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Revision 0

An Aerial Radiological Survey of the Hanford BC Controlled Area and West Lake Area

Survey Data - September 22 to 30, 2009

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

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C. Lyons
National Security Technologies, LLC

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ABSTRACT

CH2M Hill Plateau Remediation Company, a prime contractor to the U.S. Department of Energy-Richland Office (DOE-RL), requested the National Nuclear Security Administration (NNSA), Nevada Site Office (NSO) Remote Sensing Laboratory (RSL) to provide an aerial radiological survey of the BC Controlled Area (BCCA) located on the DOE-RL Hanford Site in Southeastern Washington State. Animal intrusions and subsequent wind dispersion of contaminants has resulted in shallow soil contamination within the northern part of the BC Controlled Area, an area of approximately 1,500 hectares (3,707 acres).

The data were collected by the Aerial Measuring System (AMS) Radiation and Environmental Data Acquisition and Recorder, Version V (REDAR-V) using an array of twelve 2" × 4" × 16" (5 x 10 x 40 cm) sodium iodide detectors flown onboard a twin-engine Bell 412 helicopter. The data were geo-referenced using a Differential Global Positioning System (DGPS). Gamma-energy spectra were collected every second during the survey. The surveys were performed in September 2009. The purpose of the survey was to update the previous radiological surveys of the BCCA and West Lake area. The aerial survey parameters for an altitude of 15 meters (50 feet) AGL and parallel line spacing of 23 meters (75 feet) were decided upon to maximize the man-made radiation sensitivity and reduce the effective footprint of the helicopter radiation acquisition system.

Gross Counts, inferred exposure rates, man-made activity, Cesium-137 activity and Americium-241 activity, as calculated from the aerial data are presented in the form of contoured isopleth maps superimposed on imagery of the surveyed areas. In addition, the point data results for the man-made, Cesium-137 and Americium-241 are provided as requested to facilitate ground-based characterization efforts. One of the survey objectives was to conduct a 100% gamma scan of the survey areas as per the MARSSIM scoping survey objectives. The survey flight results are provided to document the conduct of the survey to meet this objective.

The gross count and exposure rate results were comparable to the 1996 survey results. The BCCA deposition footprint was more complex than previously mapped due to the enhanced spatial resolution and detectability.

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ACRONYMS AND ABBREVIATIONS

Ac-228	Actinium-228
AGL	above ground level
Am-241	Americium-241
AMS	Aerial Measuring System
BCCA	BC Controlled Area
Bi-214	Bismuth-214
cm	centimeter
Co-60	Cobalt-60
cps	counts per second
Cs-137	Cesium-137
DGPS	Differential Global Positioning System
DOE	U.S. Department of Energy
ER	exposure rate
FWHM	Full Width at Half Maximum
GIS	Geographical Information Systems
HNR	Hanford Nuclear Reservation
K-40	Potassium-40
LOI	Line of Interest
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDA	Minimum Detectable Activity
MMGC	man-made gross count
NaI(Tl)	thallium-activated sodium-iodine
NNSA	National Nuclear Security Administration
NSO	Nevada Site Office
pCi/g	Picocuries per gram
Pb-213	Lead-214
RA	radar altimeter
RadCon	Radiological Control
REDAC	Radiation and Environmental Data Analysis Computer
REDAR-V	Radiation and Environmental Data Acquisition and Recorder, Version V
ROI	region of interest
RSL–N	Remote Sensing Laboratory–Nellis
Sr-60	Strontium-60

Th-232	Thorium-232
Tl-208	Thallium-208
U-238	Uranium-238
USGS	United States Geological Survey
µR/h	microroentgens per hour
WAAS	Wide Area Augmentation System

1. Introduction

CH2M Hill Plateau Remediation Company, a prime contractor to the U.S. Department of Energy-Richland Office (DOE-RL) requested the National Nuclear Security Administration (NNSA), Nevada Site Office (NSO), Remote Sensing Laboratory (RSL) operated by the National Security Technologies LLC (NSTec) in Las Vegas, Nevada to provide an aerial radiological survey of the BC Controlled Area (BCCA) located on the DOE-RL Hanford Site in Southeastern Washington State.

The data were collected by the Aerial Measuring System (AMS) Radiation and Environmental Data Acquisition and Recorder, Version V (REDAR-V), using an array of twelve 2" × 4" × 16" (5 x 10 x 40 cm) sodium iodide detectors flown onboard a twin-engine Bell 412 helicopter. The data were geo-referenced using a Differential Global Positioning System (DGPS). Gamma energy spectra were collected every second during the survey. This spectral data allows the system to distinguish between ordinary fluctuations in natural background radiation levels and signatures produced by man-made isotopic sources. Spectral data can also be used to identify specific radioactive isotopes.

The current survey data is in substantial agreement with previous surveys of the Hanford Nuclear Reservation (HNR) and surrounding area.

2. Survey Site Description

The Hanford Nuclear Reservation lies within the Pasco Basin of the Columbia Plateau in south-central Washington State and covers an area of 1,450-square-kilometers (560-square-miles). This area is a semi-arid, shrub-steppe region with a normal annual rainfall of 16 cm (6.3-inches). The Columbia River flows through the northern part of the reservation and forms part of the site's eastern boundary. The Yakima River runs along the southern boundary and joins the Columbia River below the city of Richland, which is located at the site's southeastern boundary. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the south-western and western boundaries. The Saddle Mountains form the northern boundary. The nearest population center is the Tri-Cities area (Richland, Pasco and Kennewick), located directly downstream from the site.

Since the facility began operation in 1944, activities at the HNR have centered on the nine graphite moderated plutonium production reactors located along the southern bank of the Columbia River within the six 100-Areas. All nine of the reactors have been shutdown. Located in the center of the reservation were two large chemical separation areas (200-East and 200-West), where plutonium and uranium were extracted from irradiated uranium fuel elements. Large quantities of liquid and solid radioactive wastes are stored at underground tank farms and burial sites located within and around the 200-Areas.

The BCCA (Hanford Waste Information Data Systems Unplanned Release Site [UPR-200-E-83]) is part of the 200-UR-1 Unplanned Release Waste Group Operable Unit (OU). The BC Cribs and

Trenches complex consists of six cribs—engineered soil waste disposal sites—and 20 trenches that were used in the 1950s to absorb more than 30 million gallons of contaminated waste from the chemical separations plant at the 200-areas. Before the Cribs and Trenches were capped with a sand and gravel intrusion barrier in 1969, badgers, rabbits, and mice had burrowed into them and eaten the cesium and strontium salts and then spread radioactivity to surrounding areas through biological processes. These animal intrusions and subsequent wind dispersion of contaminants has resulted in shallow soil contamination within the northern part of the BCCA, an area of approximately 1,500 hectares (3,707 acres).

The BCCA was divided into separate regions based on past historical information and recent analytical sampling events. The northern part of the BCC A is located north of the sand dunes that cross the controlled area from east to west. Within the northern part of the BCCA is a region (referred to as "Zone A"), which has the highest levels of contamination from Cesium-137 (Cs-137) and Strontium-90 (Sr-90). Zone A is approximately 57 hectares (141 acres). The remainder of the northern part of the BCCA contains some areas of contamination in an irregular pattern; however, these are generally considered to be of lower risk to human health and the environment. This region is referred to as "Zone B". The southernmost section of the BCCA, designated as "Zone C", is approximately 8 square miles and had a few spots of contamination.

2.1 Aerial Survey Objectives

The aerial survey parameters for an altitude of 15 meters (50 feet) AGL and parallel line spacing of 23 meters (75 feet) were negotiated with CH2M Hill to maximize the man-made radiation sensitivity and reduce the effective footprint of the helicopter radiation acquisition system to meet data quality objectives for characterization of the BC Controlled Area for pending remediation activities.

Data Quality Objectives include:

- Provide multiple data points for the planned grid areas within the sites. The grid sizes are expected to range from 1,000 m^2 to 10,000 m^2. The effective footprint for the helicopter detection system is approximately 730 m^2 at 50' (~15 meters) AGL.
- Conduct a 100% gamma scan survey of the project area as required by the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) for scoping a survey. The line spacing for the survey was reduced to 75' from the normal 100' to provide overlap between adjacent survey lines to approach the 100% goal as closely as practicable.
- Ensure that the Minimum Detectable Activity (MDA) of the acquisition system is a fraction of the range of action levels or clean-up levels under negotiation. The calculated MDA for Cs-137 at the 50' altitude was approximately 0.4 pCi/g using default assumptions for a wide area distribution and exponential distribution in soil. The lowest action level for Cs-137 is currently estimated at 2.9 pCi/g dependant on a final Cs-137 to Sr-90 ratio.

- Provide Geographical Information Systems (GIS) shape files for the contoured data and point data with sufficient metadata to allow customer manipulation of the GIS products for use in operations and other documentation.
- Conduct a survey of the West Lake and Gable Mountain Pond areas. NOTE: Due to the lack of information regarding the distribution pathways for contamination at these sites, the default assumptions for wide area distribution and exponential distribution in the soil were not used to convert the net Cs-137 counts to pCi/g levels for this report.

