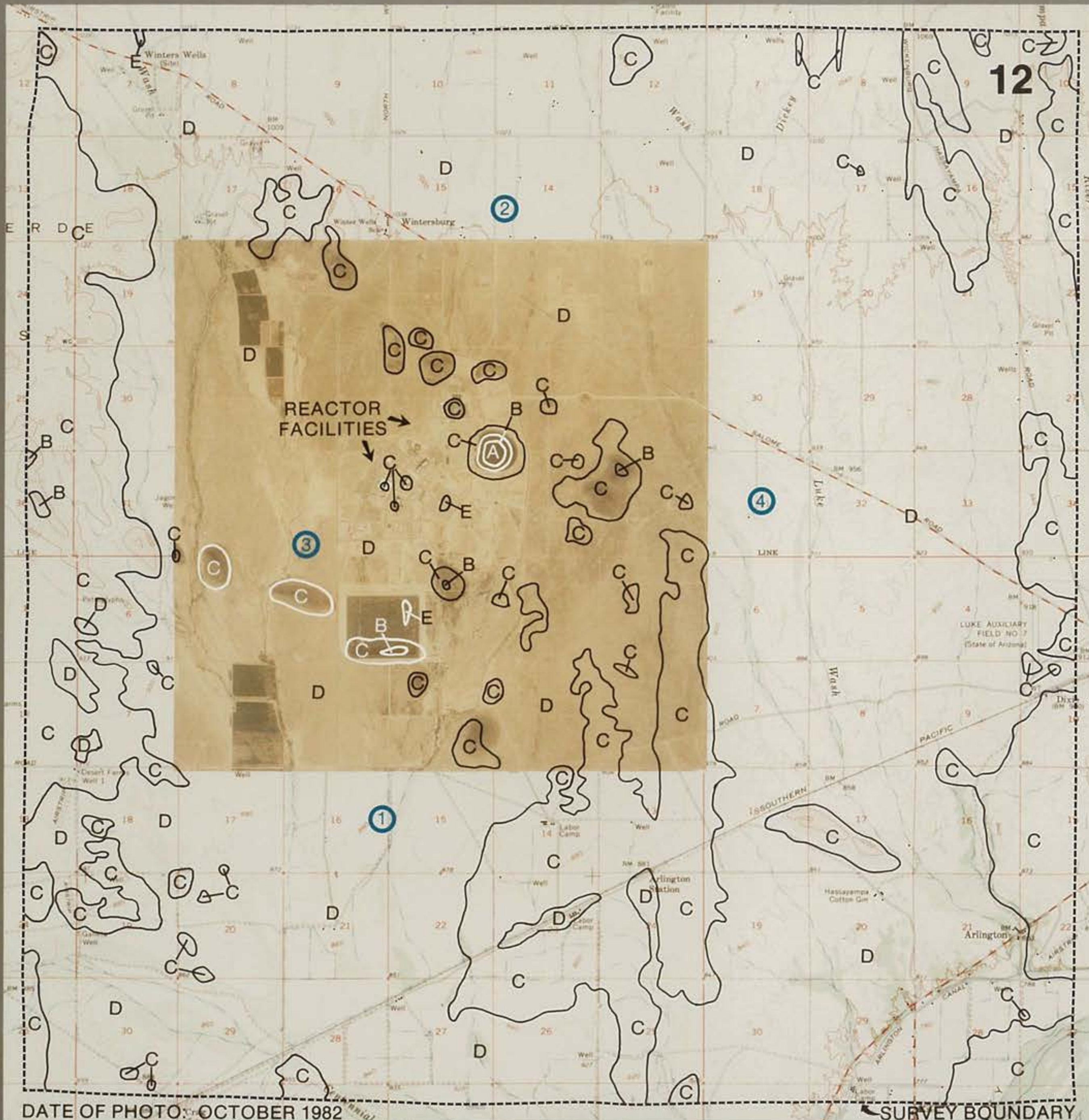
Soil samples and radiation measurements at 1 meter height (using a Reuter-Stokes Model RS-111 pressurized ion chamber) were taken at four locations, as shown in Figure 4, centered around the reactor site for comparison with the aerial measurements.

