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REMOTE SENSING LABORATORY

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AERIAL RADIOLOGICAL SURVEYS

Alan E. Proctor

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A. E. Proctor
Bechtel Nevada
Remote Sensing Laboratory
P.O. Box 98521
Las Vegas, Nevada 89193-8521
Telephone: (702) 295-8764 E-mail: proctoae@nv.doe.gov

ABSTRACT

Measuring terrestrial gamma radiation from airborne platforms has proved to be a useful method for characterizing radiation levels over large areas. Over 300 aerial radiological surveys have been carried out over the past 25 years including U.S. Department of Energy (DOE) sites, commercial nuclear power plants, Formerly Utilized Sites Remedial Action Program/Uranium Mine Tailing Remedial Action Program (FUSRAP/UMTRAP) sites, nuclear weapons test sites, contaminated industrial areas, and nuclear accident sites. This paper describes the aerial measurement technology currently in use by the Remote Sensing Laboratory (RSL) for routine environmental surveys and emergency response activities. Equipment, data-collection and -analysis methods, and examples of survey results are described.

1.0 INTRODUCTION

Aerial radiological survey methodology has been developed over the past 30 years. Initially developed by the RSL to respond to radiological emergencies related to the DOE's nuclear weapons program, the aerial survey capability has been expanded to include numerous routine and emergency response activities.

The purpose of an aerial radiation survey is to map the spatial distribution and concentration of gamma-emitting radionuclides. Real-life applications of this technique include (a) tracking and making initial assessments of radioactive plumes; (b) quickly and cost-effectively performing an overview of large, possibly contaminated areas; (c) examining populated or inaccessible areas that cannot be surveyed from the ground; and (d) providing assurance that man-made changes have not occurred in areas surrounding nuclear power plants and facilities that process radioactive materials. Over 300 aerial surveys have been carried out to date including DOE facilities, former nuclear weapons test sites, remedial action sites, nuclear power plants, industrial areas where radioactive materials were processed, several nuclear accident sites, the Kennedy Space Center, and the former USSR nuclear submarine training center. Many of these areas were known to be radioactively contaminated; others were surveyed to verify that contamination was present.

2.0 SURVEY METHODS

The RSL has developed aerial radiation surveying techniques for large-area gamma radiation surveys since the late 1960s. Earlier versions of this methodology have been reviewed in published reports.[1,2] Aerial gamma surveys are carried out using both fixed-wing and helicopter aircraft depending on the size of the survey area, the required degree of detail, and the survey costs. Figures 1 and 2 show the survey aircraft that are currently used. Rectangular detector "pods" mounted on the helicopter skids are visible in Figure 2.

2.1 Detector Characteristics

The detector system was designed to sense terrestrial and airborne gamma radiation having energies between 20 and 4,000 keV. This energy range includes emitted gamma radiation from naturally occurring radionuclides and almost all man-made gamma radiation sources. The sodium iodide, thallium-activated, NaI(T*l*), detectors are characterized by their variable sensitivity versus incident gamma energy and by a footprint size that is also energy-dependent. The variation in sensitivity with incident energy is a well-known characteristic of NaI(T*l*) detectors.

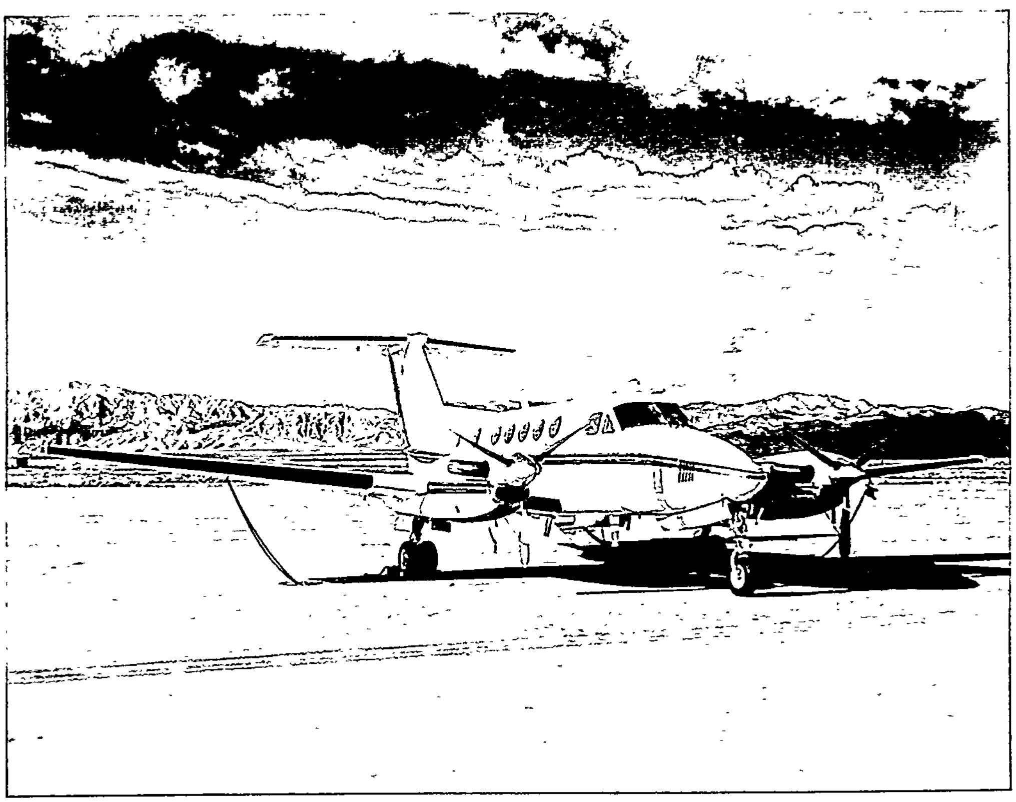


FIGURE 1. ***FIXED-WING AIRCRAFT USED IN AERIAL RADIOLOGICAL SURVEYS***

Detailed data on detector sensitivity can be obtained from the manufacturer.[3] The dependence of the viewed footprint size with energy can be (approximately) modeled using methods described in Appendix A. Because of the large footprint, sources detected by aerial systems appear to be spread over a much larger area than would be indicated by ground-based measurements.