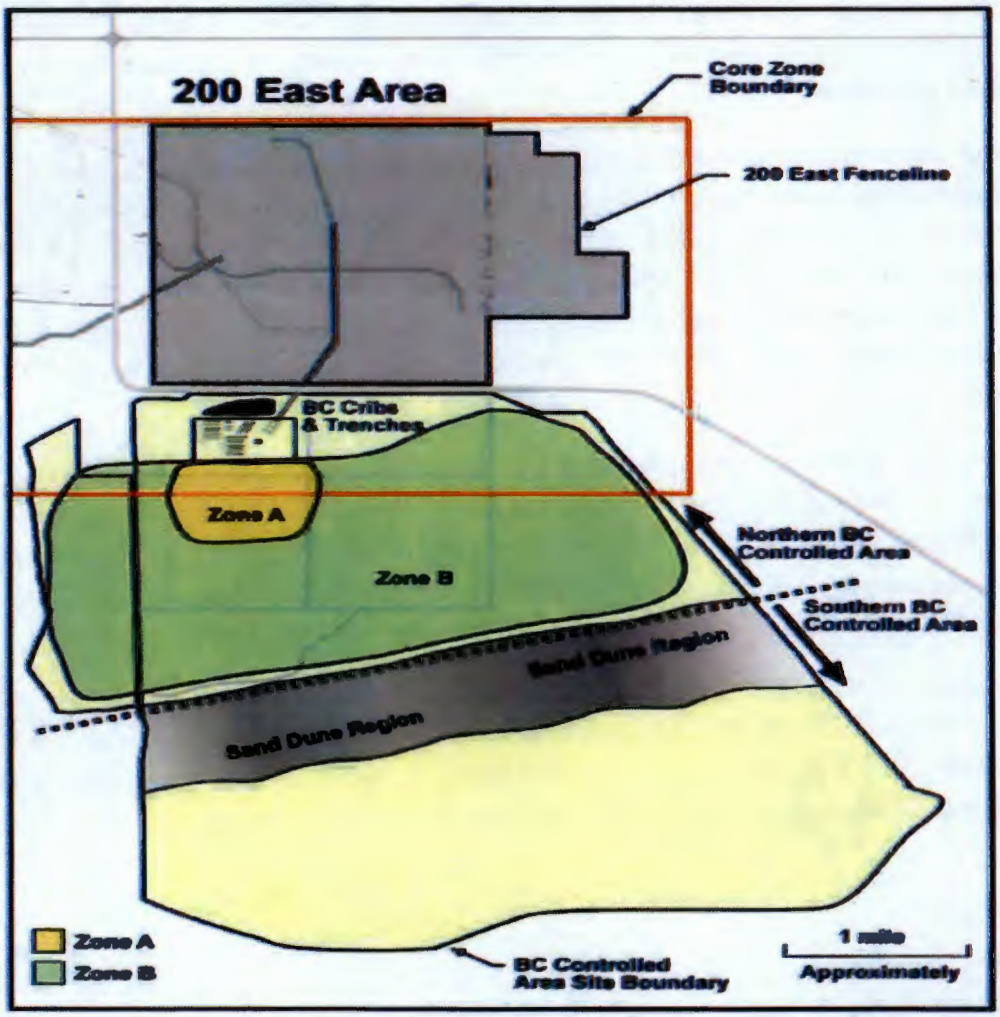


Figure 1. Map of BCCA and 200 East Area

2.2 1996 Aerial Survey

At the request of the U.S. DOE NNSA an aerial radiological survey of the HNR located northwest of Richland, Washington was conducted from February 29 to March 21, 1996, that covered a 1,450-square-kilometer (560-square-mile) area. Additional flights were conducted along the banks of the Columbia River extending from the Priest Rapids Dam in the northwest to Kennewick in the southeast. The survey was performed by the RSL, which is currently maintained and operated by NSTec.

The purpose of the survey was to measure and map the natural and man-made gamma radiation emanating from the area within and surrounding the site's boundaries. This survey was the fifth of its type at HNR and was conducted as a routine part of an on-going DOE research and environmental monitoring program.

The area was surveyed by flying at a constant ground speed of 80 knots (41 meters per second), at a nominal altitude of 61 meters (200 feet) AGL, and along a parallel set of flight lines spaced 122 meters (400 feet) apart, totaling approximately 12,900 flight line kilometers (~8,000 miles). The flight lines were flown in either a southerly or northerly direction. All data were scaled to overlay USGS topographic survey maps or selected aerial photographs (May 1996) of the HNR site and the Columbia River shoreline. The results of the 1996 survey over the 200 East area and BCCA are shown in Figure 2.

Excluding the man-made gamma footprint from the US Ecology facility, the man-made gamma footprint south of the BC Cribs and Trenches derived from previous aerial surveys was used to establish the historical BCCA boundaries that continue to be in effect for this survey and project. The HNR Radiological Control (RadCon) and project personnel had conducted limited characterization surveys within the BCCA, but had not reduced the boundaries before this survey.

The numbers within Figure 2 are references to each of the primary man-made gamma footprints from the various facilities. The net spectra results for each of these numbered areas are available in the 1996 report. The work scope for this 2009 survey included producing net spectra results for the BCCA and US Ecology sites for comparison to the 1996 net spectra results.

Figure 2. Man-made Gross Count Results from 1996 Survey

3. Survey Procedure

3.1 Aerial Survey

During the planning for the BCCA survey, the customer expressed concerns about the helicopter flying 50' AGL over active facilities and other work areas. To accommodate the work schedules and air space issues, the survey flight lines were set to fly in an east-west orientation to avoid overflight of the 200 East facilities. In addition, the survey schedule was adjusted to fly the north section of the survey area over the U.S. Ecology facility and project work areas on Friday and Saturday during normal off days. The entire BCCA flight line set-up is shown in Figure 3. The figure shows every tenth survey line because the large number (224 lines) and tight spacing of lines would cover all landmarks in the BCCA image. Figure 5 shows the planned survey lines over the West Lake site and the Gable Mountain Pond site. The Gable Mountain Pond site, Figure 4, was added to the work scope due to the 1996 survey result showing an elevated man-made anomaly ~ 1 mile from the West Lake site.

