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AN AERIAL RADIOLOGICAL SURVEY OF FRENCHMAN FLAT AT THE NEVADA TEST SITE

SOUTHERN NEVADA

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DATE OF SURVEY: JANUARY 1982

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SOUTHERN NEVADA

DATE OF SURVEY: JANUARY 1982

R. C. Hopkins

REVIEWED BY

H. W. Clark, Jr., Manager
Radiation Science

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ABSTRACT

An aerial radiological survey was conducted over Frenchman Flat at the Nevada Test Site from January 27 to February 7, 1982. Parallel lines were flown at an altitude of 100 feet (30 meters) above ground level with line spacing intervals of 200 feet (61 meters) over a 170-square-mile (440-square-kilometer) area. This covered both Frenchman Flat and the area of the Nellis Range Complex where a fallout deposition plume had exited the Nevada Test Site to the east. The aerial data obtained were reduced to a man-made radiation contour map and overlaid on a U.S. Geological Survey map. The survey detected the presence of fission and activation products.

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1.0 INTRODUCTION

An aerial radiological survey over Frenchman Flat, Area 5, at the Nevada Test Site (NTS) was conducted from January 27 to February 7, 1982. The NTS is approximately 60 miles (97 kilometers) northwest of Las Vegas, Nevada, with Frenchman Flat located in the southeast region on the border of the NTS and the Nellis Range Complex. The survey was conducted at the request of the U.S. Department of Energy, Nevada Operations Office (DOE/NV), and performed by personnel of the Remote Sensing Laboratory (RSL), operated for DOE (at the time of the survey) by EG&G Energy Measurements, Inc. (EG&G/EM).

One of RSL's primary missions is to maintain and manage an aerial surveillance program called the Aerial Measuring System (AMS).¹ Since its inception in 1958, AMS has continued a nationwide effort to document baseline radiological conditions surrounding nuclear-energy-related sites. These sites include power plants, manufacturing and processing plants, and research laboratories using nuclear materials. Frenchman Flat is of interest to DOE/NV as a location of past aboveground nuclear weapons activities.

2.0 SITE DESCRIPTION

The Nevada Test Site is operated by DOE/NV. The NTS covers approximately 1,350 square miles (3,500 square kilometers) of federally owned land and is surrounded on the north, east, and west by the Nellis Air Force Bombing and Gunnery Range. Frenchman Flat is located in Area 5, approximately 15 miles (24 kilometers) northeast of the main entrance to the NTS.

Frenchman Flat was the site of fourteen atmospheric and five underground nuclear detonations that took place between January 27, 1951, and March 26, 1968. Frenchman Flat is a 123-square-mile (318-square-kilometer) area consisting of a dry lake bed and an enclosed, desert valley basin almost entirely devoid of vegetation.

3.0 NATURAL BACKGROUND RADIATION

Natural background radiation originates from three main sources: radioactive elements present in the soil, airborne radon, and cosmic rays of extraterrestrial origin. Natural terrestrial radiation levels depend upon the type of soil and bedrock immediately below

and surrounding the point of measurement. Terrestrial gamma radiation originates primarily from the radioactive decay of elements found naturally in the soil and bedrock; namely, radioactive potassium and isotopes produced in the uranium and thorium decay chains. Local concentrations of these isotopes produce radiation levels at the surface typically ranging from 1 to 20 microroentgens per hour ($\mu\text{R/h}$).² Areas with high-uranium and/or -thorium concentrations may exhibit slightly higher levels.

One member of both the uranium and thorium radioactive decay chains is radon, a noble gas that can both diffuse through the soil and travel through the air. The level of airborne radiation due to radon and its daughter products depends on a variety of factors for a given location including meteorological conditions, mineral content of the soil, and soil permeability. Typically, airborne radiation from radon and its progeny contributes from 1 to 10 percent of the natural background radiation levels.