For uncollimated detectors such as those used in aerial surveys, the source-to-detector distance and the attenuation by the air effectively limit the viewed terrestrial area to a circular region centered beneath the detector. The size of the field of view is a function of the gamma-ray energy, the gamma-ray origin, and the detector response. Radionuclide activities on or in the soil and exposure rates normalized to one meter above ground level (AGL) are customarily reported but only as large-area averages. Activity, inferred from aerial data, for a source uniformly distributed over a large area compared to the field of view of the detectors is very good and generally agrees with ground-based measurements. However, activity for a point source, a line source, or a source activity less than the detector's field of view will be underestimated, sometimes by orders of magnitude. When this occurs, the aerial data simply serve to locate and identify such sources.

Apparent source-broadening makes comparison with ground-based measurements difficult. Radionuclides that occur as hot particles are averaged by the aerial detection system, appearing as uniform, large-area distributions. Ground surveys, however, would locate the hot particles within a smaller area and show the surrounding areas to be free of contamination. Table 1 contains estimates of the detection system's field of view or "footprint" size for several energies of interest.

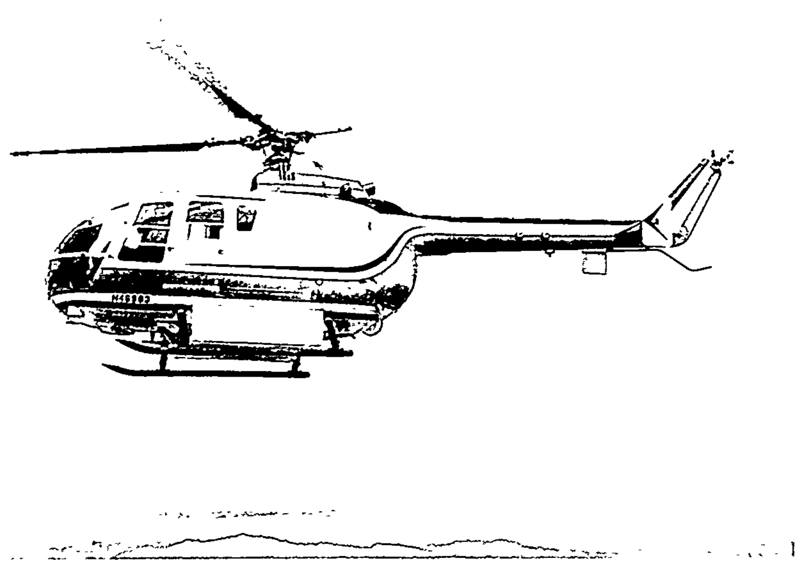


FIGURE 2. ***HELICOPTER WITH DETECTOR PODS***

Table 1. Approximate Detector Footprint Radius for Relative Count-Rate Contributions from Terrestrial Sources at a Survey Altitude of 150 ft (46 m)

Emitted Gamma-Ray Energy (keV)	Radius Where 99% of the Detected Counts Originate (ft) (m)	Radius Where 90% of the Detected Counts Originate (ft) (m)	Radius Where 50% of the Detected Counts Originate (ft) (m)
60	650 (198)	353 (108)	155 (47)
200	850 (259)	435 (133)	178 (54)
600	1,067 (325)	560 (171)	214 (65)
1,500	1,715 (523)	772 (235)	260 (79)
2,000	2,145 (654)	850 (259)	275 (84)
3,000	2,862 (872)	1,007 (307)	308 (94)
4,000	3,850 (1173)	1,150 (351)	322 (98)
6,000	4,295 (1309)	1,325 (404)	350 (107)

Detector sensitivity is not constant throughout the footprint. The maximum sensitivity occurs directly beneath the detector; the sensitivity decreases with increasing horizontal distance between the source and airborne detector. Additionally, the incident gamma rays from even a monoenergetic source include scattered gamma rays once the incident radiation reaches the airborne detectors. Footprint sizes are, therefore, dependent on the source location: distributed in the soil, dispersed in the air, shielded inside a container, etc.

2.2 Collecting Radiation Data from the Aircraft

Data collection methods are similar for both aircraft platforms; Figure 3 illustrates important details of the aerial radiological surveying process. Gamma-ray spectral data are acquired by flying the helicopter platform along a series of uniformly spaced parallel lines at a fixed altitude (e.g., 150 ft [46 m] AGL). Data are acquired continuously along these lines and recorded in one-second intervals at an airspeed of 70 knots (36 m/s). This one-second interval corresponds to a 118-ft (36-m) data interval. Comparable survey parameters for fixed-wing aircraft include a 300–500 ft (91–52 m) altitude; line spacings of 500, 1,000, or 1,500 ft (152, 305, or 457 m); and airspeeds of 120–180 knots (62–93 m/s).

Two gamma-ray spectra are accumulated from eight NaI(T*l*) detectors during each one-second interval. Other information, such as air temperature, pressure, and altitude, is also recorded during each interval.