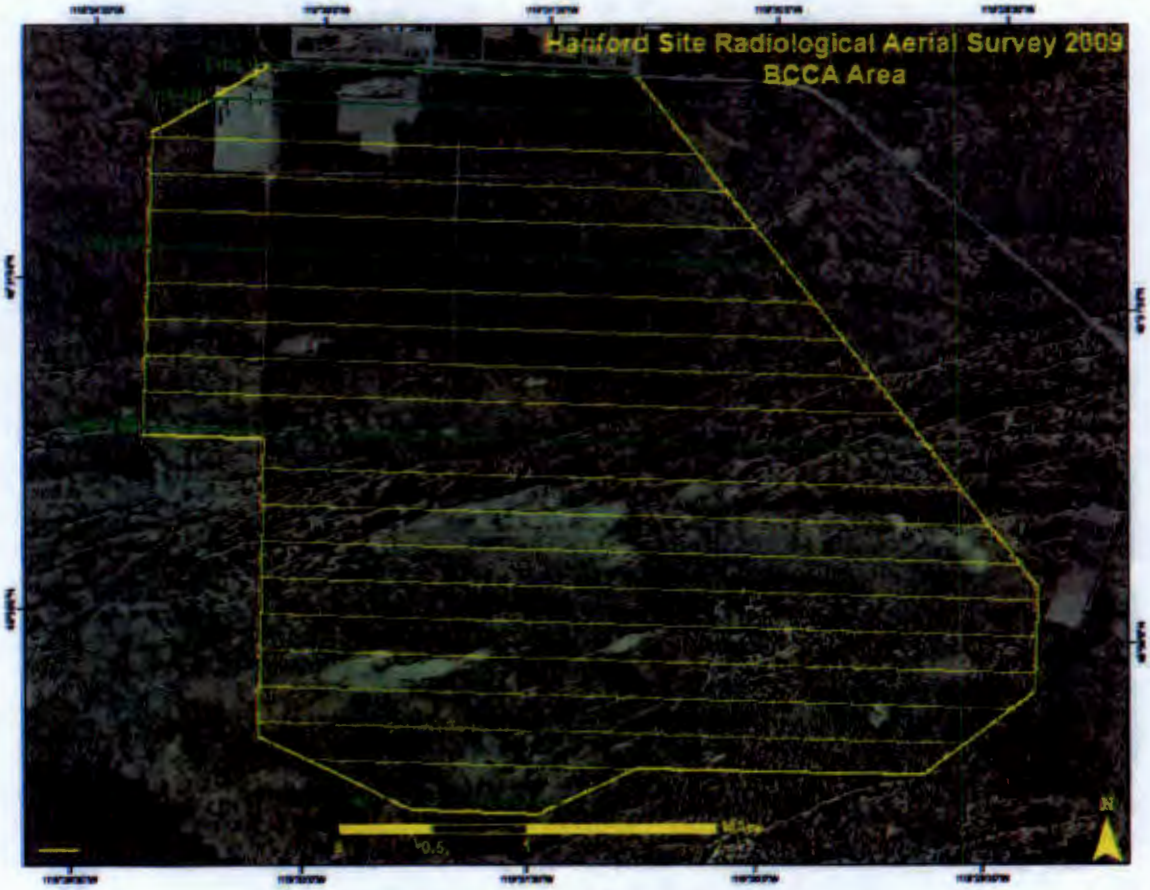


Figure 3. BCCA Planned Survey Lines

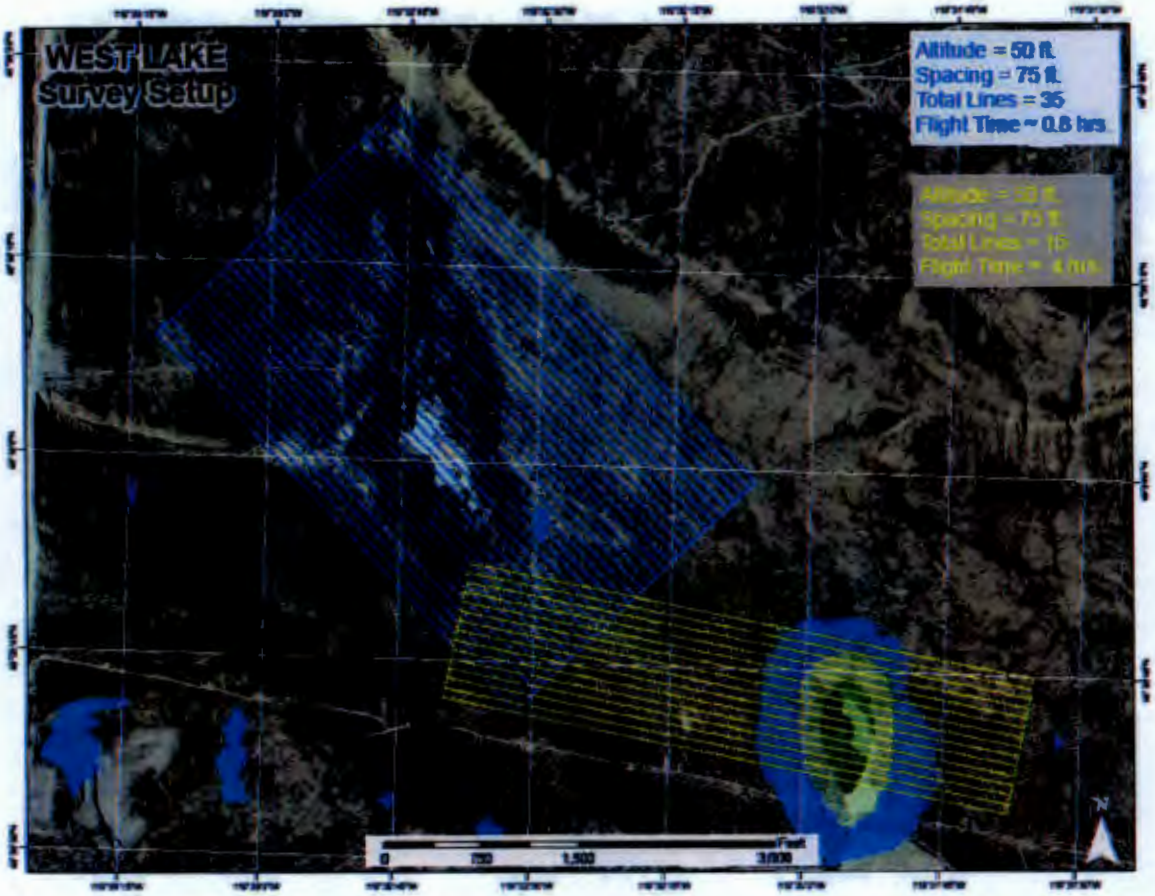


Figure 4. West Lake/Gable Mountain Pond Planned Survey Lines with 1996 Data

The use of GIS software to display AMS survey results has grown tremendously over recent years. However, the inclusion of map and image layers under the AMS results has shown the continued value of survey "perimeter" flights. The objective of the flight is to fly directly over a series of roads, power lines, pipelines, etc. at survey altitude to provide the first overlay on an image or map to be used to present data results. If the perimeter lines do not match the map or image projection, all subsequent data will not be positioned correctly. An example of the helicopter perimeter lines overlaid on a simple map projection of the HNR is provided in Figure 5. This map is acceptable for the accurate display of the survey data.

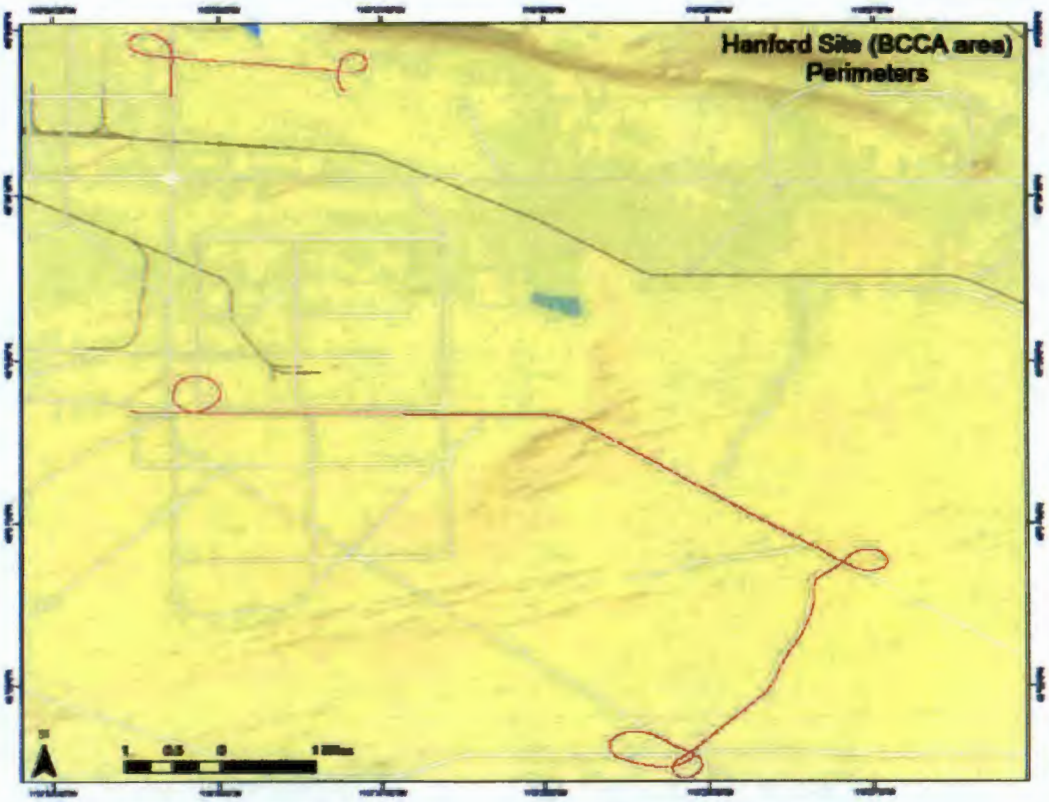


Figure 5. Example of Perimeter Line Results on a Map Layer

To assure data integrity and to monitor/correct for variations in detector background count rate due to aircraft, radon, and cosmic rays, repeated measurements were made over a fixed test line before and after each flight. A fixed test line was located on the route to each location and was chosen to represent typical geology and elevation features of each site. The path was flown at the survey altitude and survey speed and in the same direction each time. If the detectors were working properly, then any change in the amount of recorded radiation would have been an indication of a change in the amount of radon in the air (a variation that occurs over several hours) or a change in the cosmic radiation flux (a variation that occurs slowly over several days but can change abruptly due to sun spots). If the detectors were not working properly, the spectral changes would have been much larger than those typically encountered as background radiation changes. The fixed test line was located approximately 1.8 kilometers (1.0 mile) east of the BCCA.

The data set collected every second during the flight consists of positional and altitude data, atmospheric information, and gamma-ray energy spectra. The first flight of each survey was the previously discussed perimeter flight.

Another test line flown at the start and end of each survey flight was the water line. This flight consisted of selecting a section of the Columbia River with sufficient width to eliminate the terrestrial count rate contribution to the detectors. From these data, the air attenuation coefficient and an initial background count rate from cosmic radiation and the aircraft itself are determined. These values are used to adjust the measurements for minor fluctuations in altitude during subsequent flights. The river area selected was west of the US-395 Bridge connecting Pasco to Kennewick. It was approximately 3 miles southwest of the Tri-Cities airport which was the base of operations for the surveys.

