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SEPTEMBER 1989

AN AERIAL RADIOLOGICAL SURVEY OF

TECHNICAL AREA 15 AND SURROUNDINGS LOS ALAMOS NATIONAL LABORATORY

LOS ALAMOS, NEW MEXICO

DATE OF SURVEY: SEPTEMBER 1982

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DATE OF SURVEY: SEPTEMBER 1982

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ABSTRACT

An aerial gamma survey of the entire Los Alamos National Laboratory and the adjacent area was flown in September 1982. The data from a part of the survey, Technical Area 15, are presented here. Other parts of the survey data that will complete the presentation will be published in a separate report.

The gamma survey data show significant Pa-234m activity which implies U-238 activity above background levels. Concentration isopleths overlaid on aerial photographs of this area indicate the position and extent of this isotope. The inventory of Pa-234m (above background) is probably between 4 and 23 curies, depending on the actual vertical distribution of the Pa-234m in the soil.

Isopleth maps of the natural background gamma exposure rates and the total exposure rates (natural plus exposure due to Pa-234m) are included. Implied exposure rates at 1 meter above the ground range from a minimum terrestrial component of 6 μR/h to 22 μR/h over areas where Pa-234m and the parent, U-238, exist.

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1.0 INTRODUCTION

An aerial gamma survey of the entire Los Alamos National Laboratory and the adjacent area was conducted in September 1982. The survey was performed by EG&G Energy Measurements, Inc. (EG&G/EM) at the request of the U.S. Department of Energy (DOE), Office of Nuclear Safety.

The object of the survey was to measure the natural terrestrial gamma exposure rates as well as the location and intensity of anomalous, man-made gamma emitters. Gamma data from the NaI(Tl) detectors were reduced to exposure and concentration plots overlaid on aerial photographs of Los Alamos.

Because Los Alamos covers a large geographical area, gamma maps of the entire area as well as subsections of the area have been produced. The subject of this report is the subsection around Technical Area 15 (TA-15), an area of approximately 840 hectares (3.2 square miles) which is shown in Figure 1. Pa-234m was detected in this area, which implies the existence of U-238.

2.0 DATA ACQUISITION

The entire Los Alamos area, including the area around TA-15, was surveyed using a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter. Parallel flight lines, east by southeast and west by northwest, were flown under the guidance of a microwave ranging system (MRS). Two transponders on the ground (one at Mt. Cerro Piñon and one at Mt. Glorieta Baldy) and a master unit on the aircraft provided the pilot with a steering vector. Two passes through each of the major Los Alamos canyons were also flown, but not under the guidance of the MRS. The transponder signal generally could not reach the aircraft in the canyons.

An outline of the survey parameters is given in Table 1.

3.0 DATA ANALYSIS

The aerial system uses two primary methods to treat gamma fluence measurements as seen by NaI(Tl) detectors. The first is the gross count (GC) or total gamma count rate, and the second is the spectral window technique. These and other methods are described in detail in a separate publication.[1]

3.1 Gross Count

The gross count is defined as the integral count in the energy spectrum between 38 keV and 3,026 keV.

$$GC = \sum_{38\ \text{keV}}^{3{,}026\ \text{keV}} \text{Energy Spectrum} \qquad (1)$$

This integral includes all the natural gammas from K-40, U-238, and Th-232 (KUT, the major terrestrial, natural gamma emitters). Other natural contributors to this integral are cosmic rays, aircraft background, and airborne radon daughters.

The response versus altitude of the aerial system to terrestrial gammas has been measured over a documented test line near Las Vegas, Nevada, for which the concentrations of KUT and the 1-meter exposure rates have been measured separately. From this calibration, the terrestrial gross count rate has been associated with the 1-meter exposure rate in microroentgens per hour (μR/h) for natural radioactivity. The conversion equation is:

$$ER(1\ \text{m}) = \frac{[GC(A)-B]}{1324} \cdot e^{0.001494A} \qquad (2)$$

where

ER = exposure rate
A = altitude in ft
GC(A) = gross count rate at altitude A (cps)
B = cosmic, aircraft, and radon background (cps)

The coefficient, 0.001494, was normalized to the mean air temperature (17.0° C) and pressure (11.2 psi) during the Los Alamos survey.