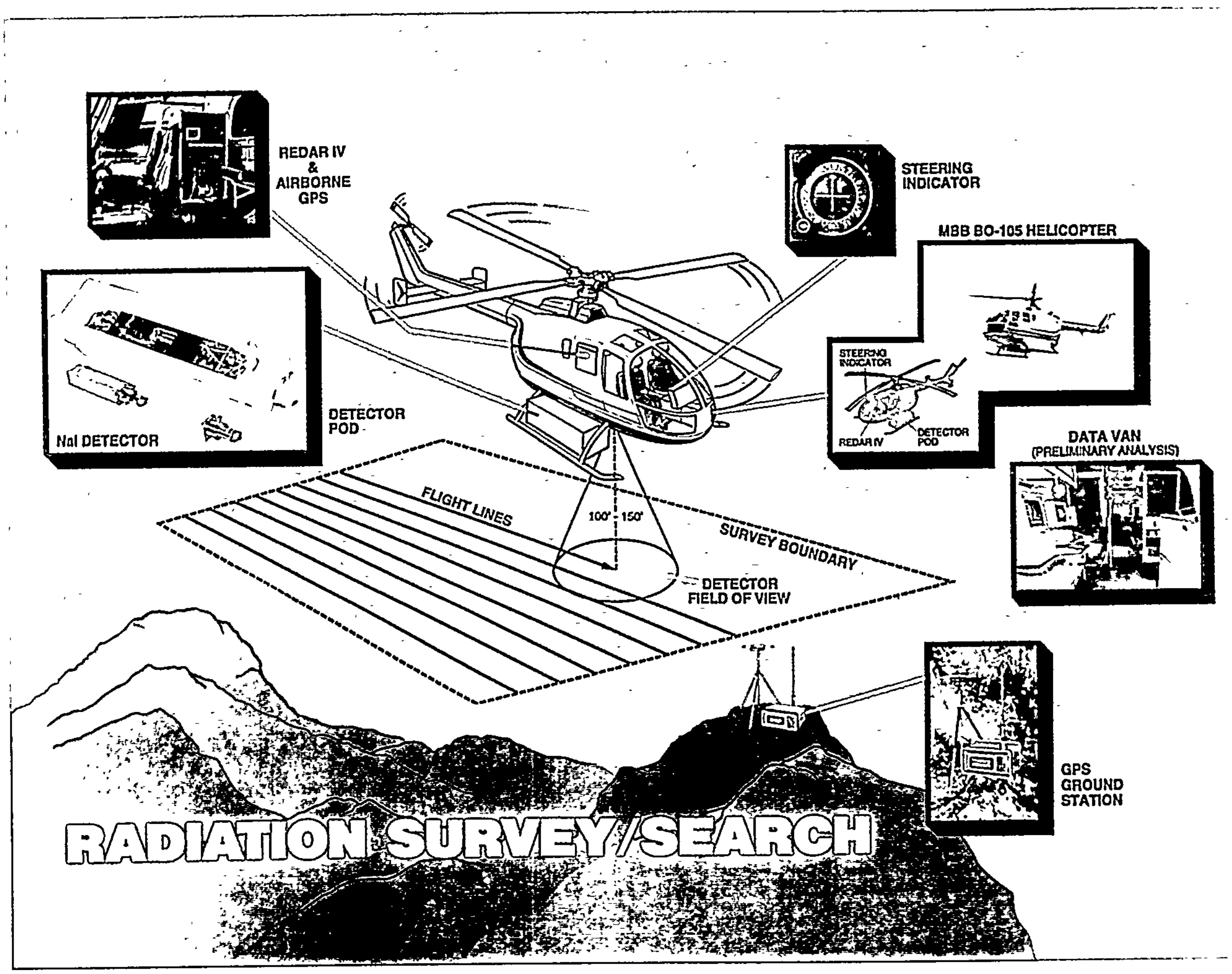


FIGURE 3. *AERIAL RADIOLOGICAL SURVEY OPERATIONS*

Aircraft position is established by a Global Positioning System (GPS) operated in differential mode. Real-time aircraft positions were determined by an on-board GPS receiver, based on the measured position from GPS satellite data and a correction transmitted from a second GPS station located at a known position on the ground. The airborne GPS receiver provides continuous positional data to a microprocessor that reformats the data for use in the RSL's airborne, computerized data-logging system. This on-board computer records the positional data and operates a steering indicator to aid the pilot in flying a set of equally spaced straight lines.

Real-time altitude measurements are made through a radar altimeter that measures the return time for a pulsed signal and converts this delay to aircraft altitude. For altitudes up to 2,000 ft (610 m), the manufacturer's stated accuracy is ±2 ft (0.6 m) or ±2 percent, whichever is greater. Altitude data were also recorded by the data-acquisition system so that variations in gamma signal strength caused by altitude fluctuations can be identified.

2.3 Data-Acquisition System

The helicopter detection system consists of eight 2- × 4- × 16-in downward-looking and two 2- × 4- × 4-in upward-looking NaI(T*l*) scintillation detectors installed in two rectangular aluminum pods. The fixed-wing survey aircraft carry from one to eight 2- × 4- × 16-in downward-looking and one 2- × 4- × 4-in upward-looking NaI(T*l*) scintillation detectors, depending on the survey application. Pulse inputs from the 2- × 4- × 16-in detectors are summed and recorded as a spectrum, as discussed below. In addition, a spectrum from one of the 2- × 4- × 16-in detectors is recorded separately to provide increased dynamic range when viewing higher-radiation areas. Counts from the 2- × 4- × 4-in detector are recorded for possible use in correcting nonterrestrial radiation contributions. The 2- × 4- × 16-in detectors are surrounded by thermal insulating foam and shielded on the top and sides with 0.03-in (0.076-cm) cadmium and lead sheets. The 2- × 4- × 4-in detectors are shielded on the bottom and sides with the cadmium and lead sheets.

Spectral data are acquired and displayed in real time using specialized instrumentation that processes, stores, and displays spectral data. This system was developed for aerial radiological surveys and contains the necessary instrumentation in a single package. The system, called the Radiation and Environmental Data Acquisition and Recorder, Version IV, (REDAR IV) system, is a multi-microprocessor and a portable data-acquisition and real-time analysis system.[4] 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 the required radiation and system information to the operator in real time. Pertinent data are recorded on cartridge tapes for later analysis.

The REDAR IV contains six subsystems: two independent systems to collect radiation data, a general purpose data input/output (I/O) system, a tape recording/playback system, a cathode-ray tube (CRT) display system, a real-time data-analysis system, and a ranging system having steering calculation and display capabilities. These subsystems, which are under the operator's control, handle functions including data collection, analysis, and display; positional and steering calculations; and data recording. Two multichannel analyzers (MCAs) in the REDAR IV system collect 1,024-channel, gamma-ray spectra (4.0 keV per channel) once every second during the surveying operation. The primary MCA (for the eight-detector spectrum) has a usable dynamic range of approximately 100,000 cps corresponding to an exposure rate at one meter AGL of about 1.5 mR/h. Spectral information at high-count rates begins to degrade at approximately half this rate; a single NaI(T*l*) detector and second MCA are used when the system is used in high-count-rate situations.