3.2 Aerial Survey Equipment

The aerial survey was conducted using the AMS helicopter. The detection system consists of a Bell-412 helicopter, a Radiation and Environmental Data Acquisition and Recorder, Version V (REDAR-V) system, a Trimble DGPS and two large detector pods externally mounted on each side of the helicopter. Each pod contained six 2" × 4" × 16" thallium-activated sodium-iodine, NaI(T*l*), gamma ray detectors.

3.2.1 Data Recording

The preamplifier signal from each detector was calibrated using naturally occurring Potassium-40 (K-40) and Americium-241 (Am-241) gamma check sources. Normalized outputs from 12 large detectors were combined in a summing amplifier, and the signal was adjusted in the analog-to-digital converter so that the calibration photopeaks appeared in preselected channels in the REDAR-V multichannel analyzer. The data from the multichannel analyzer were used to produce second-by-second records containing the number of gamma rays detected at each specific gamma-ray energy. Each record, therefore, constitutes a specific gamma-ray spectrum. As every radioactive material, natural or man-made, has its own unique set of gamma rays, spectra can be used to identify and separate sources of detected gamma radiation.

The REDAR-V, which produces the gamma-ray spectra described above, is a multi-processor data acquisition and real-time analysis system custom-designed by the RSL to operate in the severe environments associated with platforms such as helicopters, fixed-wing aircraft, and various ground-based vehicles. The system displays radiation and positional information in real time to the operator via video displays and multiple digital readouts. Archival gamma-ray spectra, aircraft position, meteorological parameters, real-time clock, and other data reference information are recorded at one-second intervals on digital data storage devices for post-flight analyses.

3.2.2 Helicopter Positioning

The helicopter's position was measured by using two systems: a Trimble DGPS (utilizing Wide Area Augmentation System [WAAS] differential corrections) and a radar altimeter (RA). The DGPS provides continuous position information using a constellation of 24 satellites. The DGPS has a horizontal positional accuracy (1 sigma) of ±1 meter (3 feet). The RA determines the helicopter's altitude by measuring the round-trip propagation time of a signal reflected off the ground. The manufacturer's nominal accuracy of the RA is quoted as 2 feet or 2%, whichever is greater.

3.2.3 Data Processing

For each flight, aerial survey data were downloaded for processing from an Iomega zip drive into the PC-based Radiation and Environmental Data Analysis Computer (REDAC) system. This system provided onsite preliminary analysis of the aerial data on a flight-by-flight basis and monitored pre- and post-flight quality assurance checks.

4. Analysis Procedures

4.1 Aerial Data Analysis

The aerial radiation data have contributions from the naturally occurring radionuclides, man-made radionuclides, airborne radon, cosmic rays, and radioactive materials present in the aircraft. Contour maps were produced by processing the aerial data using extraction methods discussed in this section. More detailed mathematical steps are discussed in the previous survey report.

4.1.1 Terrestrial Exposure Rate

The terrestrial exposure rate was derived from the integral counting rate in the gamma energy spectrum range between 38 and 3,026 keV. This count rate, measured in counts per second (cps) at survey altitude, is converted to exposure rate (ER) in μR/h at 1 meter AGL by using the following equation:

$$ER\left(\frac{\mu R}{h}\right) = \frac{GC-B}{2055} \cdot e^{(A-50)\cdot C} \qquad (1)$$

where

GC = gross count rate at survey altitude (cps)
B = background count rate at survey altitude (cps)
A = Distance above ground level from RA (feet)
C = gamma ray air attenuation coefficient (feet^{-1})

The background count rate (B), determined initially from the test line altitude profile and adjusted on a flight-by-flight basis, consists of cosmic rays, the aircraft system, and airborne radon. The air attenuation coefficient, C, also determined from the test line data, was 0.001761 $feet^{-1}$ (0.005778 $meter^{-1}$). The conversion factor (2,055 cps/μR/h) for 50 feet (16 meters) AGL was determined from documented calibration test lines located in Clark County, Nevada. The calibration range used was to relate the count rate observed at different altitudes with different detector arrays to the exposure rate measured at 1 meter (3 feet) AGL using a pressurized ionization chamber. The conversion factor assumes a uniformly distributed radiation source: 1) covering an area that is a large when compared to the field of view of the detector system (a circle with a diameter roughly twice the altitude of the aircraft), and 2) having a gamma-ray energy distribution similar to that of the natural background of the calibration test line.

4.1.2 Man-Made Gross Count

The aerial data were also used to determine the location of man-made radionuclides. The man-made gross count (MMGC) is the portion of the gross count that is directly attributed to the gamma rays from man-made radionuclides. In general, evidence of man-made radionuclides can be found from increases in the gross count rate. However, slight variations in the gross count do not always indicate the presence of a man-made anomaly, since these variations can result from geological fluctuations or changes in the ground coverage (e.g., river, dense vegetation, buildings).

In order to increase the sensitivity to detect man-made anomalies, an MMGC algorithm has been developed that uses spectral energy extraction techniques to detect man-made activity. This algorithm takes advantage of the fact that while background radiation levels often vary by a factor of two or more within a survey area, background spectral shapes remain essentially constant. More specifically, the ratio of natural components in any two regions (windows) of the energy spectrum will remain nearly constant.

Although this procedure can be applied to any region of the gamma energy spectrum, for general man-made activity, common practice is to place all counts from 38 to 1,394 keV into the man-made window (low energy sum), where most of the long-lived, man-made radionuclides emit radiation, and to place all counts above 1,394 to 3,026 keV into the natural window (high energy sum), where mostly the naturally occurring radionuclides emit radiation. The MMGC rate can be expressed analytically in terms of the integrated count rates in specific gamma energy spectral windows (keV):

$$MMGC = \sum_{E=38}^{1394} S(E) - K_{nat} \cdot \sum_{E=1394}^{3026} S(E) \qquad (2)$$

where K_{nat} is measured over an area that only contains gamma radiation from naturally occurring radionuclides as

$$K_{\text{[illegible]}} = \frac{\sum_{E=38}^{1394} S(E)}{\sum_{E=1394}^{9026} S(E)} \tag{3}$$

This MMGC algorithm is sensitive to low levels of man-made radiation even in the presence of large variations in the natural background. When man-made radioactivity has been identified, a detailed analysis of the gamma energy spectrum is conducted to ascertain which radionuclides are present.

4.1.3 Cesium-Specific Isotope Extraction Algorithm

The Cs-137 isotope has a primary a photopeak at 662 keV. The variable natural background also contributes to that photopeak. A spectrum-based algorithm can remove the variable background contribution in a second-by-second operation. The resulting data has a statistical distribution of counts centered around a net value of zero in regions of background-only. If a statistically significant source is present, its activity will show up as an excursion above the statistical bounds associated with the natural background activity.

The form and function of the Cs-137 extraction algorithm is set for the specific extraction of the Cs-137 source contribution. The source energy window (region of interest or ROI) is set to 594 through 730 keV. The background energy windows are set to 526 through 594 keV for background 1 and 730 through 798 keV for background 2. The three-window algorithm is very useful in extracting photopeak counts where the shape of the Compton-scatter contributions from other isotopes is changing significantly.

4.1.4 Cesium-Specific Volumetric Activity Conversion Algorithm

Conversion of airborne count rate information to soil volumetric activity involves a number of parameters. These include detector type, number, and configuration; flight altitude and speed; isotope of interest; specific extraction algorithm; specific distribution of isotope in soil; soil density and moisture.

For estimation purposes, AMS utilizes a sensitivity estimation program written by an RSL scientist. Provided with detector configuration, aircraft speed, and isotope of interest, the program estimates sensitivity conversion numbers for point source and infinite spatial extent distributions including surface, uniform soil depth, and exponentially distributed soil depth. Resource materials from numerous technical references as well as a number of assumptions are embodied in the software.

For the Hanford survey, the value of 0.004 pCi per gram per 1 net photopeak count of Cs-137 was utilized to create the initial Cs-137 3-window extraction pCi/g map products.

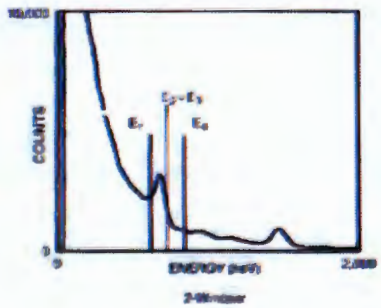
For a detailed description of the analysis techniques used to convert from spectra gross counts to an initial isotope-specific volumetric activity (pCi/g) estimate, Appendix B is provided.

