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EGG-10282-1004
UC-41
JUNE 1983

I-11482

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**REMOTE
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DEPARTMENT OF ENERGY BY EG&G

EGG--10282-1004

DE84 000440

AN AERIAL RADIOLOGICAL SURVEY OF

AREA 11

NEVADA TEST SITE

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Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS price codes

Printed copy: A02
Microfiche copy: A01

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ABSTRACT

An aerial radiological survey of Area 11's Plutonium Valley was conducted at the Nevada Test Site from 18 to 30 January 1982. Contour maps representing terrestrial exposure rates and soil concentrations of transuranics, ^{235}U and ^{137}Cs are presented on an aerial photograph. Inventories of the locale's transuranic and uranium activities are also included. EG&G performed this work at the request of the Office of Nuclear Safety, United States Department of Energy, in support of the Nevada Applied Ecology Group.

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1.0 INTRODUCTION

An aerial radiological survey of Plutonium Valley was conducted in Area 11 at the Nevada Test Site (NTS) from 18 to 30 January 1982. The survey was performed at the request of the Office of Nuclear Safety, United States Department of Energy (DOE), in support of the DOE's Nevada Applied Ecology Group. The survey utilized the DOE's Aerial Measuring System (AMS), which is operated for the DOE by the Energy Measurements Group of EG&G.¹ The purposes of this survey were to: (1) map the spatial extent and magnitude of all detectable gamma-emitting contaminants visible at the surface; (2) map the estimated external exposure rate due to all radionuclides present; and (3) determine the typical exposure rate due to natural background.

The results of this survey are reported as isopleth contour maps representing total terrestrial exposure rate and soil concentrations for ^{241}Am (a ^{241}Pu daughter), ^{235}U and ^{137}Cs (a fission product). An inventory of total ^{241}Am and ^{235}U activity present is also reported.

Previous aerial radiological surveys at the NTS were performed using a fixed-wing aircraft. During 1970 and 1971 a total of 14 areas, excluding Area 11, was flown. The 14 areas included all of the NTS accessible to a fixed-wing aircraft operating at 91 m (300 ft) above ground level.² These surveys employed an array of fourteen 10-cm diameter by 10-cm thick NaI(Tl) detectors.

A new series of aerial radiological surveys has been initiated using a helicopter-borne system. The new detection system, comprised of twenty 12.7-cm diameter by 5-cm thick NaI(Tl) detectors, coupled with lower altitude operation and reduced ground speed achieved by the helicopter, has resulted in improved sensitivity and spatial resolution over the earlier fixed-wing surveys. Areas surveyed utilizing the improved aerial survey systems have included:

Areas 25 and 26	September 1976	(Ref. 3)
Tonopah Test Range	February 1977	(Ref. 4)
Area 13	December 1977	(Ref. 5)
Yucca Flat (Areas 1-4, 6-10, 12, 15 & 17)	August 1978	(Ref. 6)
Areas 18 & 20	October 1979	(Ref. 7)

Prior to the present survey, Area 11 had been used to test and demonstrate the efficacy of searching for and detecting the presence of

plutonium with a helicopter-borne system.⁸ These earlier activities did not produce data of sufficient quantity or quality to qualify them as actual aerial radiological surveys.

Proper interpretation of the results of an aerial survey requires an appreciation of several fundamental characteristics of aerial survey data. An airborne detection system averages the flux from terrestrial sources of gamma photons over a large area (several hectares). Hence, aerial measurements may significantly underestimate the intensity of localized sources of radiation as compared to ground-based measurements. This effect becomes increasingly pronounced as the spatial extent of a source is reduced with respect to the large area averaged by the airborne detector. Soil concentrations of radionuclides estimated from aerial survey data presume a relatively accurate knowledge of the depth distribution of the radionuclides. Generally, the depth distribution is not well established, so the resulting soil concentrations may be of considerable uncertainty. Also, the estimation of external gamma exposure rates from aerial survey data presumes that the mean energy for the spectrum of a particular radionuclide causing an anomaly does not greatly differ from the mean energy for a background radiation spectrum. Because of this, the exposure rate estimated near an anomaly due to ^{241}Am , as is the case in the present survey, will be overestimated. Finally, aerial detection systems are also sensitive to airborne sources of radiation (e.g., atmospheric radon gas and daughters or natural sources aboard the aircraft) and to cosmic rays. Estimates of both the airborne sources and cosmic ray contributions have been extracted from the results. Therefore, this survey's results represent terrestrial sources only.