At Los Alamos, all GC values were normalized to an altitude of 76 meters (250 feet) using Equation 2 because the northern part of the area was flown at 91 meters (300 feet) while the southern part was flown at 61 meters (200 feet). In this way, all count rates were comparable at a common altitude. For A = 76 meters, Equation 2 becomes:

$$ER(1\ \text{m}) = (GC - B)/912\ \mu\text{R/h} \qquad (3)$$

FIGURE 1. ***LOCATION OF TECHNICAL AREA 15 AND SURROUNDING AREA***

Table 1. Hardware, Flight, and Data Parameters	
Aircraft	MBB BO-105 helicopter
Aircraft speed	37 m/s (120 ft/s)
Altitude	61 m (200 ft)
Survey line spacing	91 m (300 ft)
Survey line direction	East by Southeast (~ +102°)
Number of lines	37 on the TA-15 map
Gamma detectors	20, 12.7-cm × 5.1-cm NaI(Tℓ)
Data recording system	REDAR IV
Data recorded	Gamma spectra, atmospheric temperature and pressure, altitude, and position values from the microwave transponders
Data acquisition rate	Once per second

The gross count has been used for many years in the aerial system as a measure of exposure. Its simplicity yields a rapid assessment of the gamma environment.

Anomalous or non-natural gamma sources are found from increases in the gross count rate over the natural count rates. However, subtle anomalies are difficult to find using the gross count rate in areas where its magnitude is variable due to, for example, geologic or ground cover changes. Differential energy data reduction methods, as discussed in the next section, are used to increase the aerial system's sensitivity to anomalous gamma emitters.

3.2 Spectral Windows

The aerial system produces a gamma energy spectrum each second from which the GC is computed. Generally, the ratio of natural components in any two integral sections (windows) of the energy spectrum will remain nearly constant in any given area:

$$\sum_{E=a}^{b} ES \Big/ \sum_{E=b}^{c} ES = \text{Constant} \qquad (4)$$

where

ES = energy spectrum

E = energy

$c > b > a$

If the window, a–b, is placed where gamma rays from a man-made emitter would occur in the spectrum, the result of Equation 4 could be expected to increase over the constant value. This equation is routinely applied in the data reduction software when a search is made for specific isotopes.

In general, when a search is made for an unknown or non-specific gamma emitter, a and b are set to 38 keV and 1,400 keV, respectively; this range includes most of the long-lived gammas from man-made isotopes. The upper limit of the background window, c, is set at 3,026 keV. This window arrangement is called the man-made gross count (MMGC) ratio.

In practice, the MMGC ratio (Equation 4) was evaluated over background areas of Los Alamos to define the constant, k. Then the following equation was constructed:

$$\text{MMGC} = A - kB \qquad (5)$$

where

$$A = \sum_{E = 38\ \text{keV}}^{1{,}400\ \text{keV}} \text{Energy Spectrum}$$

$$B = \sum_{E = 1{,}400\ \text{keV}}^{3{,}026\ \text{keV}} \text{Energy Spectrum}$$

k = constant in Equation 4

The result of Equation 5, when applied to the data, yielded the excess count rates due to man-made gamma emitters.

3.3 Estimated Natural Gross Count

A corollary for the GC (Equation 1) is the estimated natural gross count (ENG) where k is the MMGC ratio of Equation 4. This equation was applied to the Los Alamos data to obtain estimates of the 1-meter exposure rates due to natural gammas and excluded most of the man-made gammas. There were a few areas of Los Alamos where this equation was not useful because gammas of energy greater than 1,400 keV were being generated by operations at the Los Alamos National Laboratory, such as at the LAMPF facility.

$$\text{ENG} = (k + 1) \sum_{E = 1{,}400\ \text{keV}}^{3{,}026\ \text{keV}} \text{Energy Spectrum} \qquad (6)$$

Both the GC and ENG equations were applied routinely to the Los Alamos data.

4.0 RESULTS

The primary results of the aerial radiological survey over the TA-15 area of Los Alamos show:

A. The existence of Pa-234m (Figure 2)

B. The isopleths of the Pa-234m concentrations (Figure 3)

C. The 1-meter total terrestrial exposure isopleths (Figure 4)

D. The 1-meter natural exposure isopleths (Figure 5). An inventory estimate of Pa-234m was also made.

4.1 Pa-234m Concentration Isopleths

The net energy spectrum (total less adjacent background) shown in Figure 2, which was observed over Area 1 in Figure 3, indicates the presence of Pa-234m, a daughter of U-238. The shoulder in this spectrum at 186 keV may also indicate the presence of U-235. The photopeaks at 776 keV and 1,000 keV in Figure 2 are rather weak. It has been assumed that the other areas (Areas 2 and 3) in Figure 3 are also due to