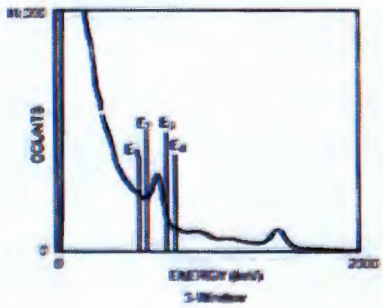
4.1.5 Americium-Specific Isotope Extraction Algorithm

Although the project had identified Cs-137 as the only significant gamma emitter within the BCCA and West Lake survey areas, data analysis for americium was requested. The HR was the primary location for plutonium production since the 1940's. Since plutonium is a very weak gamma-ray emitter, the only practical way to determine the areas of plutonium activity in the environment by using gamma-ray spectroscopy is to measure a radionuclide closely associated with plutonium that can be easily detected by its gamma radiation emissions. The most abundant gamma ray related to plutonium is the 59.5-kiloelectronvolt (keV) gamma ray from the decay of Am-241, which is a daughter product of plutonium-241. Although the plutonium used in nuclear weapons is primarily Pu-239, the plutonium also contains traces of Pu-240 and Pu-241. The helicopter detector configuration using external pods is designed to maximize sensitivity to the Am-241 gamma energy for plutonium deposition surveys.

The source energy window (region of interest or ROI) is set to 50 through 70 keV. The background energy windows are set to 38 through 50 keV for background 1 and 70 through 82 keV for background 2. The three-window algorithm is very useful in extracting low-energy photopeak counts where the shape of the Compton-scatter contributions from other isotopes is changing significantly.

Simple examples of 2-window and 3-window isotope extractions are shown:





4.1.6 Gamma Spectral Analysis

The MMGC algorithm is very general and is sensitive to changes in the low-energy portion of the spectrum. It does not identify the cause of the change. The changes can be caused by:

- A man-made isotope in the survey region
- Scattered gamma rays from natural radionuclides
- Change in the isotope ratios from where the ratio of low-energy to high energy spectral windows was measured.

Normally, the number of counts for a given energy in a 1-second spectrum are too small to make an identification of a specific isotope possible. To increase the number of counts and improve the statistics, a number of adjacent 1-second spectra are combined to produce a single spectrum for a larger area.

5. Results

5.1 Gross Count Point Data, Contour Data and Exposure Rate Contour Maps (BCCA)

Many components contribute to forming the total measured gamma-ray energy spectrum. The term "natural background radiation" is generally considered to comprise the natural terrestrial radionuclides, airborne radon gas and its daughter products, and cosmic rays. The man-made radionuclides (such as Am-241 and Cs-137), produced through human actions, are generally the components of the radiation field of most interest. The final contribution of spectrum counts to the system represents radioisotopes present in the measuring equipment and all sources of "noise" in the final spectrum—including electrical noise in the electronics.

Naturally Occurring Radioisotopes. Long-lived radionuclides present in the earth's crust are usually the largest source of natural background radiation. Naturally occurring, gamma ray-emitting isotopes found in the soil and bedrock consist mainly of radionuclides from the Uranium-238 (U-238) and Thorium-232 (Th-232) decay chains and from K-40. The most prominent natural isotopes usually seen in aerial gamma-ray spectra are K-40 (0.12 percent of natural potassium), thallium-208 (Tl-208) and Actinium-228 (Ac-228) (daughters in the Th-232 chain), and lead-214 (Pb-214) and bismuth-214 (Bi-214) (daughters in the U-238 chain). The naturally occurring isotopes typically contribute 1–10 μR/h to the background radiation field at the HNR.

Radon and its Daughters. Radon is a noble gas and a member of both the uranium and thorium decay chains. After being created in the soil from its parent radium, radon can diffuse through the soil and become airborne. While the isotopes of radon have relatively short half lives, their daughters may become attached to dust particles in the atmosphere and contribute to the airborne radiation field until the dust eventually settles to the ground. During a rain shower, much of the airborne particles are washed out of the air and deposited on the ground thus temporarily increasing the amount of terrestrial radiation that is detected.

The contribution of radon and its daughters to the background radiation field depends on several factors including the concentration of uranium and thorium isotopes in the soil, the permeability of the soil, and the meteorological conditions at the time of measurement. Typically, the amount of airborne radiation from radon and its daughters contributes 1–10 percent of the natural background radiation level seen in RSL aerial surveys.

Cosmic Radiation. Cosmic rays entering the earth's atmosphere are the third source of natural background radiation. High-energy cosmic rays (principally protons, alpha particles, and some heavier nuclei) interact with atoms in the upper atmosphere to produce showers of secondary radiation. The secondary radiation consists mainly of electrons, gamma rays, neutrons, and mesons. The NaI detectors used in the aerial surveys are sensitive to these secondary gamma rays and x-rays and to gamma rays produced when the electrons and mesons decelerate (producing bremsstrahlung radiation) and annihilate at or near the earth's surface. The contribution of cosmic rays to the background radiation field varies with elevation above mean sea level. In the continental United States, values range from 3.3 µR/h at sea level to 12 µR/h at an elevation of 3000 meters (9800 feet). The count rate measured in the NaI detectors and attributable to cosmic rays will change very little through changes in the aircraft's altitude or elevation.

Figure 6 represents the gross count point data produced in the total energy spectrum of the acquisition system during the survey. The gross counts represent the summation of all counts recorded by the 12 detectors carried by the helicopter. The point data represents each 1-second result recorded by the helicopter acquisition system. The figure contains ~40,000 data points compiled from all the separate flights over the BCCA. Figure 7 represents the same data results that have been contoured to display area average gross count rates expected between the point data results. Data points were contoured by a triangulated irregular network (TIN) software algorithm which utilizes measured point values and locations rather than gridded data.