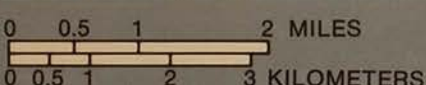
Results from the ground measurements are tabulated in Table 2, and a representative gamma spectrum collected using a Ge(Li) high resolution detector is shown in Figure 5. All of the isotopes identified in Figure 5 are from the naturally occurring uranium-238 or thorium-232 radioactive decay series with the exception of cesium-137, potassium-40, and the single escape peak of thallium-208. Both the direct field measurement with the ion chamber and the calculated value based on measured soil concentration are quoted in Table 2. An ionizing cosmic ray component, appropriate for a 950-foot elevation, of 4.3 μR/h[6] is assumed to be present in the ion chamber readings and is added to the soil sample estimates to make all values directly comparable. Aerial survey results are also listed for comparison and show good agreement.

Table 2. Comparison of External Exposure at 1 Meter Using Ground Measurements and Aerial Data

	Ground Survey Results		
Site Number	Pressurized Ion Chamber at 1 m (μR/h)	Calculated from Soil Sample (μR/h)[1]	Aerial Survey Results (μR/h)[1]
1	11.5 ± 0.2	12.1 ± 0.4	11 - 14
2	11.5 ± 0.5	12.5 ± 0.4	11 - 14
3	12.2 ± 0.4	13.2 ± 0.7	11 - 14
4	12.2 ± 0.4	12.9 ± 1.0	11 - 14

[1] An assumed cosmic ray component of 4.3 μR/h has been added to the terrestrial component.





GROUND SAMPLE LOCATIONS

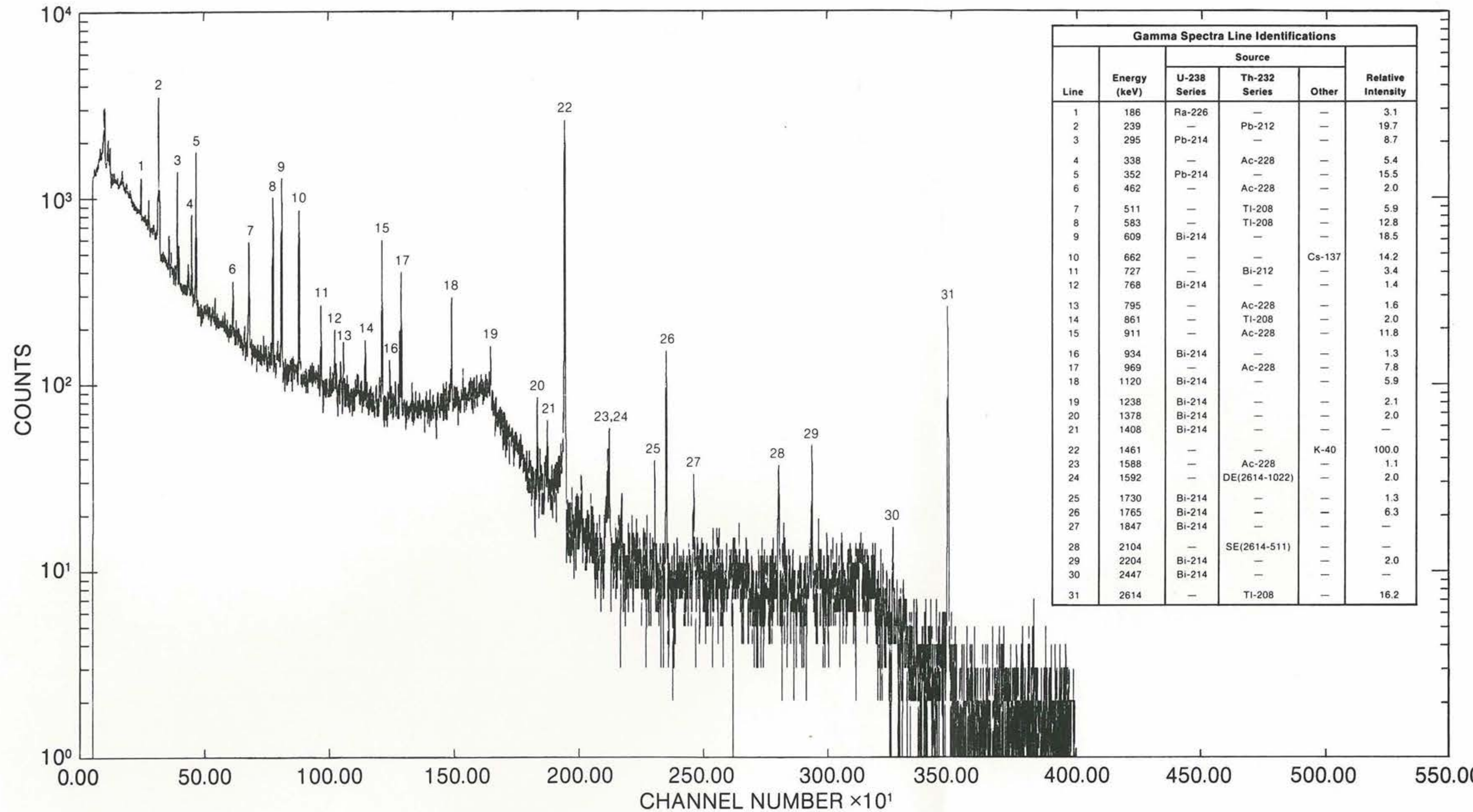
Black and white contour lines are used for purposes of clarity.

