EGG 11265-1145
UC-702
AUGUST 1995

THE
**REMOTE
SENSING
LABORATORY**

OPERATED FOR THE U.S.
DEPARTMENT OF ENERGY BY EG&G/EM

RECEIVED

JAN 03 1996

OSTI

**AN AERIAL RADIOLOGICAL SURVEY OF THE
TONOPAH TEST RANGE
INCLUDING CLEAN SLATE 1, 2, 3,
ROLLER COASTER,
DECONTAMINATION AREA
CACTUS SPRINGS RANCH
TARGET AREAS**

CENTRAL NEVADA

DATE OF SURVEY: AUGUST-OCTOBER 1993

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**AN AERIAL RADIOLOGICAL SURVEY OF THE
TONOPAH TEST RANGE
INCLUDING CLEAN SLATE 1, 2, 3,
ROLLER COASTER,
DECONTAMINATION AREA
CACTUS SPRINGS RANCH
TARGET AREAS**

CENTRAL NEVADA

DATE OF SURVEY: AUGUST-OCTOBER 1993

A.E. Proctor
T. J. Hendricks
Project Scientist

REVIEWED BY

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

This Document is UNCLASSIFIED

J. E. Jobst
Authorized Derivative Classifier

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

Abstract

An aerial radiological survey was conducted of major sections of the Tonopah Test Range (TTR) in central Nevada from August through October 1993. The survey consisted of aerial measurements of both natural and man-made gamma radiation emanating from the terrestrial surface. The initial purpose of the survey was to locate depleted uranium (detecting ^{238}U) from projectiles which had impacted on the TTR. The examination of areas near Cactus Springs Ranch (located near the western boundary of the TTR) and an animal burial area near the Double Track site were secondary objectives. When more widespread than expected ^{241}Am contamination was found around the Clean Slates sites, the survey was expanded to cover the area surrounding the Clean Slates and also the Double Track site. Results are reported as radiation isopleths superimposed on aerial photographs of the area.

1.0 INTRODUCTION

An aerial radiological survey of major sections of the Tonopah Test Range (TTR) was conducted by the Remote Sensing Laboratory (RSL) for International Technology (IT) Corporation and the United States Department of Energy (DOE).

The survey consisted of aerial measurements of both natural and man-made gamma radiation emanating from the terrestrial surface. The initial purpose of this survey was to locate depleted uranium (detecting ^{238}U) from projectiles which had impacted on the TTR. The examination of areas near Cactus Springs Ranch (located near the western boundary of the TTR) and an animal burial area near the Double Track site were secondary objectives. When more widespread than expected ^{241}Am contamination was found around the Clean Slates sites, the survey was expanded to cover the area surrounding the Clean Slates and also the Double Track site. (Double Track results will be reported later). Results are reported as radiation isopleths superimposed on aerial photographs of the area.

1.1 Aerial Radiation Measurements

RSL performs various types of radiological surveys for DOE and other customers. RSL capabilities include an airborne radiological surveillance system called the Aerial Measuring System (AMS). Since its inception in 1958, the AMS program has carried out radiological surveys of nuclear power plants, processing plants for nuclear materials, and research laboratories. AMS aircraft have been deployed to nuclear accident sites and in searches for lost radioactive sources. AMS aircraft also fly mapping cameras and multispectral camera arrays for aerial photography, and thermal mappers for infrared imagery. All survey operations are conducted at the request of federal or state agencies, and at the direction of DOE.

The TTR aerial radiological survey was part of a larger effort to identify locations on the TTR which would require environmental restoration. This program includes multispectral aerial scanning and ground-based radiation measurements. Results of these surveys are reported separately.

RSL personnel conducted the TTR aerial radiological survey from August 1993 through December 1993 at the request of the IT Corporation and for the DOE Nevada Operations Office. This was the second survey of this type at the TTR site; the first was conducted in 1977. The present survey consisted of airborne measurements of the target range area on the TTR, the Clean Slate sites 1, 2, and 3, Cactus Springs Ranch, and the animal burial area near the Double Track site.

The locating of depleted uranium (actually, detecting ^{238}U) was the initial purpose of this survey. Depleted uranium was used in projectiles which had impacted on the TTR, creating a potential health hazard. This was the first major survey effort in which RSL attempted to find depleted uranium. In addition, we attempted to determine if there was detectable

radiation from animal studies in which domestic animals were exposed to contamination during the Clean Slate tests. It was believed that the animals were kept at the Cactus Springs Ranch site and later buried near the road to the Double Track site. Significant levels of ^{241}Am contamination were found around the Clean Slate sites during the survey. The survey boundaries were then enlarged to include all of the detectable Clean Slate contamination and the Double Track site was added to the survey.

Contour plots of contamination levels at these sites were calculated from the aerial radiation data. Since the accuracy of available maps was questionable, aerial photographs were used as a basis for our plots.

1.2 Other TTR Surveys

In-situ, ground-based gamma radiation measurements were made at the Clean Slate 2 fence line. These are described in a separate report.

Aerial photography and multispectral imaging studies of the TTR were done concurrently with the radiation measurements. These measurements were part of a comprehensive effort to identify areas of environmental concern at the TTR.

2.0 SURVEY SITE DESCRIPTION

The survey area is part of the Nellis Air Force Bombing Range located in central Nevada. This range includes TTR, which contains most of the survey area, and Range 71, in which the Double Track site is located. The range is approximately 26 miles long (east/west) x 23 miles long (north/south). The Nevada Test Site (NTS) is located in the southwest corner of the range.

The area is sparsely populated; nearby towns are: Tonopah, population 4000; Goldfield, population 639; and Beatty, population 103. A number of ranches and mines surround the range.