The data-acquisition system is calibrated to a 0–4,000-keV energy range using gamma-ray sources of americium-241 (^{241}Am) at 60 keV, cobalt-60 (^{60}Co) at 1,173 and 1,332 keV, and cesium-137 (^{137}Cs) at 661 keV. A 28-keV, low-energy threshold is selected to minimize counts from the lower part of the continuum. The summed signals derived from each of the eight NaI(T*l*) detectors are adjusted prior to processing by the analog-to-digital converter so that the calibration peaks appeared in preselected channels in the MCA of the data-acquisition system.

Because the energy resolution of NaI(T*l*) crystals decreases with increasing energy, spectra are compressed to conserve storage space. Spectra are divided into three partitions where the detected photopeak width is approximately the same. Data in the first partition (0–300 keV) are not compressed to permit stripping of low-energy photopeaks such as the 60-keV photopeak from ^{241}Am. The second partition (300–1,620 keV) is compressed to 12 keV per channel while the third partition (1,620–4,000 keV) is compressed to 36 keV per channel. The highest channel contains all counts from gamma rays having energies greater than 4,000 keV.

Two full spectra, one spectrum containing data from the eight detectors and a second spectrum containing data from a single detector, and related information such as position, time, and air temperature 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 support continuous data accumulation: one memory stores data while the other memory transfers data to magnetic tape. At a survey speed of 70 knots (36 m/s), 45 data sets are acquired for each mile of flight. A typical survey contains 40,000–60,000 data sets.

3.0 PRELIMINARY DATA ANALYSIS

Data processing is initiated in the field before leaving the survey site. Data are examined before leaving the site, and a preliminary analysis is completed to ensure that the raw data are satisfactory. Terrestrial exposure rates are computed from gross count data with a correction for variations in altitude. Man-made radioactivity and isotopic net count rates (e.g., ^{137}Cs, nitrogen-16 [^{16}N], and ^{60}Co) are determined through differences between total counts in appropriate spectral windows.

All count-rate data are smoothed using a three-point sliding interval average to reduce statistical fluctuations in the data:

$$C_{i,avg} = \frac{(C_{i-1} + C_i + C_{i+1})}{3}$$

$C_{i,avg}$ is the averaged value at the ith location, and C_{i-1}, C_i, and C_{i+1} are consecutive, corrected gross count rates along a single flight line. Present analysis codes do not average nearest-neighbor data on adjacent flight lines; three-point averaging has been found to be adequate. The exposure rate is calculated from this averaged gross count rate. Three-point sliding interval averaging was also applied to man-made and net isotopic data prior to calculating radiation contour maps. Two dimensional smoothing[5] is currently under investigation. Two-dimensional smoothing algorithms require regularly spaced data. Spacing between survey data positions follows flight lines and usually does not fall on an exact grid pattern. Smoothing may be applied to data that has been "binned" (i.e., averaged over a uniform grid).

3.1 Natural Background Radiation

Natural background radiation originates from radioactive elements present in the earth, airborne radon, and cosmic rays entering the earth's atmosphere. Natural terrestrial radiation levels depend on the types of soil and bedrock immediately below and surrounding the point of measurement. Within cities, the levels of natural terrestrial radiation also depend on the nature of the pavement and building materials. The gamma radiation originates primarily from the uranium and thorium decay chains and from radioactive potassium. Local concentrations of these nuclides produce radiation levels at the surface of the earth typically ranging from 1–15 μR/h. Some areas having high concentrations of uranium and/or thorium in the surface minerals exhibit even higher-radiation levels, especially in the western states.[6] The peaks shown in Table 2 were found in a typical natural background spectrum. Measurement of natural background during a survey is an important check on system operation. Figure 4 shows a typical spectrum from natural background radiation.

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

Cosmic rays 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 1.9 mi (3 km) in Colorado.[7]

4.0 MEASURED TERRESTRIAL EXPOSURE AND MAN-MADE EXPOSURE RATES

Exposure rates are of interest for public health studies and post-accident decontamination efforts. The most basic of aerial radiological measurements, exposure rate at the aircraft is proportional to

Table 2. Gamma-Ray Photopeak Identifications—Background within a Typical Survey Area

Energy (keV)	Identification
240	^{208}Tl (239 keV), ^{228}Ac (209 keV), ^{212}Pb (238 keV)
380	^{228}Ac (339 keV), ^{214}Bi (387 keV, 389 keV)
511 (weak)	^{208}Tl (511 keV), annihilation
610	^{214}Bi (609 keV)
830 (weak)	^{228}Ac (795 keV), ^{208}Tl (861 keV)
930	^{228}Ac (911 keV), ^{214}Bi (934 keV)
1,130	^{214}Bi (1,120 keV)
1,230	^{214}Bi (1,238 keV)
1,460	^{40}K (1,460 keV)
1,750	^{214}Bi (1,765 keV)
2,160	^{214}Bi (2,204 keV)
2,560	^{208}Tl (2,614 keV)