2.0 SURVEY SITE

Area 11 is located between the eastern boundary of the Nevada Test Site and Yucca Lake. It is bounded by Area 3, Area 6 and the Nellis Air Force Range, as shown by the black dashed lines in Figures 1 through 3. The southern boundary of Area 11 with Area 5 (not shown) lies approximately 5 km (3 mi) south of French Peak.

Plutonium Valley, the region of Area 11 included in the present survey, is denoted by the white dashed lines in the figures. This region spans an area of approximately 33 square km (approximately

Figure 1. ISORADIATION CONTOURS OF TERRESTRIAL GAMMA RAY EXPOSURE RATE, OBTAINED DURING JANUARY 1982, SUPERIMPOSED ON AN AERIAL PHOTOGRAPH OF PLUTONIUM VALLEY AT THE NEVADA TEST SITE. Data obtained in the cross-hatched area cannot be contoured, but are sufficient to indicate gross trends.

Figure 2. ISOPLETH CONTOURS OF ²⁴¹Am AND TOTAL TRANSURANIC SOIL CONCENTRATIONS, OBTAINED DURING JANUARY 1982, SUPERIMPOSED ON AN AERIAL PHOTOGRAPH OF PLUTONIUM VALLEY AT THE NEVADA TEST SITE. The numbered boxes define the corresponding inventory zones. Data obtained in the cross-hatched area cannot be contoured, but are sufficient to indicate gross trends.

CONVERSION SCALE				
LETTER LABEL	SOIL CONCENTRATIONS ^a			
	²³⁵ U		¹³⁷ Cs	
	$\frac{\text{p Ci}}{\text{g}^b}$	$\frac{\text{n Ci}}{\text{m}^2}$	$\frac{\text{p Ci}}{\text{g}^b}$	$\frac{\text{n Ci}}{\text{m}^2}$
A	< 4	< 270	< 1	< 200
B	4 - 8	270 - 630	1 - 2	200 - 400
C	8 - 12	630 - 970	2 - 3	400 - 600

^a Soil concentrations inferred from respective net count rates observed at 30 m above ground level. Concentrations applicable only as averages over large areas comparable to detector's field-of-view. Concentration conversion factors presume a 2.5 cm or 10 cm relaxation depth for ²³⁵U or ¹³⁷Cs, respectively.

^bTop 5 cm.

Figure 3. ISOPLETH CONTOURS OF ^{235}U AND ^{137}Cs SOIL CONCENTRATIONS, OBTAINED DURING JANUARY 1982, SUPERIMPOSED ON AN AERIAL PHOTOGRAPH OF PLUTONIUM VALLEY AT THE NEVADA TEST SITE. The presence of ^{235}U and ^{137}Cs is denoted by white and black contours, respectively. The green box corresponds to the ^{235}U inventory zone.

12 square mi). The Area 11 survey encompassed all flyable areas within Plutonium Valley, including a portion extending into Area 3. However, the present survey did not include the portion of Area 11 south of French Peak. That area has been surveyed, but the results will be presented as part of the Area 5 survey report.⁹

A series of four nuclear "safety shots" was conducted in Plutonium Valley as part of Project 56. The blast centers of the four tests are identified in Figures 1 through 3 by the letters A, B, C and D. The tests were conducted on November 1, 3 and 5, 1955 and January 18, 1956 at Sites A, B, C and D, respectively. No measurable yield was reported for the tests conducted at Sites A, B and C. However, a "very slight" yield was reported for the test at Site D.¹⁰ The area surrounding these test sites exhibits significant contamination by various transuranic isotopes, hence access to that area has been restricted. No other announced nuclear testing has been conducted in Plutonium Valley; present utilization is limited to a technical facility located well to the south of the blast centers.

Five other announced nuclear tests have been conducted in the southern portion of Area 11 outside the boundaries of the present survey. These sites have been surveyed and, as previously mentioned, will be reported as part of Area 5's survey.

An extension of the principal survey area into the Nellis Air Force Range, encompassing nearly 30 square km (approximately 12 square mi), was surveyed in a cursory fashion. This area is denoted by cross-hatching in Figures 1 and 2. The purpose of the extension was to verify that no anomalous radioactivity exists in that area.

3.0 SURVEY EQUIPMENT AND PROCEDURES

The aerial data acquisition system employed in the Area 11 survey was comprised of a detector package and a sophisticated data acquisition system (REDAR IV)* on board a high-performance helicopter.** The detector package consisted of an array of twenty 12.7-cm diameter by 5-cm

thick (5 in. × 2 in.) NaI(Tl) scintillation detectors, as previously mentioned. The detector array was distributed equally between two cargo pods mounted on the exterior of the helicopter. Signals from nineteen of the detectors were summed to produce a single spectrum with high sensitivity. The twentieth detector was used to provide a spectrum with lower sensitivity for use in areas exhibiting greatly enhanced levels of radiation. Both spectra are simultaneously acquired and recorded. Hence, the count rate operating range of the data acquisition system is greatly extended and makes it possible to invoke various data integrity safeguards.