The TTR survey area is located in a flat plain surrounded by mountains, the Cactus Range on the west, and the Kawich Range on the east. The survey area consists of desert with dry soil and rock outcroppings. Several large, dry lake beds (Main Lake, Antelope Lake) and washes lie within the TTR survey area. The Double Track site slopes slightly to the south, but is otherwise similar to the TTR, with a large wash running along the west side. The area receives occasional snow in the winter and little rain at other times.

The TTR is used for a variety of projects. Prior to use as an Air Force range, the area contained numerous mines and several ranches. All of these are no longer in use, since the range was acquired by the Air Force in the 1940s as a B-25 training base. Both the TTR and Range 71 are routinely used by the Air Force for tests and training. Most recently, the F-117 Stealth aircraft was based at the TTR. Smart laser-guided bombs were tested near Double

Track. The site is also used for missile reentry tests and artillery tests. Fortunately, the Clean Slates 2 and 3 and the Double Track contaminated areas have not been disturbed greatly. Construction activity in the Clean Slate 1 contamination is visible on the contour plot.

Vegetation and wildlife on the TTR are typical of that found in a high (5700-ft elevation), desert environment. Grasses and shrubs growing within the areas support a wild horse population along with smaller animals and coyotes. The Bureau of Land Management (BLM) leases the surrounding area for cattle grazing.

The locations of the Clean Slates ground zero's are well known. Table 1 lists them and their respective detonation dates:

**Table 1. Clean Slate "Ground Zero"
Coordinates**

Event Name	Ground Zero Coordinates	Detonation Date
Clean Slate 1	N37° 42' 30.92" W116° 39' 25.09"	May 25, 1963
Clean Slate 2	N37° 45' 40.00" W116° 36' 48.58"	May 31, 1963
Clean Slate 3	N37° 45' 33.22" W116° 40' 48.88"	June 9, 1963

In contrast, the locations of depleted uranium are poorly known, extending along the flight line between targets running from Main Lake in the north to Antelope Lake in the south. In addition, there are two known depleted uranium artillery round impacts to the east of Main Lake. The areas with animal remains include the Cactus Springs ranch and an unmarked burial site near Double Track. Although we were uncertain of the exact location of the burial site, it appears that it should have been included in the Double Track survey area.

3.0 SURVEY METHODOLOGY

Standard aerial radiation survey techniques were used. This methodology was developed for large-area gamma radiation surveys. It has been successfully applied to more than 300 individual surveys at various locations. Figure 1 is a diagram of the aerial survey systems. Each of these is discussed below.

Gamma ray spectral data were acquired at uniform spacing along a series of parallel lines which were flown in an southwest-northeast direction at an altitude of 100 ft (30 m) above

ground level (AGL) and at a line spacing of 150 ft (46 m). Data were acquired continuously along these lines and recorded at 1-second intervals, at an airspeed of 70 knots. This time interval yields a 118-ft-long data interval. Detected gamma ray data and other information such as air temperature, pressure, and altitude were recorded at each interval.

3.1 Aerial Radiation Measurements

Data were collected using a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter with externally mounted detector pods, each containing four 2-in x 4-in x 16-in downward-looking and one upward-looking 2-in x 4-in x 4-in NaI(Tl) detectors. These detectors were surrounded by thermal insulating foam and shielded using 0.03 in cadmium and lead sheets.

The detector system was designed to sense terrestrial and airborne gamma radiation with energies between 20 keV and 4,000 keV. This energy range includes naturally-occurring and man-made gamma radiation. Output signals from individual detectors were initially calibrated with ^{241}Am and ^{22}Na sources. Individual detector gains were adjusted to normalize outputs of each detector in a summing amplifier. Lastly, the summed signal was adjusted at the analog-to-digital converter (ADC) so that the calibration peaks appeared in preselected channels in the multichannel analyzer of the data acquisition system.

Helicopter position was 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. Two ground locations whose exact locations were known from previous civil engineering surveys were used for the TTR survey. The airborne GPS receiver provided continuous position data to a microprocessor, which reformatted the data for use in RSL's airborne computerized data logging systems. This on-board computer recorded the position data and operated a steering indicator to aid the pilot in flying a set of equally spaced straight lines.

Real-time altitude measurements were made via a radar altimeter. The radar altimeter measured the return time for a pulsed signal and converted this delay to aircraft altitude. For altitudes up to 2,000 ft (610 m), the manufacturer's stated accuracy is ± 2 feet or $\pm 2\%$, whichever is greater. Altitude data were also recorded by the data acquisition system so that any variation in gamma signal strength caused by altitude fluctuations could be identified.

3.2 Detector Characteristics

Sources detected by aerial systems appear to be spread over a much larger area than would be indicated by ground-based measurements. Radionuclide activities on or in the soil and exposure rates normalized to 1 m AGL are customarily reported, but only as a large-area average. The size of the field of view is a function of the gamma ray energy, gamma ray origin, and the detector response. 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 any source activity less than the detector field of view will be underestimated, sometimes by orders of magnitude. When these occasions arise, the aerial data simply serve to locate and identify such sources. For uncollimated detectors, such as those used in this aerial survey, source-to-detector distance and attenuation due to air effectively limit the size of the viewed terrestrial area to a circular region centered beneath the detector. Detector footprints are sizeable; representative calculated radii for three emitted gamma ray energies are shown in the table below:

Table 2. Approximate Detector "Footprint" Radius for Relative Count Rate Contributions from Terrestrial Sources (100-ft survey altitude).

Emitted Gamma Ray Energy, keV	Radius (feet) from which 99% of all detected counts originate	Radius (feet) from which 90% of all detected counts originate	Radius (feet) from which 50% of all detected counts originate
60	373	307	123
200	470	373	142
600	631	514	173
1,000	814	599	188

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. Measurements of localized sources show detected activity over regions much larger than the actual source dimensions. The broadening of a point gamma emitter is shown in Table 3.