Cosmic rays (high-energy radiation originating from outer space) interact with elements of the earth's atmosphere and soil, producing an additional source of gamma radiation. Across the United States, radiation levels due to cosmic rays vary with altitude from 3.3 $\mu\text{R/h}$ at sea level to 9.8 $\mu\text{R/h}$ at elevations of 9,000 feet (2,700 meters).³

Cesium-137 (^{137}Cs), a byproduct of nuclear fission, is also present in trace amounts worldwide as a result of fallout from aboveground nuclear weapons tests conducted prior to the early 1960s by the United States and the former Soviet Union and, subsequently, by China and France. Exposure rates due to ^{137}Cs in the environment are typically less than 1 $\mu\text{R/h}$.⁴

4.0 SURVEY EQUIPMENT

The low-altitude aerial survey was flown using a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter shown in Figure 1. The twin-engine helicopter carried a crew of two and a lightweight version of the Radiation and Environmental Data Acquisition and Recorder System, Version IV (REDAR IV). The helicopter flew at an altitude of 100 feet (30 meters) above ground level (AGL) using a grid pattern composed of parallel flight lines spaced 200 feet (61 meters) apart to cover the 170-square-mile (440-square-kilometer) survey area. Refer to Appendix A for a list of the survey parameters.

FIGURE 1. MBB BO-105 HELICOPTER WITH DETECTOR PODS

Detector pods were mounted on the sides of the skid rack on the helicopter. The two detector pods contained a total of twenty cylindrical (5 inches in diameter by 2 inches thick), thallium-activated sodium iodide, NaI(Tl) , gamma-ray detectors.

The energy signals produced through the interaction of gamma rays with the NaI(Tl) crystals were analyzed by successive-approximation, analog-to-digital convertors in the REDAR IV system. The REDAR IV is a multi-microprocessor data-acquisition and real-time analysis system designed to operate in the severe environments associated with platforms such as helicopters, fixed-wing aircraft, and various ground-based vehicles. The system relays radiation and positional information in real time to the operator through video displays and multiple, light-emitting diode (LED) readouts. The gamma-ray energy spectrum, aircraft position, and weather data, such as ambient temperature and barometric pressure, are recorded at 1-second intervals on magnetic tape cartridges for postflight analysis with a ground-based minicomputer system.

The aircraft position was established using a microwave ranging system and a radar altimeter. The position was recorded on magnetic tape and directed into the steering indicator, which the pilot used to guide the aircraft along a predetermined set of flight lines.

5.0 GENERAL DATA REDUCTION

The primary objective of the Frenchman Flat survey was to map the deposition of radioactive debris from the Small Boy event. Data analysis was directed toward producing a man-made gross-count contour map. The spectral-window technique, which measures concentrations of specific nuclides, was used to

evaluate the gamma-fluence rate measurements made with NaI(Tl) detectors of the aerial measuring system. All of the aerial spectral data from the survey were examined using a spectral-window weighting method called the man-made gross-count (MMGC) algorithm. The specific data-reduction techniques and equations used in the survey are described in Appendix B.

6.0 SURVEY RESULTS

The principal result of this aerial survey is the MMGC contour map illustrated in Figure 2. The MMGC method indicates the presence of man-made gamma emitters whose gamma energies originate between 38 and 1,394 keV. This energy range includes most of the long-lived, man-made gamma emitters. The contour plot shows six general locations where man-made gamma emitters occur at Frenchman Flat. Because the MMGC analysis method does not identify particular isotopes, a net energy spectrum from each location is presented in Figure 3 and labeled Spectra 1 to 9. The primary isotopes are americium-241 (^{241}Am), ^{137}Cs , europium-152 (^{152}Eu), and cobalt-60 (^{60}Co).

The MMGC contour map indicates only the location and magnitude of fission and activation products. Generally, natural isotopes are not contoured in this process unless they have been concentrated by human industry.

The second-by-second MMGC algorithm has been averaged over three adjacent raw data points, representing 350 feet (107 meters) along the flight line, which affects the spatial resolution very little since the detector field-of-view is about 400 feet (122 meters). In Figure 2, the solid contour lines represent a 3-point average. The dashed contour lines, however, represent a 15-point average of 1,800 feet (550 meters) along the one-flight line and are therefore of much poorer resolution. The purpose of the 15-point average was to lower the minimum detectable activity and thus examine the maximum extent of fallout from any test event.