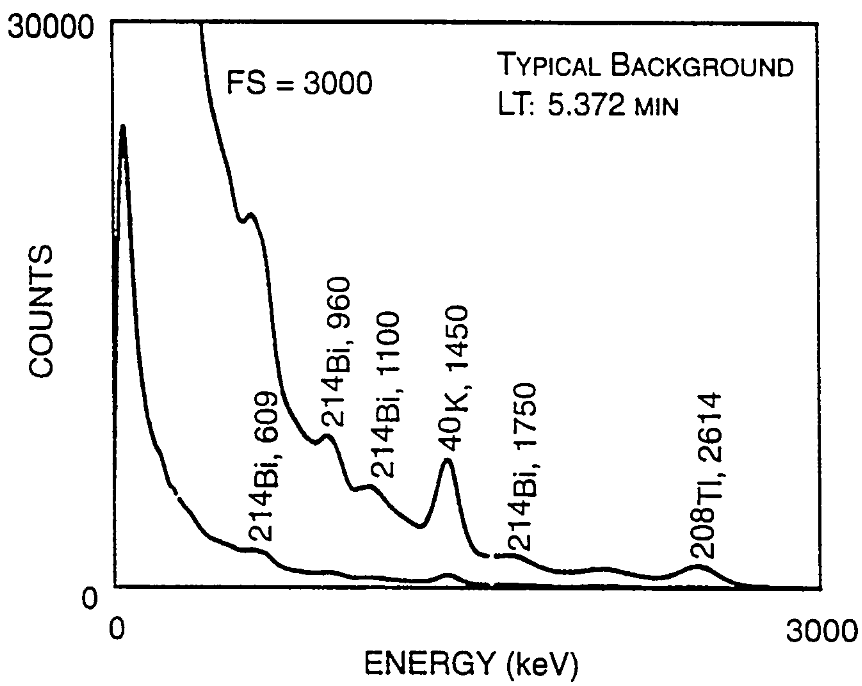


FIGURE 4. *GAMMA SPECTRUM OF A TYPICAL BACKGROUND AREA*

the detector gross count rate. The measured count rate in the aircraft differs from the true terrestrial exposure rate due to background sources in the aircraft, variations in cosmic radiation with altitude, temporal variations in atmospheric radon concentrations, and attenuation by the air of gamma rays emitted from the ground. Because raw count-rate data collected over a survey area have been found to vary, data from each flight are normalized to data that are measured over a test line at the beginning and end of each data-acquisition flight. This normalization is used to minimize the effects of variations in the natural airborne and background aircraft radiation.

The "actual" terrestrial exposure rate can be calculated as follows:

$$\mathit{Exposure\ Rate} = (\mathit{Conversion\ Factor})\ (GC - B)\ e^{-(A \cdot \mathit{altitude})}$$

GC is the gross count rate (sum of the contents of all spectrum channels) recorded by the REDAR IV system, and *A* and *B* are constants. *A* is the site-specific, atmospheric attenuation coefficient and has been found to be constant over the duration of a survey. *A* is determined from data taken at multiple altitudes over the test line. *B* represents the nonterrestrial background count rate and is calculated from test-line count rates measured before and after each survey data flight (using the previously determined value of *A*). An average value of *B*, the recorded altitude at each data interval, and the value of *A* are used to correct all measurements to yield the correct terrestrial gamma-emission rate. (Such a correction could be gamma-ray energy-dependent. At present, it is assumed that the relative contributions to the measured spectrum do not vary between the test line and the survey area, so an average correction is appropriate.)

The conversion factor, relating count rates to exposure rates, has been determined in several ways. It can be determined empirically by comparing ground-based, exposure-rate measurements of a well-characterized reference line with count rates from the airborne system. Two reference lines are maintained for survey calibration: one in Calvert County, Maryland, and a second in the Lake Mohave National Recreation Area near Las Vegas, Nevada. A conversion factor of 1.04×10^{-3} μR/h $(\mathrm{cps})^{-1}$ was recently determined using the Calvert County, Maryland, reference line.[8,9]

This conversion factor and exposure rates that were calculated using the conversion factor are correct only in regions of natural background radiation. Rates in regions where the gamma-ray spectrum is dominated by man-made activity are useful as relative indicators. For example, the spectrum near a boiling-water reactor plant site is significantly different from natural background due to the presence of gamma rays from ^{16}N.[10]

Terrestrial exposure-rate isopleth plots are also used as quality checks on the systematic variability of survey data. In particular, exposure-rate isopleths that fall along flight lines, especially along the initial or final lines of individual flights, indicate instability in the detection system. Such variations must be corrected before the data are used. If they cannot be corrected, the uncertainty (error bars) applied to the isopleth plots must be increased to eliminate obvious systematic variations.

4.1 Identifying Sources of Man-Made Radiation from Aerial Survey Data

Contaminated sites are located from isopleth maps based on a man-made radiation source algorithm, referred to as the man-made gross count rate (MMGC). This analysis provides a general overview of contamination within the survey area and also indicates the areas that should be further investigated. The MMGC algorithm is based on several observations: (a) commonly occurring man-made sources emit gamma rays having energies less than 1,394 keV while natural background sources emit gamma rays both below and above this threshold and (b) the spectrum continuum shape is relatively constant throughout the survey area. Moreover, gamma rays detected after they are scattered (*i.e.*, emitted by sources buried in soil or through atmospheric scattering) will contribute to the continuum at energies below their initial energies.

The measured spectral shape is constant over the survey area assuming a (a) stable cosmic-ray emission rate; (b) a constant background due to the aircraft, airborne radon, and natural sources; and (c) a survey area where the gamma sources and soil composition change slowly in relative comparison to the area contributing to the measured spectrum. Experience has shown that these assumptions are reasonable within statistical uncertainties over large, uncontaminated survey areas. (Significant changes in the source characteristics will invalidate this assumption. For example, changes in the MMGC are seen in spectra acquired over different terrain and when airborne radon levels change.)

If there were no systematic errors in the detection system, the sum of all gamma radiation due to man-made sources would be the difference between the spectrum in question and a typical background spectrum. Unfortunately, systematic errors make this simple subtraction impractical. A more reliable comparison can be made using the ratios of the sum of all channel contents of the spectral region from 38–1,394 keV (the region of man-made gamma emitters) to the sum of the spectral region from 1,394–3,026 keV (the region containing mostly counts from naturally occurring gamma emitters).

$$MMGC = \sum_{E = 38\ keV}^{1394\ keV} C_i - \left(Normalization \cdot \sum_{E = 1394\ keV}^{3026\ keV} C_i \right)$$

C_i represents the contents of spectrum channels corresponding to energies within the range of summation. The MMGC is the difference for a spectrum measured over an area containing man-made radionuclides, computed using the previously determined normalization constant. The constant is computed from data measured over areas free of contamination as follows:

$$Normalization\ \ Constant = \frac{\sum_{E=38\,keV}^{1394\,keV} C_i}{\sum_{E=1394\,keV}^{3026\,keV} C_i}$$

The normalization constant is derived from the data of each flight to minimize the effects of airborne radon-222 (^{222}Rn) and minor system characterization differences between flights.