Table 3. Detected Count Rate Full Width at Half Maximum (FWHM) for Localized Terrestrial Sources (100-ft Survey Altitude/150-ft survey line spacing).

Emitted Gamma Ray Energy, keV	FWHM due to sources directly beneath the detector (feet)	FWHM due to sources centered between survey lines (feet)	FWHM due to sources on adjacent survey lines (feet)
60	225	225	271
200	225	225	295
600	225	225	320
1,000	225	237	320

Apparent source broadening makes comparison with ground-based measurements difficult. Radionuclides which occur as hot particles are averaged by the aerial system as a uniform distribution. Ground surveys, however, would locate the hot particles and show the surrounding areas to be free of contamination.

3.3 Data Acquisition System

Spectral data were acquired and displayed in real time using specialized instrumentation which processes, stores, and displays spectral data. This system was developed for aerial radiological surveys and contains all necessary instrumentation in a single package. The system is called Radiological and Environmental Data Acquisition and Recorder System (REDAR). The REDAR is a multi-microprocessor, portable data acquisition, and real-time analysis system. 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 to the operator all required radiation and system information, in real time, via a 5-inch CRT display and multiple readouts. All pertinent data are recorded on cartridge tapes for postmission analysis.

A REDAR contains six subsystems: 1) two independent radiation data collection systems, 2) a general purpose data I/O system, 3) a tape recording/playback system, 4) a CRT display system, 5) a real-time data analysis system, and 6) a ranging system with steering calculation and display. These subsystems handle functions including: data collection, data analysis, data

display, position and steering calculations, and data recording which are all under operator control.

The multichannel analyzer collects two 1,024-channel gamma ray spectra (4.0 keV/channel) once every second during the survey operation. Each spectrum is first compressed from 1,024 channels to 256 channels to conserve space and then recorded for later processing. Since the resolution of NaI(Tl) crystals decreases with increasing energy, compression of the spectral data does not compromise photopeak identification and stripping techniques.

Spectra are divided into four partitions in which the detected photopeak width is approximately the same. Data in the first partition (channels 0-75), are not compressed to permit stripping of low-energy photopeaks, such as the 60 keV photopeak from ^{241}Am . The spectral compression technique reduces the amount of data storage required by a factor of four.

A full spectrum (256 channels of spectral data) and related information such as position, time, air temperature, etc., are continuously recorded every second. The REDAR system has two sets of spectral memories; each memory can accumulate four individual spectra. The two memories support continuous data accumulation: while one memory is being used to store data, the data in the other memory are being transferred to magnetic tape. A single data set, acquired each second during flight and representing the radiation measure at one location, contains two spectra, count rates from the small detectors, and other parameters such as position and altitude. There are 45 data sets for each mile of flight; the total data for the TTR survey contains 145,000 data sets.

3.4 Terrestrial Exposure Rate

The measured count rate in the aircraft differs from the true terrestrial exposure rate, due to background sources in the aircraft itself and the attenuation by the air of gamma rays emitted from the ground. Since the raw count rate data has been found to vary, each flight's data is normalized to a test line. This normalization is used to minimize the effects of airborne natural and aircraft background. A test line west of the airstrip, near Thunderbird Road, was selected for the TTR survey.

We have found that the aerial count rate can be expressed as:

$$C_{\text{terrestrial}} = (C_{\text{measured}} - A) * e^{-(B * \text{altitude})} \quad (1)$$

C_{measured} is the count rate recorded by the REDAR and A and B are constants. B is calculated from a series of flights at different altitudes; B has been found to be constant over the duration of a survey; it is determined for data taken at multiple altitudes over the test line. A is calculated from test line count rates measured before and after each survey data flight

(using the previously determined B). An average value of A , the recorded altitude at each data interval, and the value of B are used to correct all measurements to yield the correct terrestrial gamma emission rate. (Such a correction could be gamma ray emission energy dependent. At present, we assume 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 terrestrial exposure rate is calculated from the corrected emission rate.

The corrected data represent the count rate at 1 m AGL due to terrestrial sources; they can be converted to terrestrial exposure rates by scaling the count rates to ground-based ion chamber measurements or using previously calculated conversion factors.

3.5 Isotope-Specific Information from Aerial Survey Data

Aerial survey data are also examined for spectral peaks due to various radionuclides which could reasonably be expected to be present at the survey site. Nuclide-specific conversion factors take into consideration the isotopic branching ratios, the spectral window analysis used, and an assumed distribution of the source in the soil. The assumed distribution and soil attenuation at the gamma energy being analyzed clearly affect the calibration. An assumed distribution of radionuclides is often a best estimate, leading to an unavoidable uncertainty in the computed soil activity. Conversion from counts to radiation units depends on the distribution of radionuclides in the soil. Contamination may be dispersed on the surface, with no contamination below the surface, or may be distributed throughout the soil. The latter case has been found to be more probable. For TTR, an exponential distribution has been assumed:

$$S = S_0 e^{-\alpha z} \quad (2)$$

where S_0 is the soil activity per gram of soil at the surface and α is the reciprocal of the relaxation depth. This depth distribution has been proposed by Tamura, based on actual depth profile measurements. The total activity in the first 10 cm of soil is the integral:

$$S_{total} = \int_0^{10} S(z) dz = \left(\frac{S_0}{\alpha} \right) \rho \quad (3)$$

where $S(z)$ is defined in above and ρ is the soil density.

3.6 On-Site Data Processing

Data processing was initiated in the field with the Radiation and Environmental Data Analyzer and Computer (REDAC) system. This system consists of a computer analysis laboratory mounted in a mobile van. Data were examined and preliminary analyses completed prior to leaving the TTR site.