The fallout from the Small Boy event extends 12 miles (19 kilometers) to the eastern edge of the survey area and is a maximum of 2 miles (3 kilometers) wide. Gamma energy Spectra 1 and 2 indicate only ^{137}Cs and ^{241}Am in the fallout. The western circular part of the Small Boy pattern, Spectrum 3, contains mostly ^{152}Eu , a soil neutron activation product. This area, which is adjacent to ground zero (GZ), shows the

NOTE

The numbered north-south lines are gamma energy spectra locations (spectra presented in Figure 3).

Background in the eastern portion of the map is 510 cps. Background in the western portion is 1,100 cps.

CONVERSION SCALE	
MAN-MADE GROSS COUNT (CPS)	LETTER LABEL
510	A
< 510	B

FIGURE 2. FRENCHMAN FLAT MAN-MADE GROSS-COUNT CONTOUR MAP

FIGURE 3. FRENCHMAN FLAT NET GAMMA ENERGY SPECTRA

FIGURE 3. FRENCHMAN FLAT NET GAMMA ENERGY SPECTRA (continued)

presence of ^{152}Eu , and Spectrum 3a shows the absence of ^{241}Am . The ^{241}Am is probably masked by the ^{152}Eu . Note that the lowest dashed contour level has been discontinued near the GZ, because the loss of spatial resolution did not seem advantageous to present in the area of the GZ where activity rapidly changes.

Activity estimates may be made from the MMGC if the energy content of spectra is simple and the number of isotopes is small. The Small Boy fallout contains only ^{241}Am and ^{137}Cs , and a detailed examination of Spectrum 2 shows that the ^{241}Am and ^{137}Cs photopeaks contribute 8 percent and 11 percent of the MMGC, respectively. Because the ^{241}Am and ^{137}Cs concentrations are readily computed from the net photopeak count rates, values for these concentrations can be obtained from the MMGC algorithm. Table 1 lists some factors that convert the ^{241}Am and ^{137}Cs count rates to concentrations.

The Radioactive Waste Management Site (RWMS) is about 4 miles (6 kilometers) north-northwest of the Small Boy GZ and exhibits low-level MMGC activity (1,100 cps). Spectrum 4 shows a small excess of thallium-208 (^{208}Tl), a member of the natural thorium-232 (^{232}Th) decay chain, indicating a possible enrichment

over its natural abundance. The ^{241}Am signature in Spectrum 4a is quite strong and is the dominant man-made radioisotope present. Spectrum 5, from the western part of the storage area, indicates the presence of ^{152}Eu and ^{137}Cs with the possibility of some ^{60}Co .

Kay Blockhouse, on the underlying map about 2.5 miles (4 kilometers) northwest of the Small Boy GZ, exhibits residual ^{152}Eu as indicated by Spectrum 6 with no other isotopes visible. Sugar Bunker does not have a clear isotopic signature in Spectrum 7 though the MMGC suggests that some anomalous activity exists there.

Pinstripe, an underground nuclear test in 1966, vented and left a fallout field extending into the Massachusetts Mountains. The mountains precluded surveying the entire fallout pattern at the time of this survey. The inset in Figure 2 illustrates the compactness of the radioactivity in this region. Spectrum 8 shows that the fallout is predominantly ^{137}Cs . Spectrum 9 demonstrates that ^{241}Am was fairly strong at the unidentified location, 3 miles (5 kilometers) north of the Small Boy GZ. No other isotopic gammas were identifiable in the gamma energy spectrum.

Table 1. Aerial Gamma System Sensitivity Conversion Factors

Isotope	Peak Energy (keV)	α^b (cm ⁻¹)	Large Area Source ^a		Point Source	
			$(\mu\text{Ci}/\text{m}^2)^c$ cps	$(\text{pCi}/\text{g})^b$ cps	(mCi/g) cps	(mCi/g) cps
^{241}Am	60	∞	0.0022	NA ^d	0.012	0.031
		0.2	0.0085	0.11		
		0.1	0.015	0.097		
		0	NA	1.22		
^{137}Cs	662	∞	0.0007	NA	0.0065	0.013
		0.2	0.0016	0.021		
		0.1	0.0024	0.016		
		0	NA	0.010		

^a Area of source larger than a circle whose diameter is twice the survey altitude.