The REDAR IV acquires, monitors, displays and records on magnetic tape all survey data for each second of real time. The data stored on magnetic tape consist of the dual spectral data and environmental data such as outside air temperature and absolute barometric pressure. The system also acquires positional data from a microwave ranging system (MRS), a radar altimeter and an inertial navigation system. The REDAR IV processes the first two types of positional data to provide a real-time navigational display for the helicopter pilot.

Daily flight and field data analysis operations were based at the helicopter pad located at the Area 6 control point (CP). Plutonium Valley was surveyed by flying a regular grid of 96 parallel flight lines spaced 46 m (150 ft) apart 30 m (100 ft) above ground level. The helicopter maintained a relatively constant ground speed of 30 m/s (60 knots). The central flight line was oriented so as to join together all four blast sites. A series of nine lines was also flown in the Nellis Air Force Range. These lines were flown at 60 m (200 ft) above ground level and irregularly spaced 90 to 200 m (300 to 666 ft) apart. The Nellis data cannot be contoured, but are adequate to indicate if more detailed survey data are required.

Diagnostics were performed routinely to assure data integrity and facilitate analysis. Detector backgrounds due to airborne sources and cosmic ray contributions were estimated from data obtained over a fixed land test line at three widely spaced altitudes. Variations of the radon contribution were monitored by repeating measurements over the test line at survey altitude before and after each helicopter flight. The quality and calibration of the energy spectra acquired by the REDAR IV were checked immediately prior to and following each flight. The equipment and procedures

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

** Messerschmitt-Bolkow-Blohm (MBB) BO-105.

typically utilized in an aerial radiological survey are discussed by Boyns¹¹ in much greater detail.

4.0 DATA REDUCTION AND ANALYSIS PROCEDURES

The principal products of the analysis of the Area 11 survey data are isopleth contour maps of the total terrestrial exposure rate and soil concentrations for ^{241}Am , ^{235}U and ^{137}Cs . The basic procedures involved in constructing these products from the dual energy spectra data are briefly reviewed below.

The raw spectral and positional data returned by the helicopter were first examined in the field on the mobile data processing system. A rough contour map of ^{241}Am soil concentration was also initiated in the field to demonstrate data quality and to indicate areas where further survey work might be necessary. After its return to Las Vegas the data were processed to produce all four principal products and the inventories of total radioactivity of the major contaminants. All necessary refinements of the data were also applied at this stage of processing. These refinements included subtraction of improved estimates of background, application of more accurate altitude and dead time corrections, and enhancement of the positional data. Finally, the contours were superimposed on properly scaled aerial photographs.

4.1 Spatial Resolution

As previously mentioned, aerial detection systems average over large areas. This average is a result of the limited angular resolution of the detectors and the motion of the helicopter. The angular resolution of the detectors depends primarily on their angular response, air attenuation of photons in the air and soil and, of course, detector-source separation. The former two factors are quite dependent upon photon energy. For instance, due to lack of collimation the angular response of the detectors is nearly isotropic for photons of energies greater than approximately 1.5 MeV. Near 60 keV, however, the angular response is almost a cosine function due to the physical shape and arrangement of the detectors.

Similarly, air attenuation of photons is negligible over distances comparable to the aircraft altitude

for the higher energy photons, but quite significant for the 60-keV photons. These effects result in a detector field-of-view that varies considerably with energy. For a detector at an altitude of 30 m, approximately 63% ($1/e$) of the observed ^{40}K (1464-keV) count rate originates from a 140-m diameter area directly beneath the detector (1.5 hectares). Yet an area only 60 m in diameter (0.3 hectares) gives rise to the same fraction of counts due to the 60-keV ^{241}Am photons. The motion of the helicopter during the accumulation time (1 second) also contributes to averaging, as the helicopter has moved nearly 30 m. This averaging can be aggravated by smoothing the data to enhance sensitivity, if the distance traveled by the helicopter during the smoothing interval exceeds the detector's field-of-view. Hence, the three-second sliding interval average applied to the present data noticeably degrades resolution of the ^{241}Am contours along the direction of flight.