Widely dispersed sources are normally encountered in surveys of plumes from airborne contamination; small sources are normally found in facilities which handle radioactive materials. Intermediate-sized sources may be found in waste disposal ponds, spills, etc. In most cases, facility exposure rates are known, and environmental exposure rates are desired, but not well known; so, the requirement of a widely dispersed source to compute accurate exposure rates is not a problem.

The terrestrial exposure rate plots are also used as a quality check on systematic variability of survey data. In particular, exposure rate isopleths which 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 are uncorrectable, the uncertainty (error bars) applied to the isopleth plots must be increased to eliminate obvious systematic variations.

4.3 Man-Made Gross Count

The MMGC algorithm is based on our observation that commonly-occurring, man-made sources emit gamma rays having energies less than 1,394 keV, while natural background sources emit gamma rays below and above this threshold. Gamma rays detected after being scattered (e.g. emitted by sources buried in soil, and atmospheric scattering of all detected gamma rays) will form a continuum with contributions equal to or below their initial energies.

Detected gamma rays from cosmic sources are seen as a continuum which contains contributions above and below 1,394 keV. Assuming a stable cosmic ray emission rate and a constant background due to the aircraft, airborne radon, and detectors, and a survey area in which the gamma sources and soil composition change relatively slowly in comparison to the area contributing to the measured spectrum, we can assume that the contributions of the various sources (scattered and unscattered) remains constant throughout all aerial survey measurements. That is, the measured spectral shape is constant over the survey area. 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. Changes in the MMGC are seen in spectra acquired over different terrain, for example, and when airborne Radon levels change.)

Gamma rays from man-made sources are detected and added to those measured gamma rays due to natural background radiation during surveys of areas containing man-made contamination. Since these spectral contributions occur almost always at energies below 1,394 keV, their presence can be determined by comparison with spectra of background areas which do not contain man-made sources. Unfortunately, such direct comparisons are affected by systematic errors. A more reliable comparison can be made using the ratios of the integral (sum of all spectral channel contents) of the spectrum from 38 keV through 1,394 keV to the integral of the spectral region from 1,394 keV to 3,026 keV. The ratio between the lower and

4.0 DATA ANALYSIS

Several standard analysis techniques were applied to the survey data: gross count (related terrestrial exposure rate), man-made gross count, and isotopic analysis via spectral window extractions. Man-made gross count (MMGC) calculations were used successfully; numerous areas of interest were found and analyzed. Terrestrial exposure rates and MMGC were of limited interest in this survey; most of the analysis effort was directed toward ^{241}Am and depleted uranium.

4.1 Natural Background

Natural background radiation originates from radioactive elements present in the earth, airborne radon, and cosmic rays entering the earth's atmosphere from space. Natural terrestrial radiation levels depend upon the type of soil and bedrock immediately below and surrounding the point of measurement. Within cities, the levels are also dependent on the nature of the street and building materials. The gamma radiation originates primarily from the uranium decay chain, the thorium decay chain, and radioactive potassium. Local concentrations of these nuclides produce radiation levels at the surface of the earth typically ranging from 1 to 15 $\mu\text{R/h}$ (9 to 130 mrem/yr). Some areas with high uranium and/or thorium concentrations in the surface minerals exhibit even higher radiation levels, especially in the western states.

An isotope of Radon, a noble gas, is a member 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 any specific location depends on a variety of factors, including meteorological conditions, mineral content of the soil, and soil permeability. Typically, airborne radon contributes from 1 to 10% of the natural background radiation levels.

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 $\mu\text{R/h}$ at sea level in Florida to 12 $\mu\text{R/h}$ at an altitude of 3 km (1.9 mi) in Colorado.

4.2 Terrestrial Exposure Rate

Terrestrial exposure rates are based on the integral counting rate in that portion of the spectrum between 38 and 3,026 keV. This count rate (measured at survey altitude) was converted to exposure rate (microroentgens/hour) at 1 m AGL by application of a predetermined conversion factor, assuming a uniformly distributed source covering an area which is large compared with the field of view of the detector (approximately 300 to 500 m at the survey altitude of 30 m).

upper portions of the spectrum is first determined using data from an area known to be free of contamination:

$$MMGC = \sum_{E_i=38keV}^{1394keV} C_i - [K * \sum_{E_i=1394keV}^{3026keV} C_i] \quad (4)$$

C_i are 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 K . The constant, K , is computed from data measured over areas free of contamination:

$$K = \frac{\sum_{E_i=38keV}^{1394keV} C_i}{\sum_{E_i=1394keV}^{3026keV} C_i} \quad (5)$$

K values are derived from the data of each flight to minimize the effects of airborne ^{222}Ra and minor system characterization differences between flights.

MMGC plots were used in the TTR survey to identify areas needing further examination. Actual MMGC plots are not included in this report.

4.4 Isotopic Analysis

While the MMGC provides an indication of radioactive contamination, nuclide-specific information is important for such activities as contamination source identification and site remediation.

Aerial radiation data contains contributions from naturally-occurring radionuclides, man-made contamination, aircraft and detector background, and cosmic rays. For this survey, the major emphasis was placed on extracting that component arising from man-made radioactivity. Figure 2 shows a representative spectrum from an area south of the Clean Slate 1. The ^{241}Am peak is not visible; only peaks at 1.460 keV (^{40}K) and 2.614 keV (^{208}Tl) are obvious. The net spectra are channel-by-channel subtractions of a spectrum measured over a background region from the spectrum obtained over an area containing ^{241}Am . Note the spectral peak at 59.5 keV. The peak is broadened considerably, due to the characteristics of the NaI(Tl) detectors.