Detectable high-energy gamma rays, such as the 6.13-MeV gamma ray emitted by ^{16}N, interfere with the MMGC computation: the contribution to the Compton continuum due to high-energy gamma rays contributes to the total spectrum over a broad range of energies below the photopeak. This contribution changes the spectral shape, invalidating the assumption used to calculate the normalization constant.

MMGC values are likely to have less favorable statistical uncertainties than net counts for individual radionuclides since the MMGC is based on a difference of two relatively large numbers. However, the MMGC is useful as a "first look" that can be used to determine if further isotopic analysis is warranted.

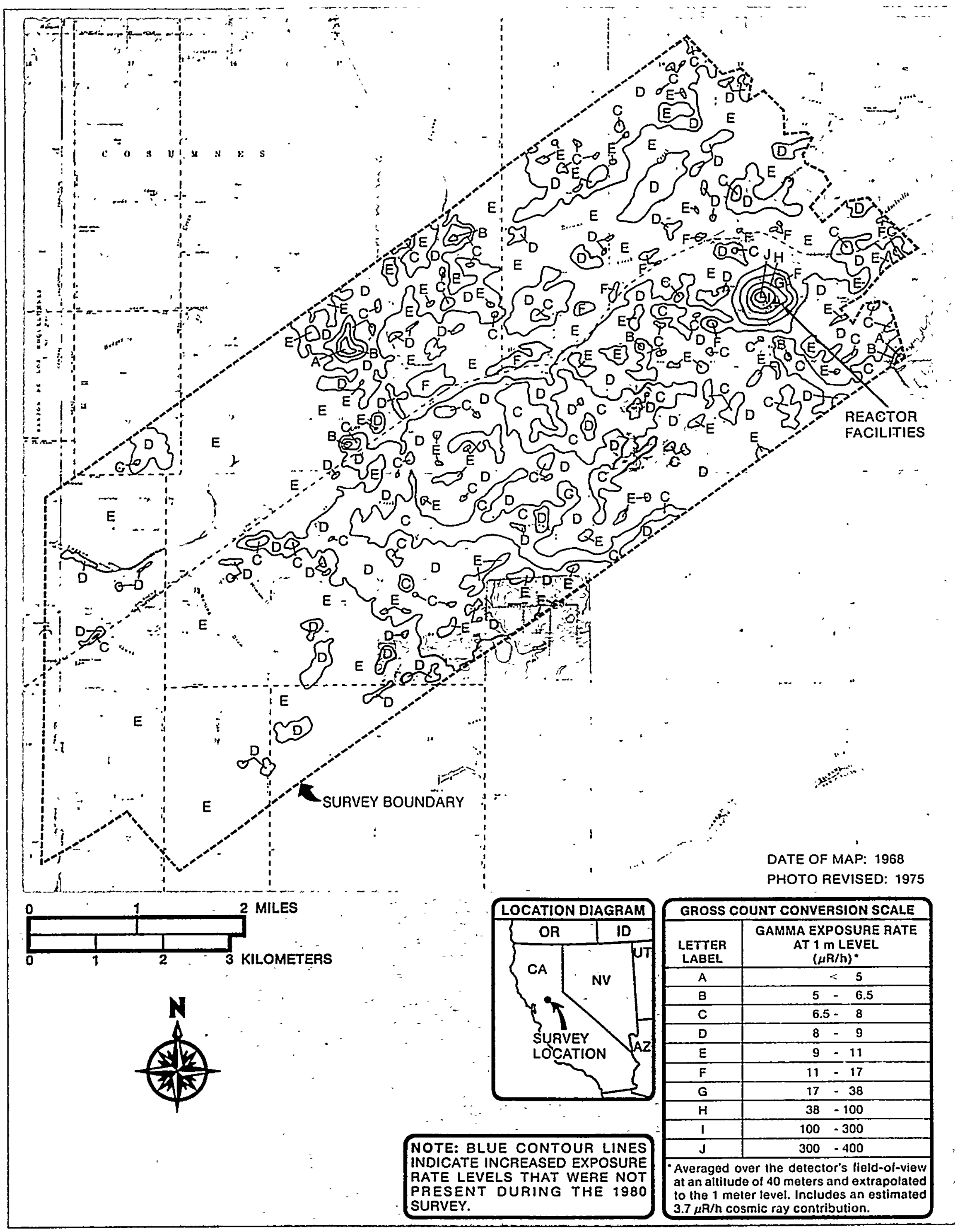
4.2 Rancho Seco Nuclear Power Plant

Two aerial radiological surveys were carried out at the Rancho Seco Nuclear Power Plant. The first survey, performed in 1980, established a baseline for exposure rate and man-made contamination in the area surrounding the site.[11] The second survey, performed in 1984, clearly showed the spread of contamination.[12]

Beginning in 1980, a U.S. Nuclear Regulatory Commission licensee began discharging a liquid radioactive effluent from the Rancho Seco station into nearby Clay Creek. By the summer of 1984, elevated contamination levels due to ^{134}Cs, ^{137}Cs, and ^{60}Co were found in several areas along the Clay, Hadselville, and Laguna Creeks.

The 1984 aerial survey was used to determine the extent of man-made contamination. The survey covered a 30-sq-mi (75-sq-km) area over the plant site and the drainage paths of the Clay, Hadselville, and Laguna Creeks. Figure 5 shows the exposure-rate contour map based on the 1984 survey data. Exposure-rate changes that occurred after the 1980 aerial survey are shown in blue. Except in the area surrounding the plant site, exposure rates were detected as expected for the area surrounding the plant site.

Large changes were seen in the MMGC levels between 1980 and 1984. Figure 6 shows the MMGC levels based on the 1980 survey data; Figure 7 shows the 1984 MMGC results. (The MMGC for both the 1980 and 1984 surveys were processed in the same way.) Evidence of the migration of contamination along the three creeks and their tributaries is readily visible. In addition, the migration path is only along the creek; no airborne deposition, for example, was present.