4.2 Exposure Rate Contours

The exposure rate contour map is constructed from the gross count observed in the measured energy spectra. The gross count is obtained from a single window defined to include all photopeaks in the entire energy spectrum due only to terrestrial sources after being corrected for counting losses and altitude variations. A window is defined as the sum of all counts observed between some maximum and minimum energies; the gross count window is 40 to 3000 keV. The gross count rate is then converted to exposure rate by application of a suitable conversion factor determined at a calibration range near Lake Mead in Arizona. The procedure is sufficiently accurate for most survey operations, since contributions to the gross count rate by the naturally occurring radionuclides are well distributed throughout the energy spectrum. Therefore, variations in relative concentrations do not greatly modify the mean energy per photon observed in the energy spectrum. However, exposure rates estimated in this way, near strong anomalies due to radionuclides that dramatically alter the mean energy per photon, may be substantially in error. For instance, exposure rates estimated in this manner near strong ^{241}Am anomalies may be overestimated by as much as 50%. But if an anomaly is localized, area averaging effects lead to a simultaneous underestimate. Hence, the exposure rates reported near anomalies as described above are imprecise. Yet exposure

rates in regions exhibiting only natural background are, typically, accurate to about 1 microrentgen per hour ($\mu R/h$).

4.3 Isotopic Concentration Contours

The contour map of soil concentration for a particular radionuclide is constructed from the net count rate observed in a prominent photopeak characteristic of that nuclide. This net count rate is obtained by subtracting an expected background count rate from the total count rate observed in the photopeak window. The expected background count rate is estimated from the ratio of the count rate observed in the photopeak window to that observed in one or more "background" windows when only natural background radiation is present.

These net count rates, measured at a given altitude, are then extrapolated to soil concentration by consideration of detector-source separation; attenuation due to air, soil and the detector assembly; source soil depth distribution; and detector angular response. Generally, all these quantities are well established except for the depth distribution of the source radionuclide in the soil. But the impact of this uncertainty upon the soil concentration per unit mass (e.g., $\frac{\mu Ci}{g}$) can be greatly reduced if the concentration is averaged over a depth of approximately 1.8 times the gamma ray mean free path in the soil. In this case a 100% error in the soil depth distribution leads to an uncertainty in soil concentration of only approximately 30%. Soil concentrations per unit area (e.g., $\frac{nCi}{m^2}$) are obtained by integrating the concentration per unit mass to infinite depth. Concentrations obtained in this way are subject to substantial error due to the depth distribution uncertainty. The same 100% error in depth distribution now leads to soil concentration uncertainties greater than 200%. Hence, confidence in the values reported on the soil concentration contour maps must be tempered by appreciation of the potential error due to soil depth distribution uncertainty in addition to the customary limitation due to averaging over large areas.

The extrapolation procedures are briefly reviewed in the following discussion for each isotope soil concentration contour map produced. A detailed description of this procedure is found in previously published reports.^{12,13}

4.3.1 Construction of the ^{241}Am Soil Concentration Contour Map

Construction of the contour map requires that the count rate due to the 60-keV ^{241}Am photopeak be extracted from the energy spectrum observed at every position within the survey area. The procedure utilized to extract this net count rate is outlined below in reference to Figure 4, in which a gamma photon energy spectrum exhibiting the 60-keV ^{241}Am photopeak is shown.

The ^{241}Am net count rate, N , is given by:

$$N = B - K \cdot (A + C)$$

where

A = count rate observed in the lower "background" window ($30 \leq E \leq 46$ keV)

B = count rate observed in the photopeak window ($46 \leq E \leq 74$ keV)

C = count rate observed in the upper "background" window ($74 \leq E \leq 90$ keV)

$K = \frac{B}{A + C}$ measured in an uncontaminated area for each flight (≈ 1.30)

However, as illustrated in Figure 4, some of the photopeak and a prominent "tail" also appear in the "background" windows. Most of the counts in the tail should actually be included in the photopeak count rate, since it is principally due to the escape of an iodine x-ray from the NaI(Tl) scintillator. However, a small portion of this tail (less than 10%) is due to Compton scattering and a ^{241}Am photopeak at 26 keV; these contributions should not be included. Hence, a correction was applied to adjust the photopeak count rate to include the iodine x-ray escapes, but not the impact of the Compton tail and 26-keV photopeak. This correction⁵ can be written:

$$CN = \left(\frac{1}{1 - K \cdot R} \right) \cdot N$$

$$\approx 1.40 \cdot N$$

where

CN = corrected count rate

N, K as before

R described below

Figure 4. SKETCH OF ENERGY SPECTRUM EXHIBITING ²⁴¹Am PHOTOPEAK

A net ^{241}Am energy spectrum was constructed by subtracting a normalized spectrum obtained in an area exhibiting only natural background radiation from the spectrum obtained in an area exhibiting significant ^{241}Am contamination. The ratio, R , of the count rates observed in the "background" windows to the photopeak window was computed from this net spectrum.