This spectrum is relatively simple; spectral window calculations containing contributions from several radiation sources require multiple "stripping" of peak and background regions to estimate contributions due to individual sources. "Difference spectra" of areas of interest and representative background spectra, consisting of channel-by-channel subtractions may be useful in visually examining suspected contaminated areas. Ideally, the difference would yield a Gaussian-shaped peak(s) at appropriate energy(s) for the radionuclide(s) in question, over a much-reduced continuum. We consider this condition a requirement for verifying the isotopic isopleth plots. In some cases, most notably in Area 9 of TTR, we found an apparent positive ^{241}Am net spectral count rate; however, upon examination of the difference spectrum from this area, we discovered from the "peak" shape that the positive count rate was actually due to a change in the continuum. The apparent positive ^{241}Am was removed from the isopleth plot.

Relative isotopic count rates are computed using "spectral window" methods. For example, the ^{241}Am relative rate due to the peak shown in Figure 2, a representative gamma spectrum, would be computed as follows: A normalized value of the counts accumulated in two background windows, 38 to 50 keV and 70 to 82 keV, is subtracted from the ^{241}Am photopeak window, 50 to 70 keV, to remove counts due to natural and other man-made isotopes that appear in the ^{241}Am photopeak window. The (relative) photopeak count rate due to ^{241}Am is equal to:

$$Rate(^{241}\text{Am}) = \sum_{\text{photopeak}} C_i - K_{\text{normalization}} * \left[\sum_{\text{background}_2} C_i + \sum_{\text{background}_1} C_i \right] \quad (6)$$

The value of K , the normalization factor, is determined from spectra measured over areas whose natural background spectra are similar to those of the area containing ^{241}Am , but are known to be free of ^{241}Am .

4.5 Depleted Uranium Processing

A variation of the standard isotopic analysis was developed for depleted uranium. Peak windows were set on both the 766 keV (722-806 keV) and the 1,001 keV (950-1058 keV) peaks to obtain maximum sensitivity. A background region between 1,118 and 1,430 keV was used. The ^{238}U net count rate is:

$$Rate(^{238}\text{U}) = \sum_{\text{photopeak}_{766\text{keV}}} C_i + \sum_{\text{photopeak}_{1001\text{keV}}} C_i - K_{\text{normalization}} * \left[\sum_{\text{background}} C_i \right] \quad (7)$$

K is determined from spectra measured over areas which are known to be free of ^{238}U . The

boundaries of the peak and background regions were found first from the spectrum of a depleted uranium sample, and then adjusted by computing the channel-by-channel ratio of the depleted uranium spectrum to the background spectrum. After these regions were selected, all survey spectra were examined to compute a value of K which would yield an average of zero net counts for the survey. (This is equivalent to assuming that most of the survey area is free of depleted uranium). Unique K values were determined for each flight; they ranged from 1.060 to 1.208, with an average of 1.1543. Figure 3 shows the measured spectrum of the depleted uranium sample. Channels having large ratios were included in the peak regions.

4.6 Minimum Detectable Activity

The Minimum Detectable Activity (MDA) was estimated by three methods: an estimate of the uncertainty based on calculated anticipated count rates, the count rate which is three times the spread (3σ) of the actual net count rate values measured during the survey, and by Lloyd Currie's methods. In all cases, we assumed that the uncertainty, 1σ , is equal to the square root of the count rate in question. Also, the uncertainty values for net isotopic count rates are based on the uncertainty of a difference of sums of spectral windows:

$$\sigma_{net} = \sqrt{K_1^2 * \sum_{peak}^E C_i + K_2^2 * \sum_{background_1}^E C_i + K_3^2 * \sum_{background_2}^E C_i} \quad (8)$$

Constants, K_s , refer to those normalization constants used in the net count rate calculations.

Table 4 lists the calculated MDAs, based on counting statistics. The authors are grateful to Richard Maurer, WAMO, for supplying the computer code used to calculate the values in Table 4. The total Pu to ^{241}Am ratio of 10 ± 3 was provided by Sandia Health Physics.

A special analysis method using two spectral windows centered around 766 and 1,001 keV and one background window above 1,600 keV was developed to maximize our sensitivity to depleted uranium. Table 4 values were based on a sum of the branching ratios for the 766 and 1,001 keV peaks, and an average energy (883 keV) for attenuation estimates.

Once the survey is complete, a working MDA can be estimated from the deviation from the mean value of a specific net isotopic count, based on either the " 3σ " traditional practice or Currie's analysis. The " 3σ " value has been favored for radionuclides having positive net isotopic counts; Currie's methods are useful for estimating detection limits when no positive net counts were found.

Table 4. Calculated Minimum Detectable Activity vs. Gamma Energy for Different Source Geometries.

Assuming: 3σ , 70 knots, 100-ft survey altitude, 2.5-cm sample averaging depth, 3-cm relaxation depth, unity branching ratio and unity "spectral window" factor.

	<i>Point Source</i>		<i>Distributed Source</i>		
Energy (keV)	directly beneath the detector (mCi)	beneath the detector: offset by 150' (mCi)	uniform distribution vs. depth (pCi/g)	exponential distribution vs. depth (pCi/g)	uniformly distributed on the surface ($\mu\text{Ci}/\text{m}^2$)
60	0.05	0.1	0.94	0.64	0.042
200	0.05	0.1	0.54	0.37	0.025
600	0.05	0.1	0.28	0.19	0.013
1200	0.05	0.15	0.23	0.15	0.010
^{241}Am (60 keV; actual branching ratio)	0.14	0.28	2.6	1.8	0.12
Total Pu	1.4	2.8	26	18	1.2
Depleted U (766 + 1001 keV, summed branching ratios)	2.8	6.5	21.	14.	0.92

Use of 3σ levels has been found to be a good rule of thumb for setting the lowest contour levels in isopleth plots. A 3σ level implies that 99 percent of all data corresponding to zero net isotopic counts (corresponding to no activity present) will be below this level, and therefore will not appear on the isopleth plot. The working MDA for total plutonium assuming an exponentially distributed source was 25 pCi/g, by the 3σ method, which compares reasonably well with the predicted value of 18 after the predicted value was multiplied by 1.6, which is the spectral window ratio. The resulting predicted value is 28 pCi/g.