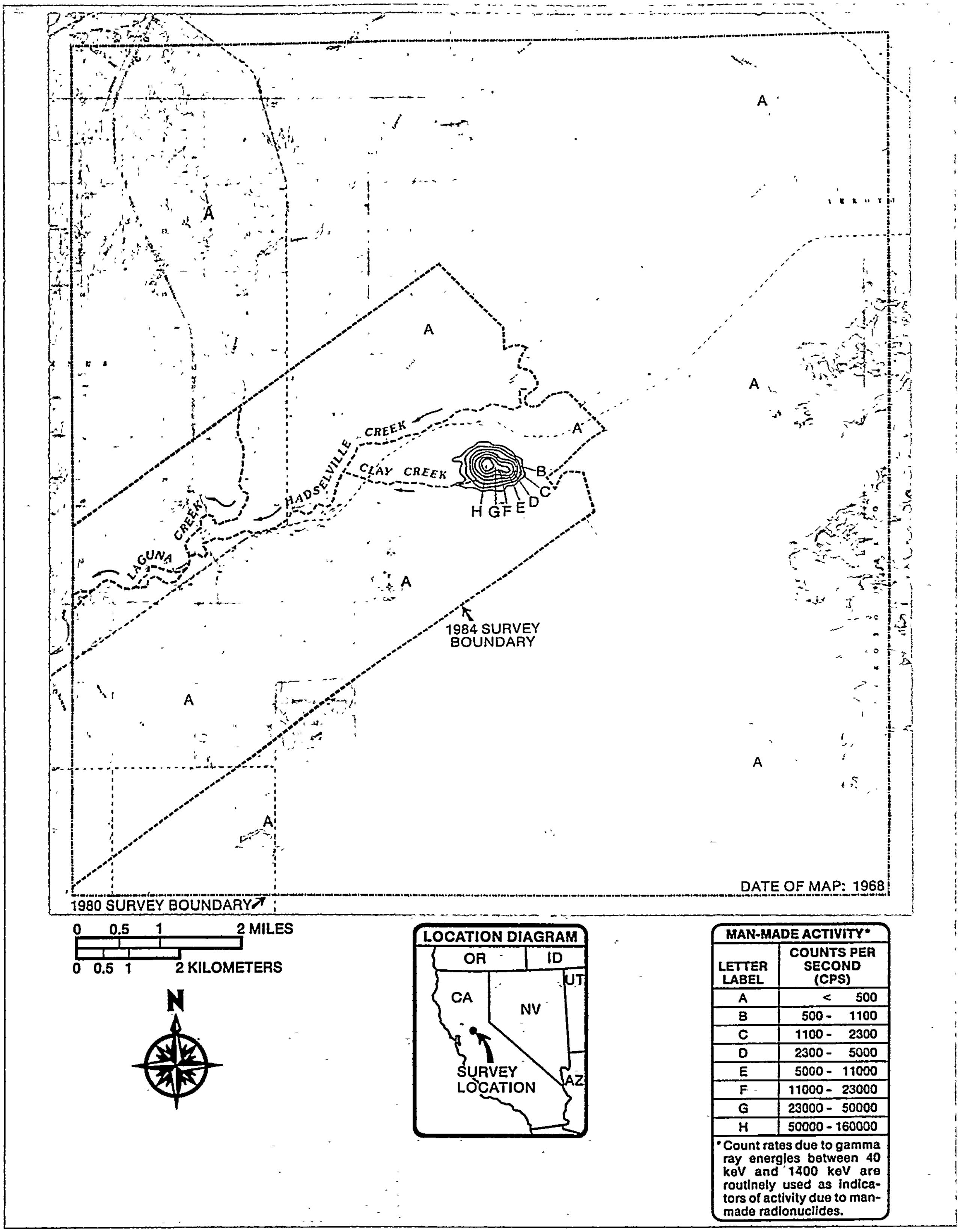
GROSS COUNT CONVERSION SCALE

LETTER LABEL	GAMMA EXPOSURE RATE AT 1 m LEVEL (μR/h)*
A	< 5
B	5 - 6.5
C	6.5 - 8
D	8 - 9
E	9 - 11
F	11 - 17
G	17 - 38
H	38 - 100
I	100 - 300
J	300 - 400

*Averaged over the detector's field-of-view at an altitude of 40 meters and extrapolated to the 1 meter level. Includes an estimated 3.7 μR/h cosmic ray contribution.

NOTE: BLUE CONTOUR LINES INDICATE INCREASED EXPOSURE RATE LEVELS THAT WERE NOT PRESENT DURING THE 1980 SURVEY.

FIGURE 5. *RANCHO SECO EXPOSURE-RATE MAP*



MAN-MADE ACTIVITY*

LETTER LABEL	COUNTS PER SECOND (CPS)
A	< 500
B	500 - 1100
C	1100 - 2300
D	2300 - 5000
E	5000 - 11000
F	11000 - 23000
G	23000 - 50000
H	50000 - 160000

* Count rates due to gamma ray energies between 40 keV and 1400 keV are routinely used as indicators of activity due to man-made radionuclides.