The data were also smoothed with a three-second sliding interval average and corrected for altitude variations and counting losses as previously mentioned.

Soil concentrations were obtained by rescaling the corrected net count rate by suitable conversion factors. The conversion factors, computed after Stuart¹⁴, were obtained for a soil density and transuranic relaxation depth reported as typical of Area 11.^{15,16,17}

The conversion factors applied were:

$$8.1 \times 10^{-2} \left(\frac{\text{pCi}}{\text{g}} / \text{cps} \right) (5 \text{ cm deep soil sample})$$

$$7.0 \left(\frac{\text{nCi}}{\text{m}^2} / \text{cps} \right)$$

Alternative conversion factors for soil concentration per unit mass can be selected from Figure 5 for various choices of relaxation depth and soil sample depth. Variation of estimated soil concentration per unit area as a function of relaxation depth is illustrated in Figure 6. Appendix A recounts key parameters used to construct the ^{241}Am soil concentration conversion coefficients.

4.3.2 Construction of the ^{235}U Soil Concentration Contour Map

The presence of ^{235}U is not characterized by a single photopeak but by a cluster of several photopeaks. Hence, a net count rate for this cluster was extracted to construct the ^{235}U contour map. The range of energy spanned in the extraction procedure included 72% of the photon flux due to ^{235}U decay. The limits of the range were empirically determined to provide maximum sensitivity to the presence of ^{235}U , but this choice is also slightly

sensitive to the presence of ^{241}Pu and daughters. The extraction procedure is reviewed below:

$$^{235}\text{U} \text{ net count rate} = N = A - K \cdot B$$

where

A = count rate observed in the photopeak cluster window. ($126 \leq E \leq 246 \text{ keV}$)

B = count rate observed in the "background" window ($246 \leq E \leq 3008 \text{ keV}$)

$K = \frac{A}{B}$ measured in an uncontaminated area
 ≈ 0.44

As customary, the data were smoothed with a three-second sliding interval average and corrected for altitude variations and counting losses.

Soil concentrations were estimated from a conversion factor computed assuming all flux to be of an energy of 186 keV, the location of the most prominent photopeak at the center of the window. Conversion factors computed for the minimum and maximum energies in the window did not differ sufficiently to warrant a weighted average of values computed for each photopeak. The relaxation depth, soil sample depth and soil density were the same as those used for the ^{241}Am calculation. Expected conversion factor uncertainties may be considerably greater than those reported for ^{241}Am .

The values applied were:

$$2.9 \times 10^{-2} \left(\frac{\text{pCi}}{\text{g}} / \text{cps} \right)$$

$$2.5 \left(\frac{\text{nCi}}{\text{m}^2} / \text{cps} \right)$$

The key parameters are reviewed in Appendix A.

4.3.3 Construction of the ^{137}Cs Soil Concentration Contour Map

Construction of the ^{137}Cs contour map follows a procedure exactly analogous to that employed

Figure 5. ²⁴¹Am SOIL CONCENTRATION CONVERSION FACTORS

Figure 6. ²⁴¹Am AREA CONCENTRATION CONVERSION FACTORS

for the ^{241}Am map. In this case the window energy ranges become:

A = count rate in lower "background" window
($518 \leq E \leq 590$ keV)

B = count rate in 662 keV photopeak window
($590 \leq E \leq 722$ keV)

C = count rate in upper "background" window
($722 \leq E \leq 794$ keV)

$K = \frac{B}{A + C}$ measured in an uncontaminated
area (≈ 0.934)

The customary smoothing and corrections have been applied to the data. A correction factor of 1.6 has been applied to the photopeak count rate as previously discussed in regard to ^{241}Am .

The soil concentration was computed for the 662-keV photopeak, assuming a soil depth distribution of 10 cm and a sample depth of 5 cm. The conversion coefficient used for the final results was an average of that computed for an isotropic and a cosine detector response. This has been shown to be a good approximation for 662-keV gamma rays. The values used for the reported result are:

$$1.5 \times 10^{-2} \left(\frac{\text{pCi}}{\text{g}} / \text{cps} \right)$$

$$2.8 \left(\frac{\text{nCi}}{\text{m}^2} / \text{cps} \right)$$

Although the accuracy of the soil concentrations may be limited due to uncertainties in depth distribution and spatial extent of the contamination, the contours are valid indicators of the presence of ^{137}Cs in excess of typical background concentrations.