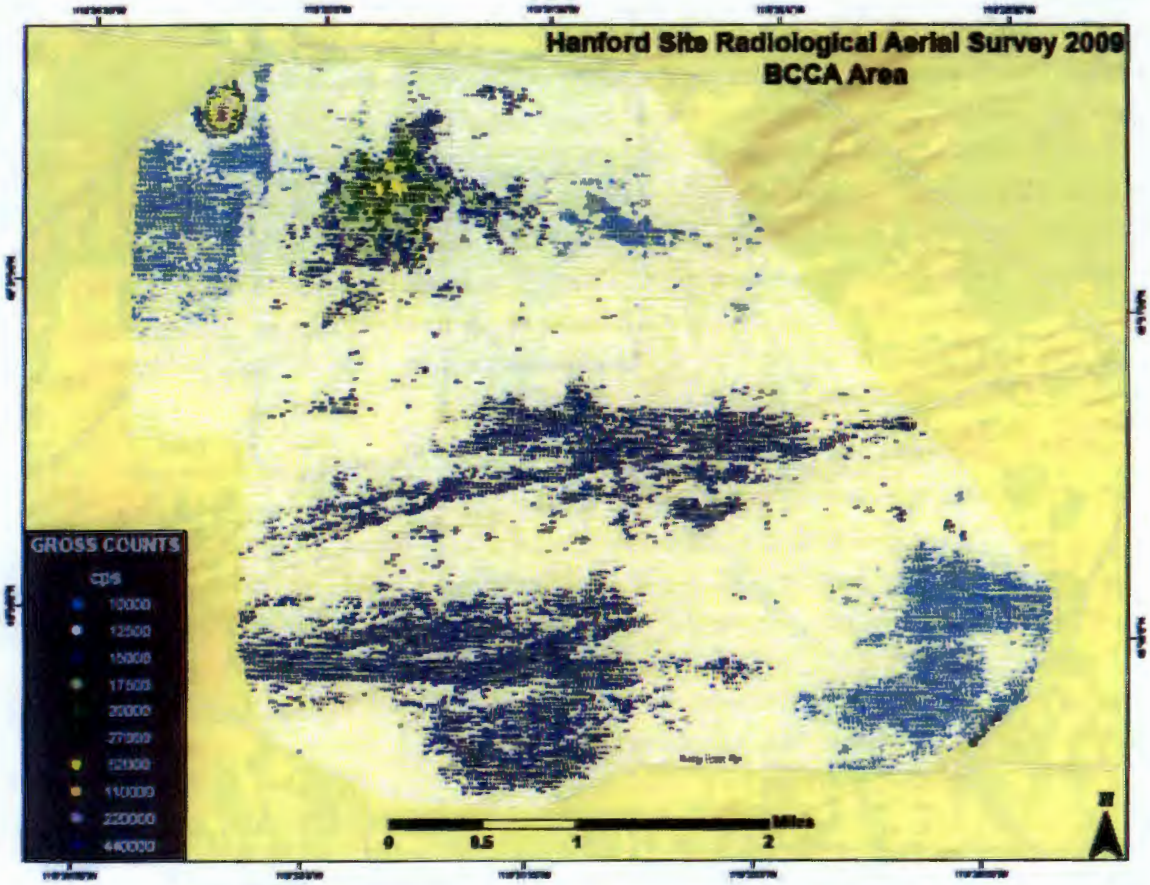


Figure 6. BCCA Total Energy Spectra Gross Count Point Data Results

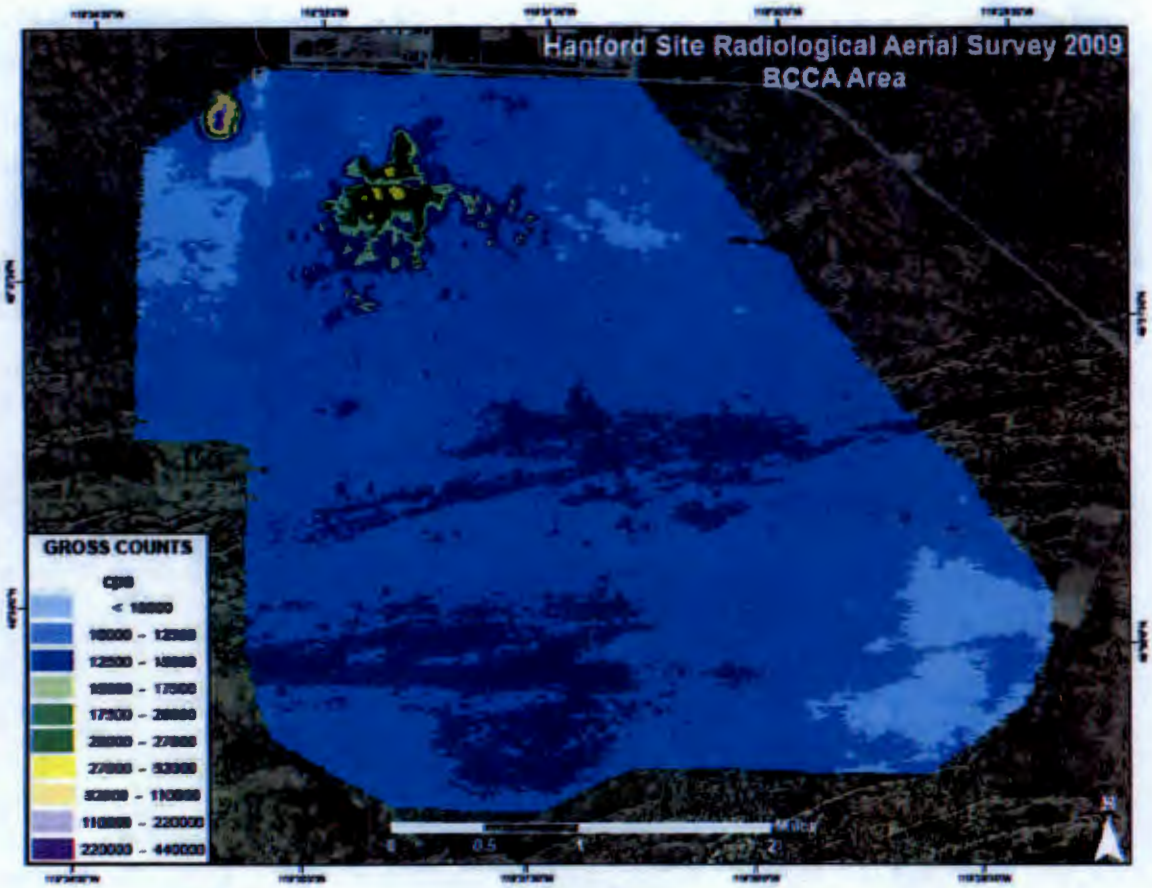


Figure 7. BCCA Total Energy Spectra Gross Count Contoured Data

Figure 8 displays the terrestrial-only gamma exposure rate inferred from the aerial data in the form of a color-fill contour map superimposed on a projected image of a portion of the HNR. Processing of the aerial measurement data removes cosmic ray, radon and aircraft contributions. The map shows high levels of radiation at the locations identified as the BCCA and U.S. Ecology facility. Over most of the survey area, the inferred exposure rates averaged 11 μR/h or less (terrestrial plus cosmic) and were typical for the natural background at the HNR. The background exposure rates are in good agreement with previous 1996 survey data.[2]

NOTE: The gamma-ray spectral composition in regions of man-made activity is significantly different from the composition observed in regions of natural background activity. Therefore, the exposure rates are estimates that are useful for relative comparisons and not as absolute values. A single exposure rate conversion, (2,055 cps/μR/h) for 50 feet (16 meters) AGL, was used to convert observed gross counts to the inferred exposure rate contours presented in Figures 8 and 11. This conversion is strictly valid only for naturally occurring radionuclides. Since this conversion is based on the higher average gamma ray energy for naturally occurring isotopes than the man-made isotope

energies observed in the BCCA survey areas, the inferred exposure rates within the man-made footprints overestimate the actual exposure rates that would be observed by portable instruments at 1 meter AGL.

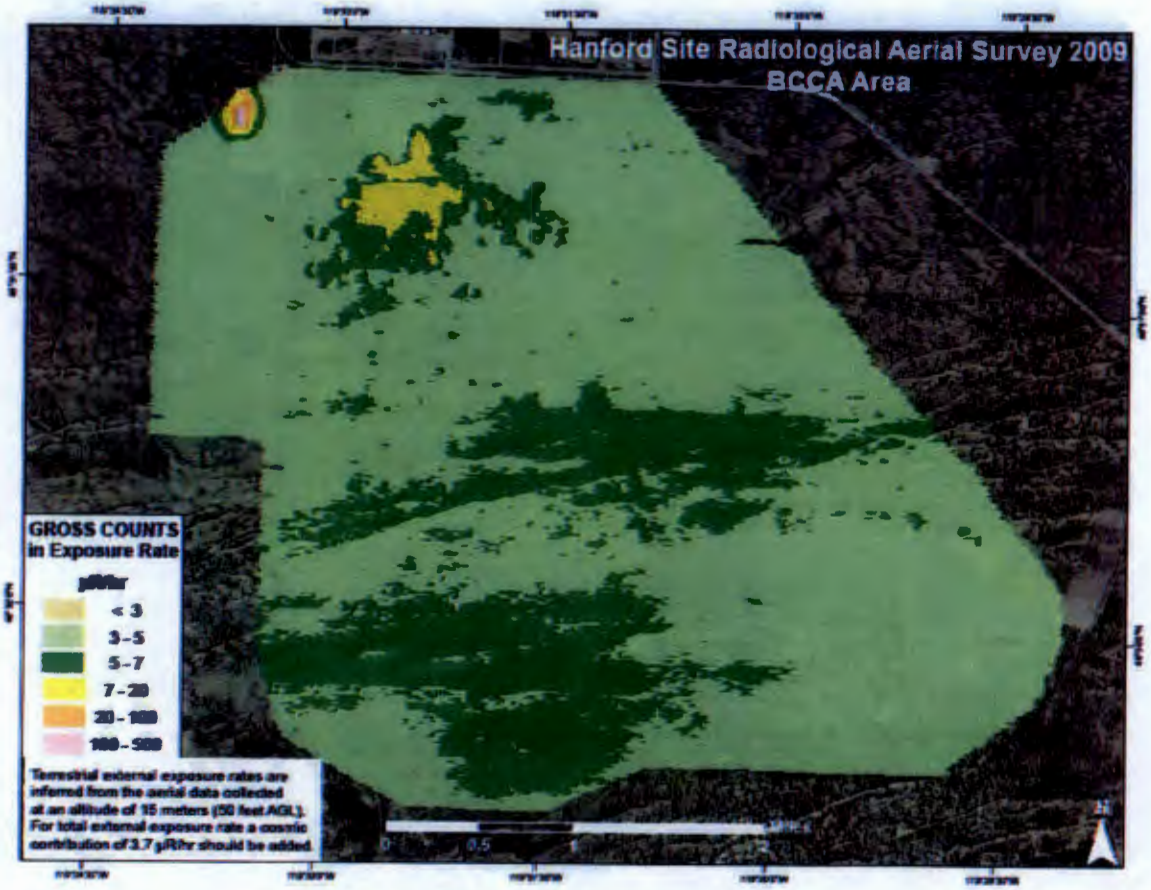


Figure 8. BCCA Inferred Gamma Exposure Rates

5.2 Gross Count Point Data, Contoured Data and Exposure Rate Maps (West Lake and Gable Mountain Pond)

Figure 9 represents the gross count point data produced in the total energy spectrum of the acquisition system during the survey of West Lake and South of West Lake sites. The gross counts represent the summation of all counts recorded by the 12 detectors carried by the helicopter. The point data represents each 1-second result recorded by the helicopter acquisition system. The figure contains ~2,000 data points compiled from one flight over each site. Figure 10 represents the same data results that have been contoured to display area average gross count rates expected between the point data results.