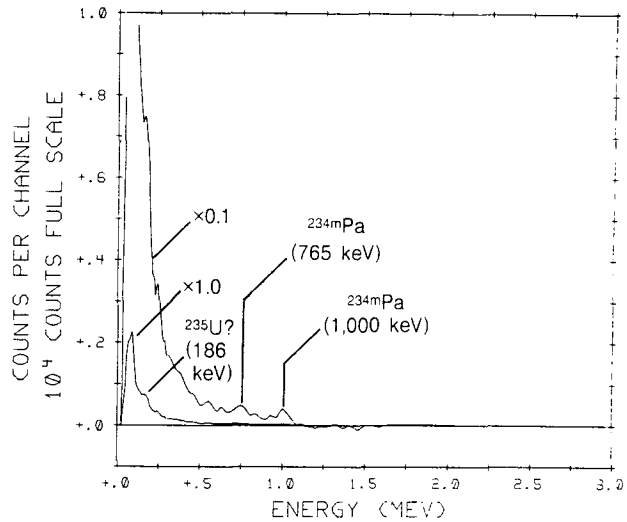

FIGURE 2. ***Pa-234m GAMMA ENERGY SPECTRUM***

Pa-234m. The photopeaks in the spectra from these areas are less visible than those in Figure 2.

The concentration isopleths in Figure 3 were obtained using the MMGC technique discussed in Subsection 3.2. Since the sensitivity of the aerial system to monoenergetic gamma emitters in the soil may be computed (Appendix A), and the ratio of the 1,000 keV counts to total counts is known from Figure 2, the sensitivity of the MMGC to Pa-234m may be computed also. Some values of MMGC sensitivity, S_A-MMGC, are given in Table 2 for several values of vertical exponential distribution of Pa-234m in the soil. Values for S_v^0 (sensitivity to the ground surface volume) and S_A-Photopeak (sensitivity of the 1,000 keV gamma count rate to the activity per unit area) are also listed.

The other low-level isopleths (Level B) shown in Figure 3 are highly uncertain; they may indicate Pa-234m or may not. That is, they may be generated by the counting statistics. Level B (1,125 cps) represents the 3σ uncertainty level which might be interpreted as the minimum detectable counting level for Pa-234m.

An estimate of the Pa-234m and associated U-238 inventory (Appendix B) can be made from the isopleths in Figure 3. Table 3 lists inventories for three possible concentration distributions.

There are many uncertainties in converting count rates to concentrations. These uncertainties lie in the correct interpretation of the energy spectra (Areas 2 and 3 provided poor spectra); the validity