Key parameters associated with the ^{137}Cs contour map are also reviewed in Appendix A.

4.4 Isotope Inventory

A desirable result of extracting isotopic soil concentrations from aerial data is the estimation of the total activity present in a particular region of interest. Inventories obtained from aerial measurements, with their superior averaging over large

areas, can actually achieve better estimates than those utilizing ground-based measurements, especially in areas having highly variable activity.

An inventory is simple to perform. First, the area averaged net count rate for the isotope of interest is determined. This is done by integrating the net count rate observed at each point within the region of interest over that region and renormalizing by the number of points for which data were acquired in that region. Hence, the total activity in the region is merely the product of the area enclosed in the inventory region, the area averaged net count rate, and the soil concentration conversion factor per unit area, determined as described earlier. Accuracy of this procedure is limited principally by the precision of the soil concentration conversion factor coefficient.

5.0 PRESENTATION AND DISCUSSION OF RESULTS

The results of the aerial radiological survey of Plutonium Valley are presented in Figures 1, 2 and 3 as isopleth contours, representing exposure rate or isotope concentrations superimposed on an aerial photograph. The external exposure rate due to gamma radiation from terrestrial sources is presented in Figure 1 in units of $\mu\text{R/h}$ extrapolated to 1 m above ground level. Total exposure rate can be estimated by including a cosmic ray exposure rate of approximately $5.1 \mu\text{R/h}$. The isopleth contours representing ^{241}Am and transuranic soil concentrations, extrapolated from the aerial data, are presented in Figure 2. Contours representing ^{235}U and ^{137}Cs soil concentration are shown jointly in Figure 3. Soil concentrations are reported in both pCi/g and nCi/m² for the soil characteristics reported as typical for Area 11. Inventories of soil contamination for both ^{241}Am and ^{235}U are also reported.

5.1 Terrestrial Exposure Rate Contour Map

The exposure rate contour map is somewhat featureless and dominated only by variations in natural background radiation. Anomalies are observed only at three of the blast centers and at a curious area of very low background exposure rate.

Exposure rates due to natural terrestrial background radiation are observed to vary over a wide

range; primarily between 10 and 18 $\mu\text{R/h}$ with an average over the survey area of 16 $\mu\text{R/h}$. Exposure rates observed in the northern portion of the survey area tend to be somewhat greater, 2 to 4 $\mu\text{R/h}$, than those observed in the south. The area exhibiting an anomalously low exposure rate is denoted as Location 1 in Figure 1. This anomaly is located near the site of a former instrument or camera station, where some excavation is evident. Therefore, the low exposure rate may be due to removal of more naturally radioactive overburden or to the importation of fill possessing much lower concentrations of natural radionuclides.

No contamination is evident in the Nellis Air Force Range extension or in the vicinity of the LANL technical facility. Natural terrestrial exposure rates are observed to range from 10 to 14 $\mu\text{R/h}$ near the technical facility.

Exposure rates near each of the blast centers are also reported. However, the values are subject to the accuracy limitations discussed in Section 4.2. Hence, these results should be used for comparison and qualitative descriptions only. Very little excess exposure rate can be observed at blast site A. Contamination in that area leads only to a minor local distortion of the E-level contour. The presence of excess radioactivity is, however, apparent at blast sites B, C and D. There is no evidence in the exposure rate contours to suggest the existence of a plume or any other type of contamination migration from the blast sites.

5.2 Transuranic Soil Concentration Contour Map

The presence of plutonium is difficult to establish directly from aerial measurements as performed in the present survey. However, the concentration of these transuranics can be inferred from aerial measurements of ^{241}Am soil concentration and known ratios of transuranic activity to ^{241}Am activity, as established from soil sample analyses. The ratios of Pu to Am are reported to range from 5.4 to 8.1 for soil samples obtained in Area 11.¹⁶ A value of 5.8, probably most representative, was utilized to compute the total transuranic soil concentrations reported in Figure 2.

Average soil concentrations per unit mass are expected to be much less uncertain than those per unit area, as previously discussed. They can

also be expected to be more reliable than the exposure rates reported in Figure 1 over the blast sites. The total uncertainty in reported values for ^{241}Am concentration (in pCi/g) is expected to be of the order of 50%. The minimum detectable activity, MDA, corresponding to the lower value of the B contour interval, is 12 pCi/g. Hence the A-level represents areas in which the ^{241}Am soil activity is at or below the MDA.