CONVERSION SCALE

LETTER LABEL	TERRESTRIAL RADIATION INTENSITY AT 1 METER (μR/h)*
A	< 6
B	6 - 8
C	8 - 11
D	11 - 14
E	14 - 18

*Inferred from aerial data collected at an altitude of 90 meters (300 feet). An additional 4.3 μR/h due to ionizing cosmic radiation must be added to obtain the total ionizing exposure rate.

Figure 4. *TERRESTRIAL GAMMA RAY ISORADIATION CONTOUR LEVELS FOR THE NOVEMBER 1982 SURVEY OF THE PALO VERDE NUCLEAR GENERATING STATION NEAR WINTERSBURG, ARIZONA*



Gamma Spectra Line Identifications

Line	Energy (keV)	Source: U-238 Series	Source: Th-232 Series	Source: Other	Relative Intensity
1	186	Ra-226	—	—	3.1
2	239	—	Pb-212	—	19.7
3	295	Pb-214	—	—	8.7
4	338	—	Ac-228	—	5.4
5	352	Pb-214	—	—	15.5
6	462	—	Ac-228	—	2.0
7	511	—	Tl-208	—	5.9
8	583	—	Tl-208	—	12.8
9	609	Bi-214	—	—	18.5
10	662	—	—	Cs-137	14.2
11	727	—	Bi-212	—	3.4
12	768	Bi-214	—	—	1.4
13	795	—	Ac-228	—	1.6
14	861	—	Tl-208	—	2.0
15	911	—	Ac-228	—	11.8
16	934	Bi-214	—	—	1.3
17	969	—	Ac-228	—	7.8
18	1120	Bi-214	—	—	5.9
19	1238	Bi-214	—	—	2.1
20	1378	Bi-214	—	—	2.0
21	1408	Bi-214	—	—	—
22	1461	—	—	K-40	100.0
23	1588	—	Ac-228	—	1.1
24	1592	—	DE(2614-1022)	—	2.0
25	1730	Bi-214	—	—	1.3
26	1765	Bi-214	—	—	6.3
27	1847	Bi-214	—	—	—
28	2104	—	SE(2614-511)	—	—
29	2204	Bi-214	—	—	2.0
30	2447	Bi-214	—	—	—
31	2614	—	Tl-208	—	16.2

Figure 5. *GAMMA RADIATION SPECTRUM FROM SOIL SAMPLE NUMBER 1 MEASURED IN THE LABORATORY WITH A Ge(Li) DETECTOR. The energy scale conversion factor is 0.75 keV/channel.*

APPENDIX A
SURVEY PARAMETERS

Location:	Palo Verde Nuclear Generating Station, Wintersburg, Arizona
Survey Coverage:	256 km^2
Survey Date:	4 to 15 November 1982
Project Scientist:	R.A. Semmler
Survey Altitude:	90 meters (300 feet)
Line Spacing:	150 meters (500 feet)
Lines Surveyed:	106
Detector Array:	Twenty 12.7-cm diameter by 5.1-cm thick NaI(Tl) detectors (Cd band shield)
Acquisition System:	REDAR IV
Aircraft:	MBB BO-105 Helicopter
Data Processing:	

Gross Count Window: 0.04 to 3.00 MeV

Conversion Factor: 754 cps per μR/h

Cosmic Ray Contribution: 4.3 μR/h

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