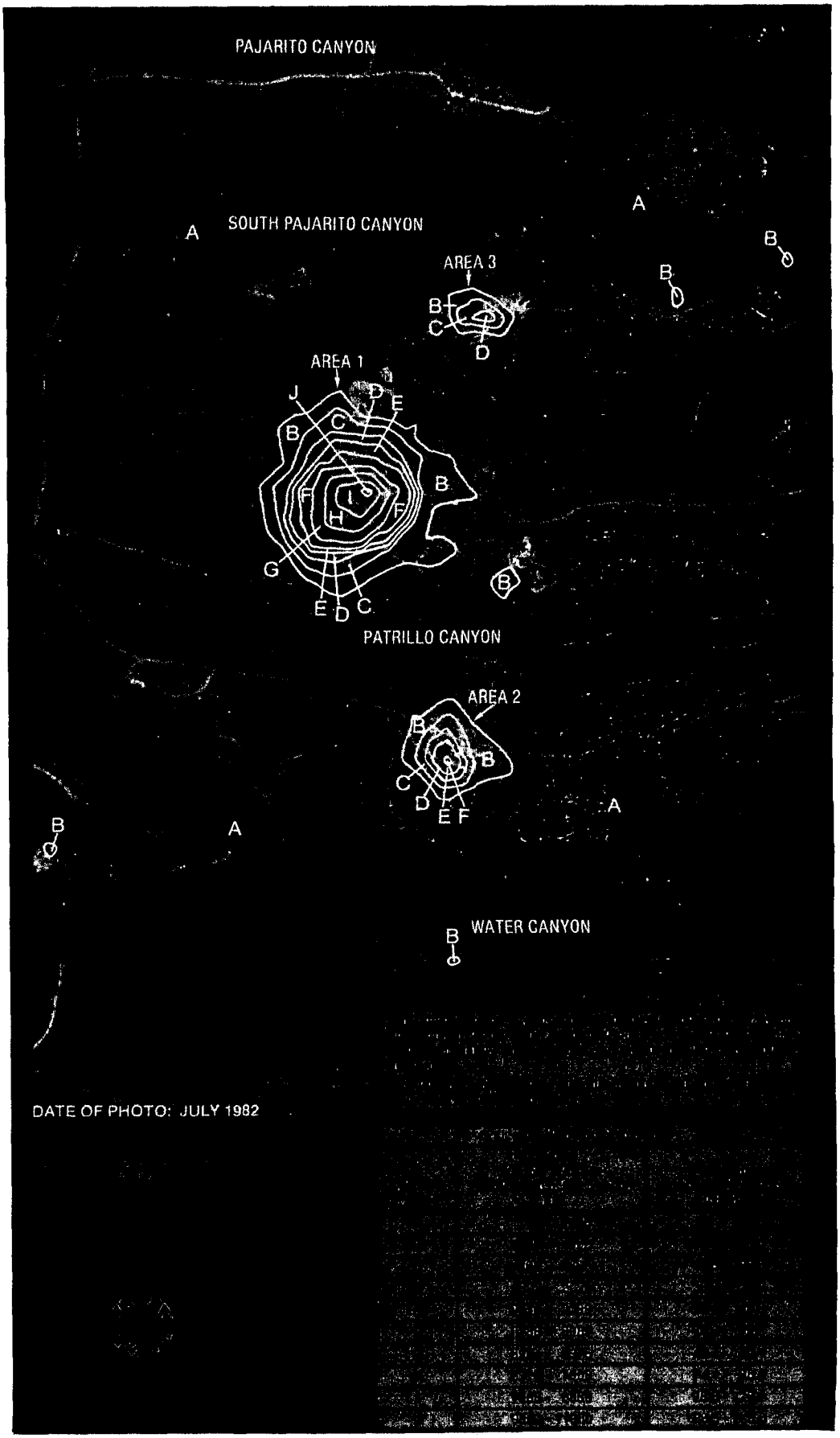

FIGURE 3. ***CONCENTRATIONS OF Pa-234m AROUND TECHNICAL AREA 15, LOS ALAMOS NATIONAL LABORATORY***

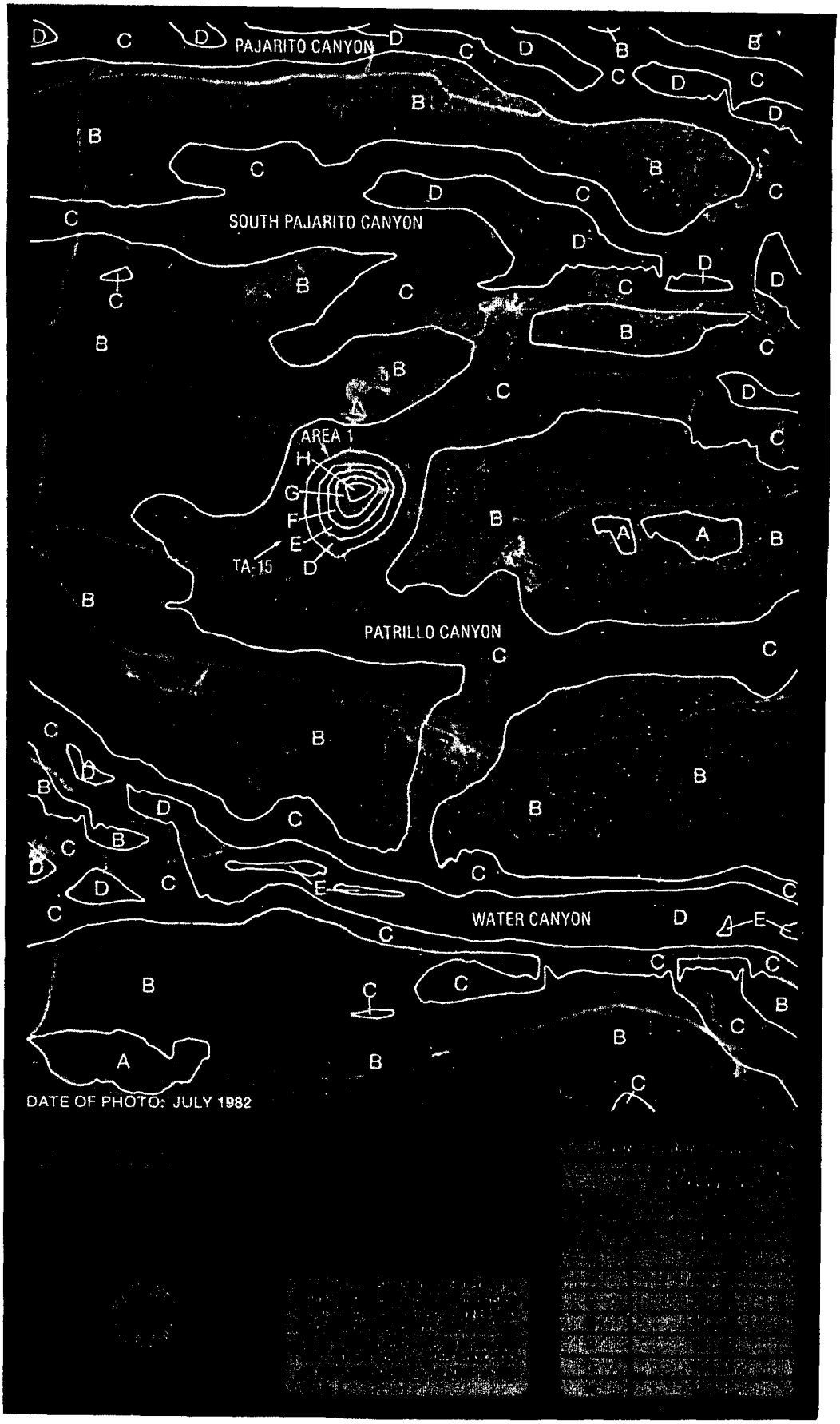

FIGURE 4. ***TOTAL TERRESTRIAL EXPOSURE RATE AROUND TECHNICAL AREA 15, LOS ALAMOS NATIONAL LABORATORY***

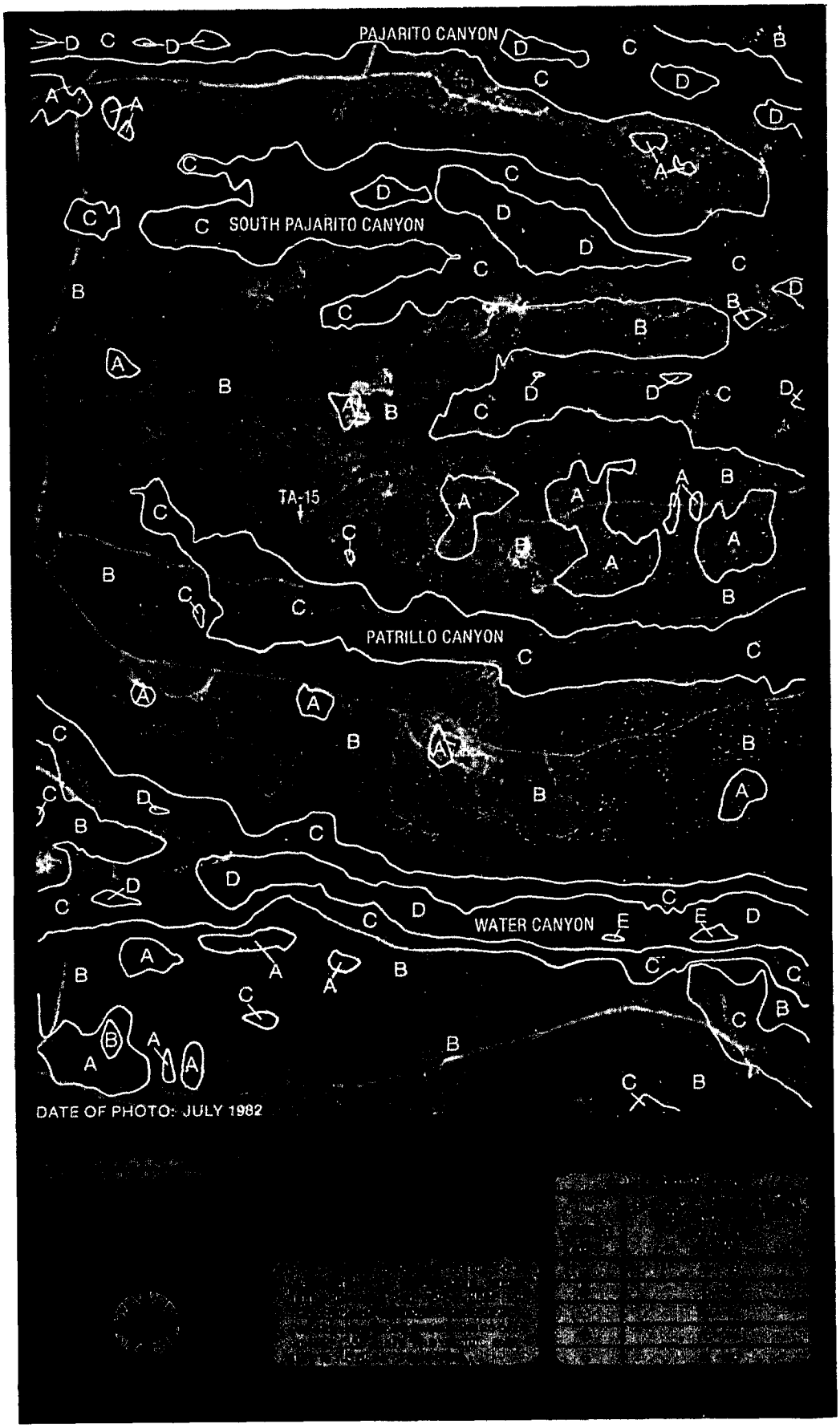

FIGURE 5. ***NATURAL TERRESTRIAL EXPOSURE RATE AROUND TECHNICAL AREA 15, LOS ALAMOS NATIONAL LABORATORY***

Table 2. Sensitivity to Pa-234m			
α^a (cm^{-1})	S_v^0 ($pCi/cm^3 \cdot cps$)	S_A-Photopeak[b] ($\mu Ci/m^2 \cdot cps$)	S_A-MMGC ($\mu Ci/m^2 \cdot cps$)
1.0	30.2	0.30	0.0055
0.3	12.1	0.40	0.0073
0.1	6.8	0.68	0.0124
0.03	4.8	1.60	0.0291
0.01	4.3	4.30	0.0782

[a] Vertical concentration parameter in $C = C_0 \exp(-\alpha z)$.

[b] S_A-Photopeak refers to the Pa-234m 1 MeV gamma.

Table 3. Pa-234m Inventory Estimates for TA-15				
	Curies			
α^a (cm^{-1})	Area 1	Area 2	Area 3	Total
1.0	3.6	0.5	0.1	4.2
0.1	8.10	1.2	0.3	9.6
0.03	19.0	2.8	0.7	22.5

[a] Vertical distribution parameter.

of the concentration distribution model; and the azimuthal smearing of count rates due to the moving aircraft and the large, solid-angle view of the detectors. From experience, however, the uncertainty is expected to be about a factor of two. Appendix C discusses uncertainties in more detail.