FIGURE 6. *RANCHO SECO 1980 MAN-MADE CONTAMINATION*

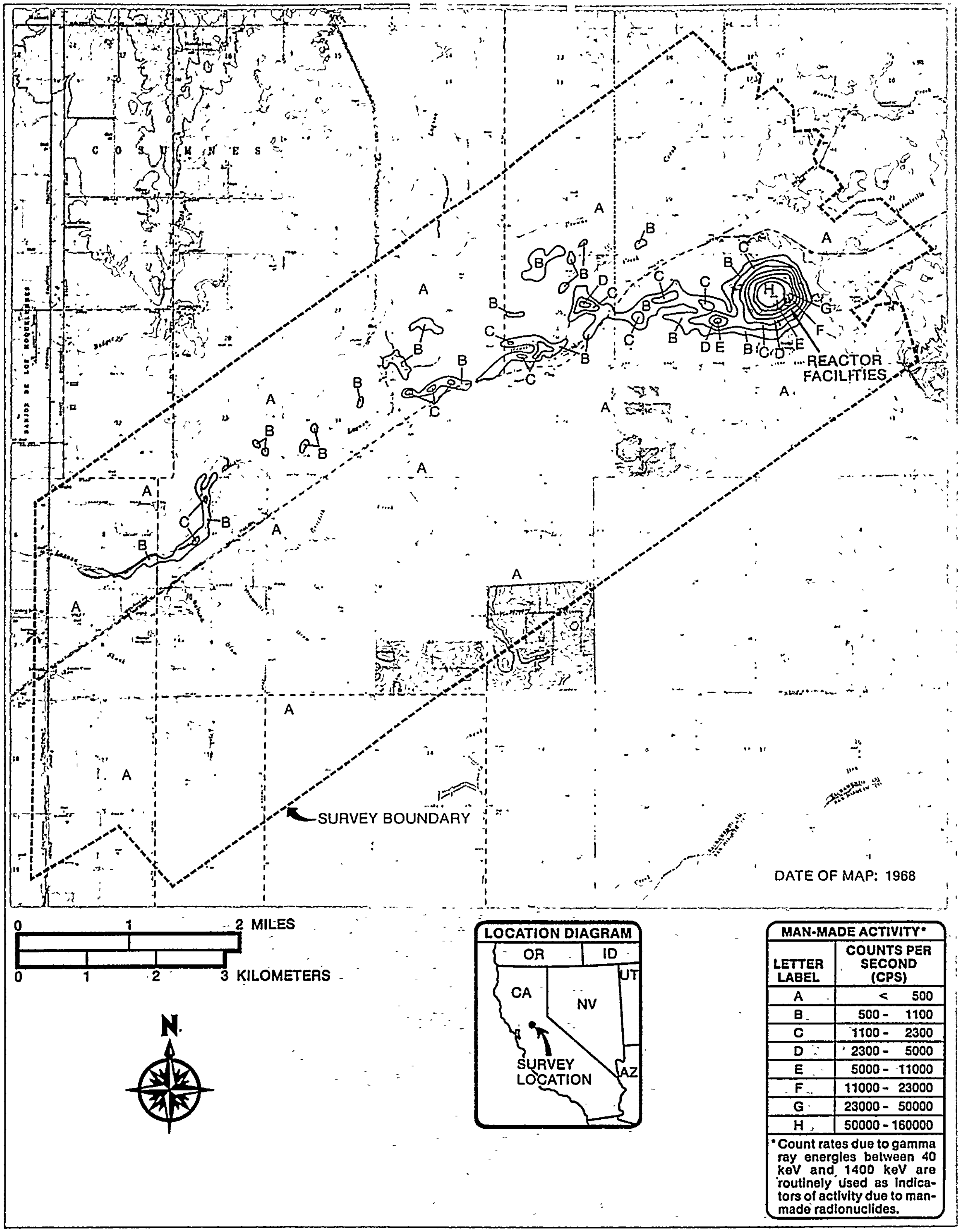


FIGURE 7. *RANCHO SECO 1984 MAN-MADE CONTAMINATION*

Examination of spectra collected over the areas of elevated MMGC rates verified that the contamination was primarily due to ^{137}Cs, with some areas also showing detectable concentrations of ^{134}Cs and ^{60}Co. Figure 8 is a spectrum collected over an area contaminated with these three radionuclides.

5.0 RADIONUCLIDE-SPECIFIC INFORMATION FROM AERIAL SURVEY DATA

While the MMGC provides an indication of radioactive contamination, positively identifying contamination sources is important for activities such as predicting risks to the public. Aerial survey data are summed and examined for spectral peaks due to various radionuclides that could reasonably be expected at the survey site. Annihilation radiation at 511 keV was also examined as this line was prominent in previous survey data from boiling-water reactor sites.

Spectral-stripping techniques were used to analyze aerial radiation data. (Peak fitting is not used because peak shapes from the NaI[T*l*] detectors are broad and frequently overlap.) Spectra from areas of interest (usually those with significant MMGC levels) are analyzed by subtracting, channel-by-channel, a spectrum of a known background area. These spectra are sums of all spectral data acquired within the area:

$$\text{Difference Spectrum}_i = C_{i,\text{site of interest}} - K_{diff} \cdot C_{i,\text{background}}$$

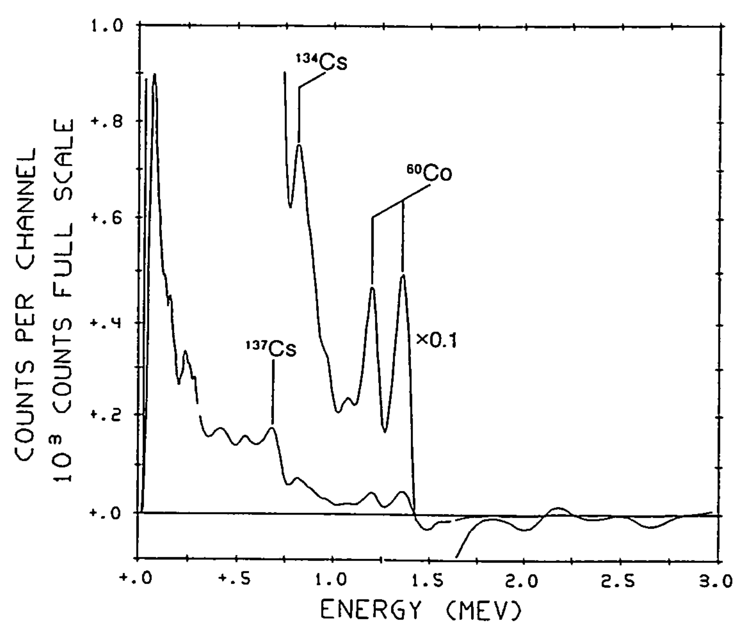


FIGURE 8. ***RANCH SECO SPECTRUM FROM CONTAMINATED AREAS***