Blast centers B, C and D exhibit strong transuranic contamination. Peak soil concentrations of ^{241}Am are estimated as 3.7, 5.3 and 7.7 nCi/g at blast centers B, C and D, respectively. The most prominent feature in the contour map is the extensive plume originating from blast centers C and D. This plume proceeds north-northeast to a ridge near the Area 3/Area 11 boundary, where the plume is channeled through a pass in the ridge to the edge of the survey area. The plume was not followed into the neighboring West Fork Scarp Canyon; doing so would have required emplacement of microwave ranging system transponders in the Nellis Air Force Range, which was not possible at that time. However, this plume is not expected to extend much further beyond the survey boundary, since observed ^{241}Am soil concentrations are rapidly approaching the MDA. Also associated with the C and D blast centers is an area of contamination migrating to the south-southwest. This migration follows a wash, which is blocked by an earthen dam some 700 m beyond the southernmost point of this migration.

A demonstration site for the Cleanup and Treatment Program (CATP) is located about 200 m southeast of blast site C, as indicated in Figure 2. Two strips, 12-m wide by 100-m long, placed 30 m apart have had several centimeters of surface soil removed. The effect of this cleanup has only a marginal impact on the C-level contour over the site. Post-cleanup soil concentrations were reported to range from 3 to 10 pCi/g.¹⁶ Although this level of contamination is well below that of the surrounding vicinity, the small spatial extent of the cleanup area strongly limits its impact on the large area concentrations represented by the contours.

A small area of ^{241}Am contamination is also clearly visible at a radioactive waste dump, identified in Figure 2. The shape of the unsmoothed contours suggests the area is small in size. Hence peak activity is probably substantially greater than indicated in the figure. No evidence of ^{241}Am

contamination is observed in the Nellis Air Force Range extension.

An inventory of transuranic radioactivity is presented in Section 5.4.

5.3 Joint ^{235}U and ^{137}Cs Soil Concentration Contour Map

Soil concentrations of both ^{235}U and ^{137}Cs are shown jointly in Figure 3. White and black contours are used to delimit soil concentrations of ^{235}U and ^{137}Cs , respectively.

A relatively small degree of ^{235}U contamination is observed in the vicinity of blast site A. Maximum soil concentrations of 12 pCi/g are observed near the center of the site. However, since the central region of contamination is small compared to the airborne detector's field-of-view, actual concentrations may be much greater. The ^{235}U MDA was determined to be approximately 4 pCi/g. No other regions of ^{235}U contamination were detected. The inventory of ^{235}U present at site A is reported in the following section.

Contamination due to ^{137}Cs can be observed at only two locations. The most significant is located at blast site D, where soil concentrations up to approximately 3 pCi/g are indicated. This value is probably much too small due to the highly localized nature of the source. The presence of contamination in this location is consistent with reports that a slight fission yield was obtained in the test at site D.¹⁰

Another region of ^{137}Cs contamination can be observed in the southern portion of the survey area, identified as Location 2 in Figure 3. Contamination in this region appears to be widely scattered and just in excess of the MDA of approximately 1 pCi/g.

5.4 Inventories of Major Radionuclides

Inventories of transuranic nuclides (^{241}Am , $^{239,240}\text{Pu}$) and ^{235}U have been determined from the aerial survey data. The results of these inventories are reported in Tables 1 and 2 as the total radioactivity, in Curies, due to a particular nuclide within the prescribed inventory zones. These zones are designated by boxes in Figures 2 and 3 for the transuranic and uranium inventories, respectively. The overall uncertainty in the reported values is estimated to be approximately 50%.

The transuranic inventory results are reported in Table 1. Only the ^{241}Am soil concentration, hence total activity, was measured in the aerial survey. The values reported for $^{239,240}\text{Pu}$ are inferred from Pu to Am ratios reported as a result of earlier soil sample studies.¹⁶ Eight inventory zones are indicated in Figure 2 by the numbered blue boxes. Zones 1, 2 and 3, comprising only the immediate vicinity surrounding each of blast sites B, C and D, respectively, account for 83% of the total transuranic radioactivity observed in Plutonium Valley. A region of contamination migrating away from site D along a wash is inventoried by zone 4. The plume, which extends

Table 1. Aerial Inventory of Transuranics in Plutonium Valley

Zone	Area ($\times 10^5 \text{m}^2$)	Average ^{241}Am Activity ($\mu\text{Ci}/\text{m}^2$)	Total ^{241}Am (Ci)	Transuranic Ratio ($^{239,240}\text{Pu}/^{241}\text{Am}$)	Total Pu (Ci)
1 (Site B)	2.79	18	5.2	7.8	41
2 (Site C)	2.62	36	9.4	5.8	54
3 (Site D)	3.12	65	20	5.8	110
4 (Wash)	1.63	0.60	0.10	5.8	0.58
5 (Plume)	15.5	2.2	3.4	5.8	20
6 (Plume)	9.17	0.96	0.88	5.8	5.1
7 (Plume)	23.3	0.54	1.2	5.8	7.0
8 (Dump)	0.44	13	0.56	5.8	3.2
TOTAL	60.3		12.0		240

northeast from blast sites C and D, is divided into three inventory zones (5, 6 and 7). Finally, zone 8 surrounds a small radioactive waste dump.