4.2 Total Terrestrial Exposure

The total terrestrial exposure isopleth map (Figure 4) indicates the 1-meter exposure from the sum of the natural and man-made terrestrial components. The cosmic and variable airborne radon components are not included on the map.

The exposure levels appear to be above background levels only in Area 1 of this map. About 7.8 hectares (19 acres) are included in Area 1. Areas 2 and 3 (Figure 3) do not show elevated exposure levels in Figure 4, although Area 2 does measure at 1 μR/h above background when a finer isopleth interval (1 μR/h) is used for the plot.

The exposure levels in Area 1 extend to an estimated 20 to 22 μR/h. This may be an underestimate because the aerial system has a wider view of the surface than measurements taken at the 1-meter level.

The natural exposure levels are larger in Water Canyon than on the plateau areas or in Potrillo and Pajarito Canyons. Perhaps the increase is due to the walls of this canyon, which are relatively close together, and may thus contribute more to exposure than do widely-separated walls or a flat plane. The sensitivity of the aerial system to natural terrestrial radiation has been measured for flat plains, not for canyons. The results of specific flights through these canyons at 45-meter (150-foot) altitudes do not indicate the presence of man-made radioactivity.

4.3 Natural Terrestrial Exposure

The natural terrestrial exposure isopleths due to K-40, the U-238 chain, and the Th-232 chain are

illustrated in Figure 5. These isopleths were obtained from the fraction of the energy spectrum greater than 1,400 keV, as discussed in Subsection 3.3. Note that the higher exposure levels in Area 1 (Figure 4) do not appear because the Pa-234m gamma rays occur at less than 1,400 keV.

The mean natural background exposure over the map area is 9.5 μR/h. The mean total exposure over the map area is the same, i.e., less than 1 percent larger.

APPENDIX A

AERIAL DETECTOR SENSITIVITIES TO TERRESTRIAL GAMMAS

The EG&G/EM aerial detector system consists of two pods, each containing ten 12.7-cm × 5.1-cm (5-in. × 2-in.) NaI(Tl) cylindrical detectors. The sensitivity of these pods is dependent on several parameters, as listed in Equations 1 and 2 below.