^b Activity distribution of the form $A = A_0 e^{-\alpha z}$; z = depth in soil.

^c Surface concentration A_0 in Footnote b.

^d NA: Not applicable.

7.0 SUMMARY

An aerial radiological survey of Frenchman Flat, Nevada, was conducted from January 27 to February 7, 1982. An area of 170 square miles (440 square kilometers) was surveyed at an altitude of 30 meters (100 feet) above ground level using a grid pattern consisting of parallel flight lines nominally spaced 200 feet

(61 meters) apart. Spectral analysis of the data revealed the presence of man-made radioisotopes related to nuclear weapons testing activities. The survey mapped a large fallout pattern containing ^{241}Am and ^{137}Cs , which extended 12 miles (19 kilometers) to the east, off the NTS and onto the Nellis Range Complex.

APPENDIX A

SURVEY PARAMETERS

Survey Site:	Frenchman Flat, Nevada Test Site
Survey Dates:	January 27 to February 7, 1982
Survey Altitude:	100 feet (30 meters)
Line Spacing:	200 feet (61 meters)
Line Direction:	North-South
Lines Surveyed:	417
Ground Speed:	70 knots (36 meters per second)
Survey Coverage:	Approximately 170 square miles (440 square kilometers)
Survey Aircraft:	MBB BO-105
Navigation System:	MRS/INU
Acquisition System:	REDAR IV
Detector Array 1:	Twenty 5- × 2-inch NaI(Tl) Detectors
Detector Array 2:	One 5- × 2-inch NaI(Tl) Detector
Project Scientist:	R. Reiman
Data Analyst:	T. Hendricks

APPENDIX B

GENERAL DATA ANALYSIS METHODS

A few methods used to treat gamma energy spectra as measured by NaI(Tl) are discussed below.

Gross Count Rate

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

$$GC = \sum_{E=38 \text{ keV}}^{3026 \text{ keV}} ES \quad (\text{B-1})$$

where

E = energy

ES = energy spectrum

This integral includes all the natural isotope gammas from ^{40}K , ^{238}U , and ^{232}Th (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, where 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 micro-roentgens per hour ($\mu\text{R/h}$) for natural radioactivity. The conversion equation is as follows:

$$E(1m) = \frac{GC(A) - B}{1167} \cdot e^{0.00179A} \quad (\text{B-2})$$

where

$E(1m)$ = exposure rate extrapolated to 1 meter AGL ($\mu\text{R/h}$)

A = altitude in feet

$GC(A)$ = gross count rate at altitude A (cps)

B = cosmic, aircraft, and radon background (cps)

B is obtained either from flights over bodies of water, where the terrestrial count rate is absent or from flights at several altitudes over the same uniform area of land where this background count rate can be calculated. 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 nonnatural, gamma sources may be found from increases in the gross count rate. However, subtle anomalies are difficult to find using the gross count rate in areas where its magnitude is variable due, for example, to geological or ground-cover changes. Differential methods for energy data reduction, as discussed in the next section, are used to increase the sensitivity of the aerial system to anomalous gamma emitters.

Man-Made Gross-Count Search Method

The aerial system produces a gamma energy spectrum each second where the gross count 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:

$$\sum_{E=a}^b ES / \sum_{E=b}^c ES = \text{Constant} = K \quad (\text{B-3})$$

where

$$a < b < c$$

The window, $a-b$, is placed where gamma rays from a man-made emitter would occur in the spectrum. The result of Equation B-3 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.

$$S = \sum_{E=a}^b ES - K \sum_{E=b}^c ES \quad (\text{B-4})$$

The net signal, S , is zero unless anomalous gamma rays are measured in the window defined by a and b .

Equation B-4 is used to locate specific isotopes by setting a and b to enclose the photopeak of the particular gamma from the isotope of interest. For the general case when a man-made isotope is sought, a , b , and c are set at 38 keV, 1,394 keV, and 3,026 keV,

respectively. Because most long-lived, man-made isotopes emit gammas in the energy range of 38 keV to 1,394 keV, Equation B-4 becomes a general search tool and is called the man-made gross count.

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