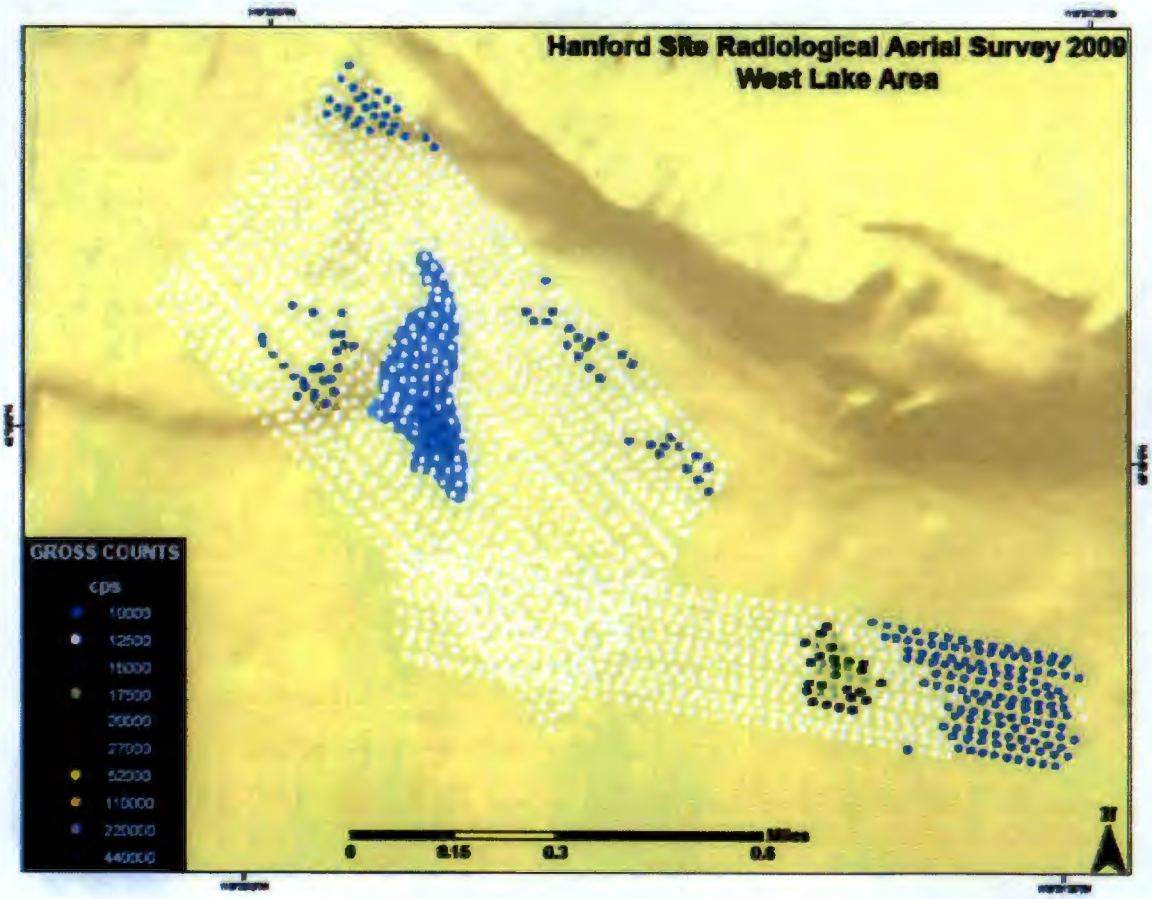


Figure 9. West Lake and Gable Mountain Pond Total Energy Spectra Gross Count Point Data

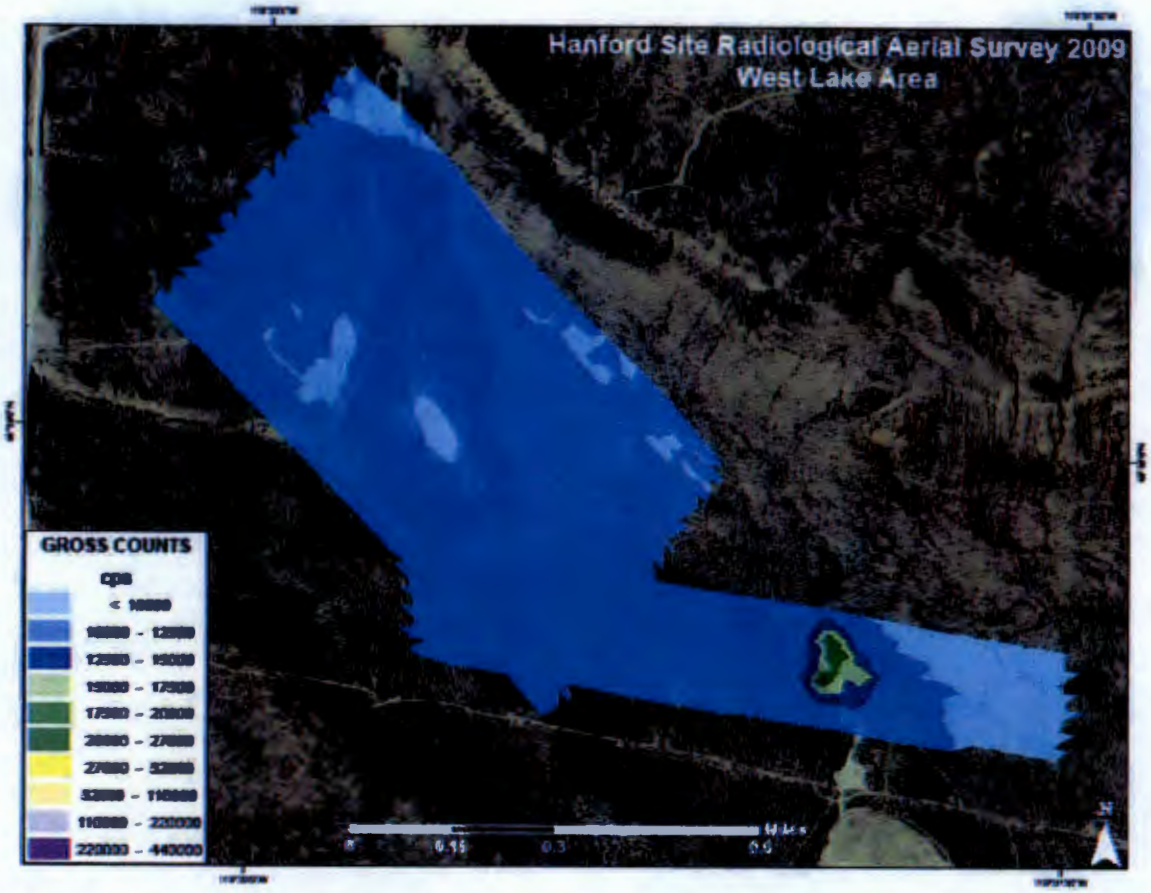


Figure 10. West Lake and Gable Mountain Pond Total Energy Spectra Gross Count Contour Data

Figure 11 displays the terrestrial-only gamma exposure rate inferred from the aerial data in the form of a color-fill contour map superimposed on a projected image of the West Lake area of the HNR. Processing of the aerial measurement data removes cosmic ray, radon and aircraft contributions. The map shows high activity at the same location identified in the 1996 survey. Over most of the survey area, the inferred exposure rates average 11 μR/h or less and are typical for the natural background at the HNR. The background exposure rates are in good agreement with previous 1996 survey data.[2]