Currie's approach was used to estimate the detection limits for ^{238}U and ^{241}Am . For isotopic measurements for ^{238}U , for example, the uncertainty of the net count rate is related to the rates in the photopeak and background windows:

$$\sigma_{(^{238}\text{U})}^2 = \sigma_{\text{net rate}}^2 = \sigma_{\text{photopeaks}}^2 + K_{\text{normalization}}^2 * \sigma_{\text{background}}^2 \quad (9)$$

This approach is advantageous in that an uncertainty can be calculated from the actual data, rather than from statistics and estimates of systematic errors. It is, therefore, more reliable.

To use Currie's method, we need an estimate of $\sigma_{\text{background}}$. The distribution of net counts, σ_{net} , is measurable by plotting all net isotopic counts for the survey. A $\sigma_{\text{background}}$ can be found from σ_{net} and the calculated K value. Since most of the net count rates are zero (i.e., the area is mostly free of contamination), from the definition of K :

$$\begin{aligned} \text{Net Rate} &= \sum_{\text{photopeak}} C_i - K_{\text{normalization}} * \sum_{\text{background}} C_i = \\ \sigma_{\text{photopeak}}^2 - K_{\text{normalization}}^2 * \sigma_{\text{background}}^2 &= 0 \end{aligned} \quad (10)$$

and the usual definition of the statistical uncertainty of a counting rate. Here, the counting times are equal for photopeak and background rates; the rates are sums of different areas of the same spectra. It would have been more straightforward to compute the distribution of the actual background window counts; however, the background and peak regions are subject to systematic variations that change from one flight to the next. These variations are not seen in the net count, since it is the difference of two quantities each with equal systematic variations. The uncertainty in the net count rate can be rewritten as:

$$\sigma_{\text{net rate}}^2 = \sigma_{\text{photopeaks}}^2 + K^2 * \sigma_{\text{background}}^2 = [K * \sigma_{\text{background}}^2] + K^2 * \sigma_{\text{background}}^2 \quad (11)$$

The FWHM (and corresponding σ_{net}), measured from the distribution of net photopeak rates and $\sigma_{\text{background}}$ calculated from Equation 11, may be used to estimate several MDA values. Since they are based on measured quantities, the uncertainties and MDAs include both statistical variations and systematic error sources.

The traditional method for determining lowest level contour uses $3 * \sigma_{\text{net}}$. That value was applied to the radiation isopleths presented in this report.

Lloyd Currie devised three parameters, L_C , L_D , and L_Q , to describe MDA. L_C , the critical level, is the minimum measured net count for which we would state that a radionuclide had

been detected if we found this net count rate in the survey data. Currie defines the critical level as:

$$L_C = 2.33 * \sigma_{background} \quad (12)$$

Net count rate data at the L_C level indicate the presence of the isotope in question. We would state that we had detected depleted uranium, for example, if the depleted uranium present caused a net count that was equal to or above the critical level. Terrestrial activity corresponding to the L_C count rate level may not be found, due to the spread in measured values arising from counting statistics and/or systematic variations. Currie defines L_D the a priori detection limit, as the smallest net count for which we could expect to consistently detect the radionuclide in question. In terms of activity, we could "always" find terrestrial radioactivity for which the net count rate was greater than or equal to L_D . (Actually, we would detect it 95 percent of the time. The 95 percent value is arbitrary; it determines the values of constants used in Currie's equations.) This value is larger than the critical level:

$$L_D = 2.71 + 4.65 * \sigma_{background} \quad (13)$$

Currie defines a determination limit, L_Q , which defines the smallest net value in which the spread in the measured uncertainties of net isotopic count rates is 10 percent or less of the magnitude of these net values. Net count rates greater than or equal to this limit are quantitative, in that the uncertainties are relatively small. Currie's determination limit is:

$$L_Q = 50 * [1 + (1 + \frac{\sigma_{background}^2}{12.5})^{1/2}] \quad (14)$$

Several types of systematic errors should be noted: The most obvious errors would arise from day-to-day variations in the detection equipment; however, we can compensate for these using the test line data. Variations in radionuclides across the survey area vertically (radionuclide depth distribution) and the size of the activity (horizontal distribution) contribute to the measurement uncertainty. Clearly, an incorrect assessment of the radionuclide depth distribution will cause large systematic errors. In addition to the effects of soil attenuation and radionuclide distribution, the uniformity with which the radioactivity is dispersed over the survey site affects the apparent measured activity.

The best situation would be one in which the distribution of activity varied slowly in comparison to the detector footprint size. Unfortunately, some radionuclides are effectively point sources when viewed from the survey altitude. Apparent activities from such sources are lower than the actual source activity, sometimes by large factors. Total uncertainty may

be quite large in some data points. We have found that uncertainties due to systematic errors can be minimized by direct experimental characterizations of the detection system and by use of algorithms such as the MMGC which minimize the effects of these known uncertainties.

5.0 RESULTS

Radiation contour plots were made for the TTR site and for several areas of interest: 1) the Clean Slates, 2) Cactus Springs Ranch, and 3) the location of an impact of a depleted uranium artillery round. Of these, data from the Cactus Springs Ranch and the artillery round impact site did not show sufficient evidence of dispersed contamination to warrant further study. The others were analyzed in greater detail.

5.1 Gross Gamma Count Rates and Terrestrial Exposure.

Figure 4 shows the distribution of terrestrial exposure rates for the TTR survey area. The most probable value, 14.6 $\mu\text{R/hr}$, is typical of the region. Cosmic and airborne contributions have been removed from terrestrial exposure rates prior to generating the distribution. Step-like variations in the distribution are possibly due to geological features: dry lake beds, washes, and mountainous areas.