An earlier ground-based survey, utilizing the FIDLER* detection system, contoured and inventoried blast sites B, C and D. That inventory integrated only that portion of the area in which the contamination exceeded five times the background uncertainty. Hence, the areas involved in the inventory zones of the FIDLER survey were nearly an order of magnitude smaller than the areas inventoried in the present aerial survey. The aerial survey inventory results for blast sites B, C and D were redetermined using square areas comparable in size to those measured in the FIDLER survey. The redetermined aerial survey inventory results and the FIDLER survey results

are reported in Table 3, where significant differences between the aerial and ground-based inventories are apparent. The aerial results tend to be three times greater than the corresponding ground-based measurements. This difference is well in excess of the expected uncertainties. Investigation indicates that only one-half of the discrepancy can be resolved through consideration of maximum reasonable uncertainties in soil density and relaxation depth. Since the region of greatest contamination is the same size or smaller than the detector's field-of-view after data smoothing, a finite source size correction may be necessary. However, this correction would only aggravate the discrepancy by increasing it another 20%.

An inventory of total radioactivity due to ^{235}U is reported in Table 2 for blast site A. The inventory zone is designated by the green box in Figure 3. Again, total uncertainty is expected to be less than 50%.

*Field Instrument for the Determination of Low Energy Radiation.

Table 2. Aerial Inventory of ^{235}U in Plutonium Valley

Zone	Area ($\times 10^5 \text{m}^2$)	Average ^{235}U ($\mu\text{Ci}/\text{m}^2$)	Total ^{235}U (Ci)
1 (Site A)	1.45	2.6	0.38

Table 3. Comparison of Aerial and FIDLER Plutonium Inventories

Site	Aerial Survey		FIDLER Survey	
	Area ($\times 10^4 \text{m}^2$)	Total Pu Activity (Ci)	Area ($\times 10^4 \text{m}^2$)	Total Pu Activity (Ci)
B	1.98	18	1.99	6.2
C	2.96	30	2.97	8.9
D	5.80	66	5.80	19

APPENDIX A

KEY PARAMETERS UTILIZED IN COMPUTATION OF
CONCENTRATION CONVERSION COEFFICIENTS

	²¹⁴ Am	²³⁵ U	¹³⁷ Cs
1. Altitude above ground level (m)	30.5	30.5	30.5
2. Density of air (g/cm ³)	1.16×10^{-3}	1.16×10^{-3}	1.16×10^{-3}
3. Mass attenuation coefficient for photon in air at S.T.P. (cm ² /g)	0.185 @ 60 keV	0.13 @ 186 keV	0.080 @ 662 keV
4. Mean free path of above photon (m)	46.6	64.0	108
5. Mass attenuation coefficient for photon in aluminum detector enclosure (cm ² /g)	0.27 @ 60 keV	0.13 @ 186 keV	0.075 @ 662 keV
6. Thickness of enclosure (0.152 m @ 2.70 g/cm ³) (g/cm ²)	0.41	0.41	0.41
7. Actual area of 20 12.7 cm × 5.1 cm NaI(Tl) detectors	2534	2534	2534
8. Photo-fraction	0.98	0.97	0.60
9. Interaction ratio	0.99	0.99	0.77
10. Photons per disintegration	0.357	0.72	0.90
11. Soil density at Area 11 (g/cm ³)	1.5	1.5	1.5
12. Mass attenuation coefficient for photon in dry soil (cm ² /g)	0.25	0.14	0.076
13. Depth distribution of ²⁴¹ Am in soil assuming exponential form ¹² (cm)	2.5	2.5	10
14. Soil sample to depth of (cm)	5	5	5
15. Soil concentration conversion coefficient $\left(\frac{\text{pCi}}{\text{g}}/\text{cps}\right)$	8.1×10^{-2}	2.9×10^{-2}	1.5×10^{-2}
16. Area concentration conversion coefficient $\left(\frac{\text{nCi}}{\text{m}^2}/\text{cps}\right)$	7.0	2.5	2.8

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