Beginning with a vertical concentration distribution:

$$C(z) = C_0 \, e^{-\alpha z} \qquad \gamma/cm^3 \cdot s \qquad (1)$$

where

C_0 = the surface concentration, $\gamma/cm^3 \cdot s$

α = exponential concentration factor, cm^{-1}

z = depth in soil, cm

the sensitivity of the pods to a monoenergetic gamma distribution may be written.

$$S_v^0 = \frac{C_0}{cps} = \frac{1}{X} \qquad \gamma/cm^3 \cdot s \cdot cps \qquad (2)$$

where

$$X = \frac{A_0}{2} \int_0^{\theta = 90°} \frac{R(\theta)\, e^{-\mu_a h \sec\theta} \tan\theta \, d\theta}{\alpha + \rho \mu_g \sec\theta}$$

A_0 = detector effective area for monoenergetic gamma total absorption in the detector for fluence perpendicular to the ground surface, cm^2

$R(\theta)$ = relative effective area versus the angle, θ, measured from the ground perpendicular to the pod

μ_a = the air mass attenuation coefficient for the gamma energy in question, cm^2/g

μ_g = the soil mass attenuation coefficient for the gamma energy in question, cm^2/g

h = the detector (aircraft) altitudes in units of air thickness, g/cm^2

ρ = soil density, g/cm^3

The sensitivity, S_v^0, may be used to convert a photopeak count rate from the detector or pod output to the soil surface concentration, C_0.

In practice, the effective area, A_0, is measured with known point sources of different energies. The angular factor, $R(\theta)$, is measured and approximated with unity, cosine θ, or a linear combination of these to fit an angular response at a given gamma energy.

Other useful conversions may be obtained from S_v^0. These are:

1. The sensitivity per unit soil surface area

$$S_A = \frac{S_v^0}{\alpha} \qquad \gamma/cm^2 \cdot s \cdot cps \qquad (3)$$

2. The sensitivity per unit soil surface mass

$$S_\rho^0 = \frac{S_v^0}{\rho} \qquad \gamma/g \cdot s \cdot cps \qquad (4)$$

3. The sensitivity to a soil sample of depth z

$$S_\rho^z = S_v^0 (1 - e^{-\alpha z}) / \rho \alpha z \qquad \gamma/g \cdot s \cdot cps \qquad (5)$$

The sensitivities in Equations 2, 3, 4, and 5 are for the monoenergetic gammas represented by the photopeaks in the measured energy spectra. Sometimes it is useful to use the total spectrum (Compton's plus photopeak) because the counting statistics have less variance. When using the total spectrum from a particular isotope, a conversion factor from cps to concentration can be obtained from the total spectrum count rate to the photopeak count rate ratio, T/P. The conversion for the total spectrum count rate, then, is simply the monoenergetic conversions of Equation 2, 3, 4, and 5 divided by the total-to-peak ratio.

Example sensitivity:

Suppose we are interested in the sensitivity to the Pa-234m gamma at TA-15, Los Alamos National Laboratory. Assume that the concentration distribution is exponential with a 10-cm relaxation depth such that:

$$C = C_0 \, e^{-0.1z} \qquad \gamma/cm^3$$

Other parameters in Equation 1 (the sensitivity equation) are:

$A_0 = 760\ cm^2$

$h = 7.5\ g/cm^2$ (76 m altitude)

$\mu_a = 0.0636\ cm^2/g$

$\mu_g = 0.0636\ cm^2/g$

$\rho = 1.5\ g/cm^2$ (an assumption)

$\alpha = 0.1\ cm^{-1}$

Then from Equation 2:

$$1/S_v^0\ [R(\theta) = 1] = 809 \quad cps \cdot cm^3 \cdot s/\gamma$$

$$1/S_v^0\ [R(\theta) = \cos\theta] = 521 \quad cps \cdot cm^3 \cdot s/\gamma$$

The average of the two computations above approximates the angular response of the 12.7-cm × 5.1-cm detector pods.

$$\overline{1/S_v^0} = (809 + 521)/2 = 665 \quad cps \cdot cm^3 \cdot s/\gamma$$

and

$$\overline{S_v^0} = 0.0015 \quad \gamma/cm^3 \cdot s \cdot cps$$

We average the inverse sensitivities, $1/S_v^0$, for the two angular responses to obtain the average response of two systems of equal size, one of isotropic angular response and one of cosine θ.