5.2 Man-Made Gross Count Rates

MMGC rates were computed for all TTR data. Areas having elevated MMGC values were investigated further. For example, statistically significant MMGC values were found for active TTR facilities. These areas were analyzed using local background data, as noted previously. Computed MMGC values were used to generate contour plots of these areas. The actual MMGC plots were not included with this report since the isotopic plots are of greater interest.

5.3 ^{241}Am and Plutonium in the Clean Slates Sites

Substantial ^{241}Am contamination was found around the Clean Slates sites. Contamination was found far beyond the Clean Slate fenced areas, extending several miles southeast of the fence boundaries. ^{241}Am is a daughter of ^{241}Pu , which was a constituent of the original weapon material. Sandia National Laboratory has reported that a ratio of 10 ± 3 Plutonium to ^{241}Am in the dispersed material at Clean Slate 2. Since the Pu concentration is generally of greater interest, we have scaled the radiation isopleth contour levels to indicate total Plutonium. Radiation isopleth plots are shown in Figures 5, an overall view of the TTR site, and in Figures 6, 7, and 8, which show Clean Slates 1, 2, and 3, respectively. These plots are superimposed on maps and aerial photographs; distance scales are provided and the locations of the exclusion fences are shown as green lines.

We can estimate the minimum detectability of ^{241}Am from the large group of survey data.

The distribution of net ^{241}Am counts is shown in Figure 9. The FWHM is 77 counts. Traditional 3σ and Currie's detection limit estimates are shown in Table 5. Using $K = 0.950$ from the net isotopic counts, $\sigma_{net} = 32.7$ and $\sigma_{background} = 24.02$.

Calculated and actual MDAs and appropriate conversion factors yield the various limits for ^{241}Am measurement and Plutonium:

Table 5. ^{241}Am and Plutonium Detection Limits

Detection limit	^{241}Am net counts	Distributed Plutonium contamination, pCi/g, not gridded	Distributed Plutonium contamination, pCi/g, gridded: 450 ft x 450 ft
Lowest contour level	33.68	----	25
Measured $3 \times \sigma$	98.1	132.1	38.1
Currie's L_C	56.0	75.43	21.8
L_D	114.4	153.7	44.4
L_Q	515.1	693.8	200.3

5.4 Depleted Uranium

Analysis of the ^{238}U spectral windows yielded an ambiguous radiation isopleth plot shown in Figure 10. The net depleted uranium counts are nearly zero; small negative and positive net counts were present. There is some limited correlation of depleted uranium with the range targets, especially at Main Lake, but this is attributed to fluctuations in the net counts from different terrestrial conditions. Since an observer reported that pieces of depleted uranium were visible and could be detected with hand-held instruments in the target areas, we initially believed that we should expect to detect depleted uranium in this area. (The aerial system is capable of detecting depleted uranium fragments, based on previous survey results at other sites). Later, we were informed that most of the depleted uranium debris had been removed from the TTR immediately after each impact, so it is unlikely that detectable quantities of depleted uranium were present within the survey area. We did not detect depleted uranium within the TTR survey area.

We can estimate the minimum detectability of depleted uranium from the large group of survey data for use in future surveys; this working value can be compared with the calculated values presented in Table 4. The distribution of net depleted uranium counts is shown in

Figure 11. The FWHM is 58 counts. Knowing that this represents the distribution of a very large sample of data, the uncertainty in the background count may be found using the measured FWHM from Figure 11, and the average value of $K = 1.1543$ from the net isotopic counts: $\sigma_{net} = 24.63$ and $\sigma_{background} = 15.62$ counts.

Calculated and actual MDA, with appropriate conversion factors, provides the detection limits for depleted uranium shown in Table 6.

Table 6. ^{238}U Detection Limits

Detection limit	^{238}U net counts	Surface contamination, $\mu\text{Ci}/\text{m}^2$
Calculated $3 \times \sigma$	38.0	0.92
Measured $3 \times \sigma$	73.9	1.77
Currie's L_C	36.4	0.88
L_D	75.3	1.82
L_Q	276.5	6.69

The measured 3σ value is close to Currie's L_D ; however, the calculated detection limit is approximately half of the 3σ and L_D values. (L_D is close to $3 \times \sigma_{net}$ which is 4.7 times $\sigma_{background}$). Differences between measured and estimated limits were attributed to the use of multiple spectral windows in the net count calculation (which the calculated limit does not consider) and to error sources unaccounted for in the actual survey data. Currie's L_D is a measure of the true MDA. The L_Q value is much larger; unfortunately, we do not often have the luxury of such large net counts. The experimentally determined detection limit for depleted uranium dispersed on the surface at the TTR is 75.3 net counts, or $1.8 \mu\text{Ci}/\text{m}^2$.

6.0 TTR SITE SURVEY PARAMETERS

Survey Site: Tonopah Test Range areas, including the Main Lake and Antelope Lake target areas and range between them, the Roller Coaster Decontamination Area, the Cactus Springs Ranch

Survey Coverage: 90 mi²

Survey Date: August 1993 through October 1993

Survey Altitude: 30 m (100 ft)

Aircraft Speed: 36 m/s (70 knots)

Survey Flight Line Spacing: 46 m (150 ft)

Survey Flight Line Length: flight lines varied in length from
2 to 10 miles

Survey Flight Line Direction: southwest-northeast

Number of Survey Flight Lines: approximately 600

Detector Array: 8 each: 2-in x 4-in x 16-in Na(Tl) detectors
2 each: 2-in x 4-in x 4-in Na(Tl) detectors

Data Acquisition System: REDAR IV

Aircraft: MBB BO-105 helicopter (Tail Number: N70EG)

Survey Crew:

1. A. Proctor
2. M. Lukens
3. S. Geherty
4. L. Hall
5. T. Schaus
6. L. Americo
7. L. Brewer
8. S. Foster
9. T. McKissick
10. W. Vincuilla
11. S. Dean
12. E. McKinney
13. K. Roesner
14. G. DeMoss
15. R. Mazurkewiz

REDAR IV
&
AIRBORNE
GPS

STEERING
INDICATOR

MBB BO-105 HELICOPTER

DATA VAN
(PRELIMINARY ANALYSIS)

GPS
GROUND
STATION

NaI DETECTOR

DETECTOR
POD

Figure 1: Aerial radiation survey data collection methodology

Figure 2: Representative spectra collected over a radiologically clean "background" area and an area of the TTR known to contain ^{241}Am contamination. The largest visible spectral peak in the data is due to ^{40}K . "Net" spectra are channel-by-channel differences between spectra from the plume area and background spectra. The 60 keV ^{241}Am spectral peak is visible in the "net" spectra.

NET PLUME AREA SPECTRA (PLUME - NORMALIZED BACKGROUND)

Figure 3: Gamma ray spectrum from a representative sample of depleted Uranium. Spectral windows for use in analysis of the TTR data were selected using this spectrum.

Figure 4: Distribution of natural terrestrial exposure rates. Terrestrial exposure rates were calculated from gross count data. Exposure rate values are typical of what would be expected in the area.

Figure 5: Locations of Plutonium (from measured ^{241}Am) contamination found during the TTR aerial survey. Survey boundaries are shown as straight blue lines. Only the 25 pCi/g isopleth is shown in red; exclusion fences are shown in green.

Figure 6: Plutonium (measured ^{241}Am) contamination isopleth for the Clean Slate 1 site. The exclusion fence is shown in green. Note that much of the contamination is outside the fence.

LETTER	PC1/gm
A	25
B	40
C	100
D	200
E	400
F	1000
G	2000

ZONE	# OF PIXELS	PIXEL AREA SQUARE MILES
25-40	52	0.278
40-100	51	0.270
100-200	16	0.116
200-400	17	0.123
400-1000	7	0.051
1000-2000	2	0.015

DATA WERE TAKEN AT 100 FEET ABOVE GROUND AT 70 KNOTS GROUND SPEED.
 DETECTOR ARRAY CONSISTED OF 8 - 2 x 4 x 16 INCH HAI(TL) DETECTORS.
 A 450 x 450 FT PIXEL WAS USED FOR SUMMING DATA.

CONVERSION ASSUMPTIONS WERE:
 COSINE DETECTOR RESPONSE
 3 CM RELAXATION DEPTH
 2.5 CM SAMPLE DEPTH
 PU/AM RATIO = 10
 AM PHOTOPEAK COUNTS = WINDOW COUNTS x 1.6

Improved Road
 116° 37' 30"

Figure 7: Plutonium (measured ^{241}Am) contamination isopleth for the Clean Slate 2 site. The exclusion fence is shown in green. Substantial areas of contamination were found outside the fence.

LETTER	Pu PCI/gm	ZONE	# OF PIXELS	PIXEL AREA SQUARE MILES
A	25	25-40	52	0.378
B	40	40-100	51	0.370
C	100	100-200	16	0.116
D	200	200-400	17	0.133
E	400	400-1000	7	0.051
F	1000	1000-2000	2	0.015
G	2000			

DATA WERE TAKEN AT 100 FEET ABOVE GROUND AT 70 KNOTS GROUND SPEED. DETECTOR ARRAY CONSISTED OF 8 - 2 x 4 x 16 INCH NaI(Tl) DETECTORS. A 450 x 450 FT PIXEL WAS USED FOR SUMMING DATA.

CONVERSION ASSUMPTIONS WERE:
 COSINE DETECTOR RESPONSE
 3 cm RELAXATION DEPTH
 2.5 cm SAMPLE DEPTH
 Pu/Am RATIO = 10
 Am PHOTOPEAK COUNTS = WINDOW COUNTS x 1.6

5582AT

5553AT

5537AT

5508AT

5510

5513AT

PG 6 PA
5685

Figure 8: Plutonium (measured ²⁴¹Am) contamination isopleth for the Clean Slate 3 site. The exclusion fence is shown in green. Some contamination was found outside the fence.

Figure 9: Distribution of ^{241}Am net counts. Minimum Detectable Activity values were computed from this distribution.

Figure 10: ^{238}U radiation isopleth plot based on data from the TTR aerial gamma survey. One net negative (-3σ , green) and one net positive ($+3\sigma$, red) isopleth are shown. No detectable ^{238}U was found.

Figure 11: Distribution of ^{238}U net counts. Minimum Detectable Activity values were computed from this distribution.

DISTRIBUTION

DOE/DP

L. E. Gordon-Hagerty (1)
O. W. Taylor (1)

DOE/HQ

OSTI (2)

DOE/NV

K. J. Cabbie (10)
M. R. Dockter (1)
Public Reading Room (1)
TIO (1)

EG&G/EM

J. F. Doyle LVAO (1)
T. J. Hendricks LVAO (1)
H. A. Hopkins LVAO (1)
A. E. Proctor LVAO (1)
G. R. Shipman WAMO (1)
W. J. Tipton LVAO (1)
P. H. Zavattaro LVAO (1)
Central Files (1)

LIBRARIES

RSL (20)
TIC (1)
WAMO (1)

AN AERIAL RADIOLOGICAL SURVEY OF THE TONOPAH
TEST RANGE
INCLUDING CLEAN SLATE 1, 2, 3,
ROLLER COASTER,
DECONTAMINATION AREA
CACTUS SPRINGS RANCH
TARGET AREAS
CENTRAL NEVADA
EGG 11265-1145

DATE OF SURVEY: AUGUST-OCTOBER 1993
DATE OF REPORT: AUGUST 1995