The other sensitivity values may be computed from S_v^0:

$$S_A = S_v^0/\alpha = 0.0015/0.1 = 0.015 \quad \gamma/cm^2 \cdot s \cdot cps$$

$$S\rho = S_v^0/\rho = 0.0015/1.5 = 0.0010 \quad \gamma/g \cdot s \cdot cps$$

$$S_\rho^5 = S_v^0(1 - e^{-\alpha z})/\rho\alpha z$$

$$= 0.0015(1 - e^{-0.1 \times 5})/1.5 \times 0.1 \times 5$$

$$= 0.00079 \quad \gamma/g \cdot s \cdot cps$$

To convert any of these sensitivities whose units contain γ/s to pCi, multiply by the inverse of the branching ratio (0.006) times 0.037 disintegration/s·pCi which is 4,505 pCi·s/disintegration.

Finally, the total-to-peak ratio (Compton's plus photopeak divided by the 1 MeV photopeak) is 55. So the photopeak sensitivities above may be converted to total spectrum sensitivity by dividing by 55.

APPENDIX B

RADIOACTIVE INVENTORY COMPUTATION

The EG&G/EM aerial systems gather and compute enough information to estimate a radioactive inventory above the minimum detectable activity in soil. The information used is:

1. A geometric and radiometric scaled isopleth map of the area
2. The mean count rate above background in each isopleth interval
3. The conversion from count rate to a specific isotope concentration distribution in the soil

The area enclosed by each isopleth interval is measured with a suitably fine grid paper and multiplied by the conversion coefficient (μCi/m^2·cps). The sum of these computations for all the isotope intervals yields the inventory. Where the concentration distribution (α) in the Equation $C = C_0 e^{-\alpha z}$ is not well known, a range of inventories may be computed from different α values.

APPENDIX C

UNCERTAINTIES IN MEASUREMENT AND INTERPRETATION

A number of uncertainties may contribute to misinterpretation of aerial gamma data listed in the contour map or tables of sensitivity and inventory. The sources of uncertainty are contour broadening, basic calibration uncertainty, and airborne gamma emitters.

CONTOUR BROADENING

Contours (or isopleths) are computed from a linear extrapolation to a given magnitude between neighboring, actual data points. One might expect some contour distortion from the finite distance (about 100 ft) over which each data point is collected, but this uncertainty is small compared to that due to source detection, both before and after the detector arrives over the source. Thus, a point source on the ground will appear as a set of concentric circular isopleths or contours centered on a point source. The diameter of the circular contours will depend on the gamma energy of the source, the angular response of the detector, and the intensity of the source as well as the minimum detectable activity of the detection system. The area enclosed by any contour, then, will be enlarged or reduced depending on whether that area contains more or less activity than its surroundings. The aerial measuring system does not have an automated computing method that will convert aerial intensity/position data to source distribution. Rather, informed interpretations of a contour map should be made by technical people.

CALIBRATION UNCERTAINTY

The sensitivity of the aerial gamma system to monoenergetic sources has been measured versus angle in the laboratory. The extrapolation of an aerial photopeak count rate to a source concentration in or on the ground is computed. This method has been verified many times by flying the aerial system over known sources. The uncertainty in such monoenergetic source measurements is 10% or less of the source value.

The sensitivity of the aerial system to natural elements (K-40, U-238 and progeny, and Th-232 and progeny) is checked several times each year from flights at several altitudes over a documented test line beside Lake Mead, Nevada. The test line has been documented by:

1. Counting many soil samples
2. *In situ* NaI(Tl) detector measurements
3. *In situ* high purity germanium detector measurements
4. Ion chamber measurements in a gridded configuration

The aerial total count rate versus altitude yields a curve to extrapolate an aerial measurement to the ground. The uncertainty of the exposure measurement derived from these data is $\pm 7\%$ of the exposure due to KUT (K-40, U-238, and Th-232).

AIRBORNE GAMMA EMITTERS

Radon (Rn-222) daughters are a significant contribution to the gamma count rates measured by the aerial system. Total count rates from Rn-222 vary from zero to perhaps 2,000 cps. This contribution, including that from cosmic rays and aircraft materials, is measured separately for each aircraft flight. A pass over a large body of water (if nearby) is made, or a dual altitude method over a test line is used to compute the total of radon plus cosmic plus aircraft background. In general, the water contains no activity, so the background contributions to the gamma count rate are measured directly. The dual altitude method yields two equations in two unknowns (the terrestrial count rate and the background count rate) and is a less preferable method than using "over water" measurements. The vertical distribution of the radon concentration may be the largest uncertainty in the dual altitude method, and the count rate uncertainty may be as large as 500 cps ($\sim$0.5 μR/h) in terms of terrestrial exposure.

REFERENCES

1. Boyns, P.K. July 1976. *The Aerial Radiological Measuring System (ARMS)*: Systems, Procedures and Sensitivity. Report No. EGG-1183-1691. Las Vegas, NV: EG&G/EM.