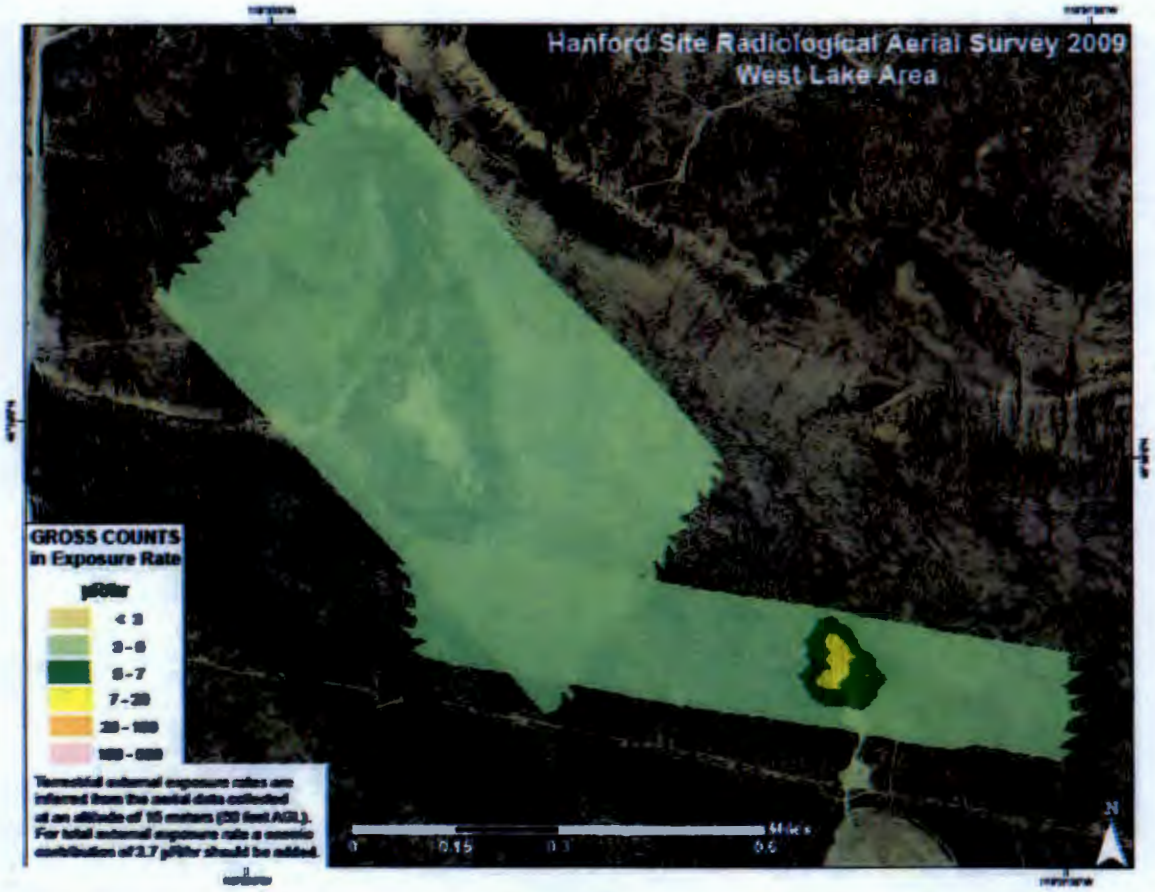


Figure 11. West Lake and Gable Mountain Pond Inferred Gamma Exposure Rates

5.3 Man-Made Gross Count Point Data Map (BCCA)

The MMGC algorithm (discussed in the Section 4.1.2) was used to study the aerial data for man-made radionuclides in the survey area. The MMGC map (Figure 12) shows the activity that is attributable to gamma radiation from man-made radioisotopes with the variable natural background component removed. Figure 12 shows the results as point data in place of the normal contour data map at the customer's request.

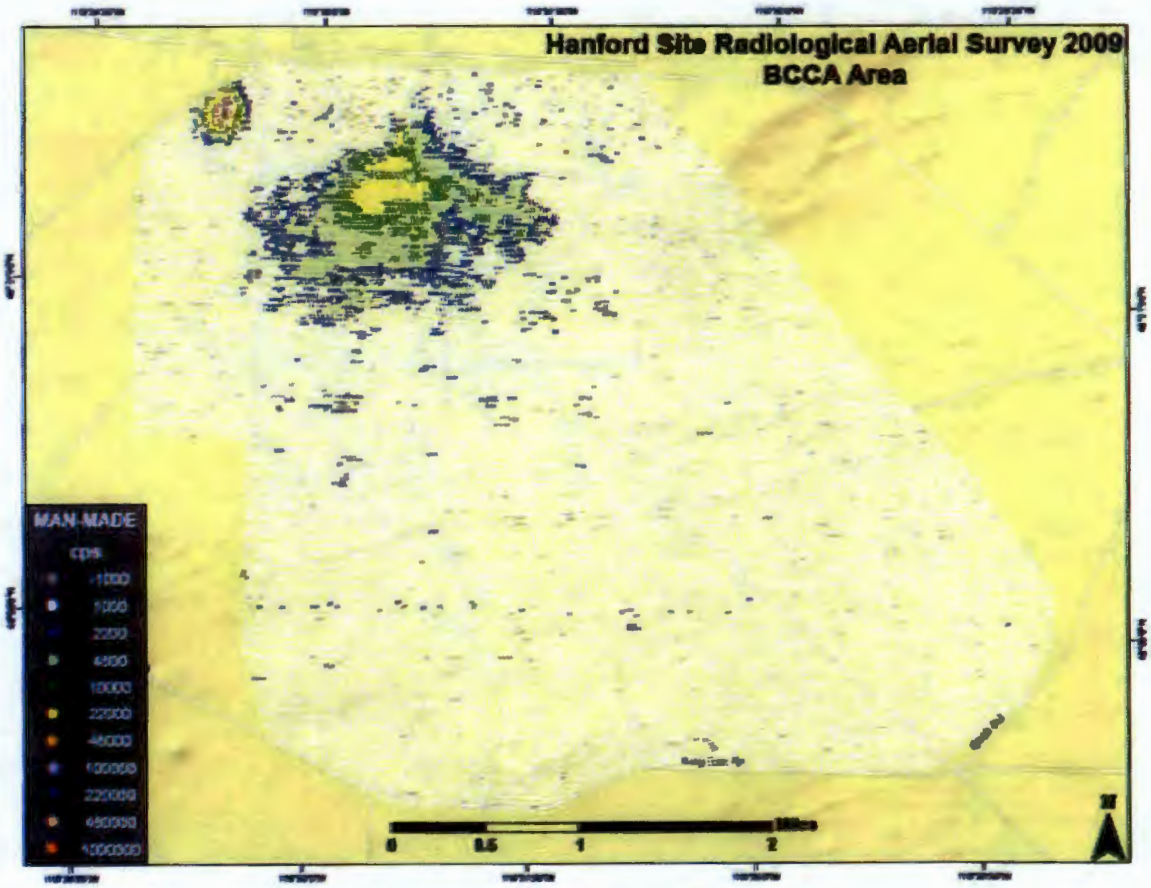


Figure 12. BCCA Man-Made Gross Count Point Data

5.4 Cesium-137 Extracted Isotope Counts Point Data and Contoured Data Maps (BCCA)

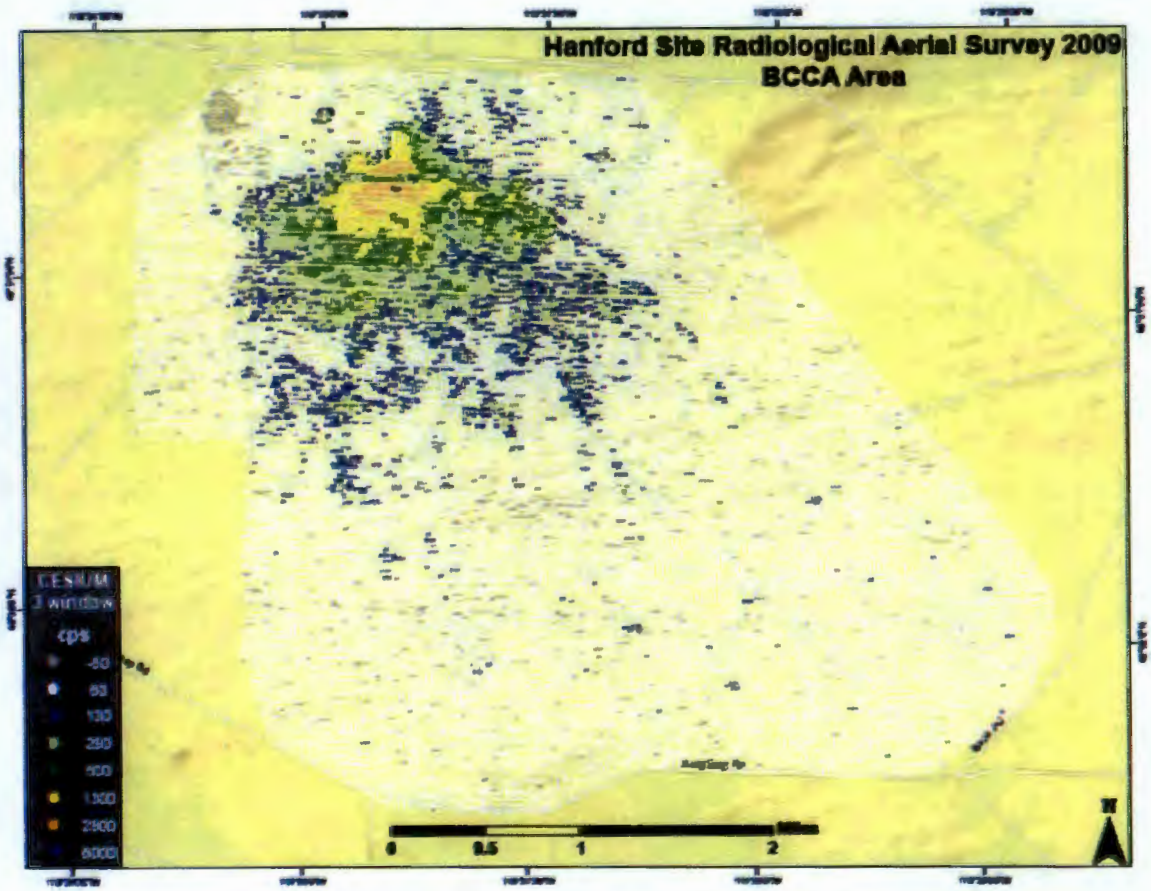


Figure 13. BCCA Cesium-137 Net Counts Point Data Results

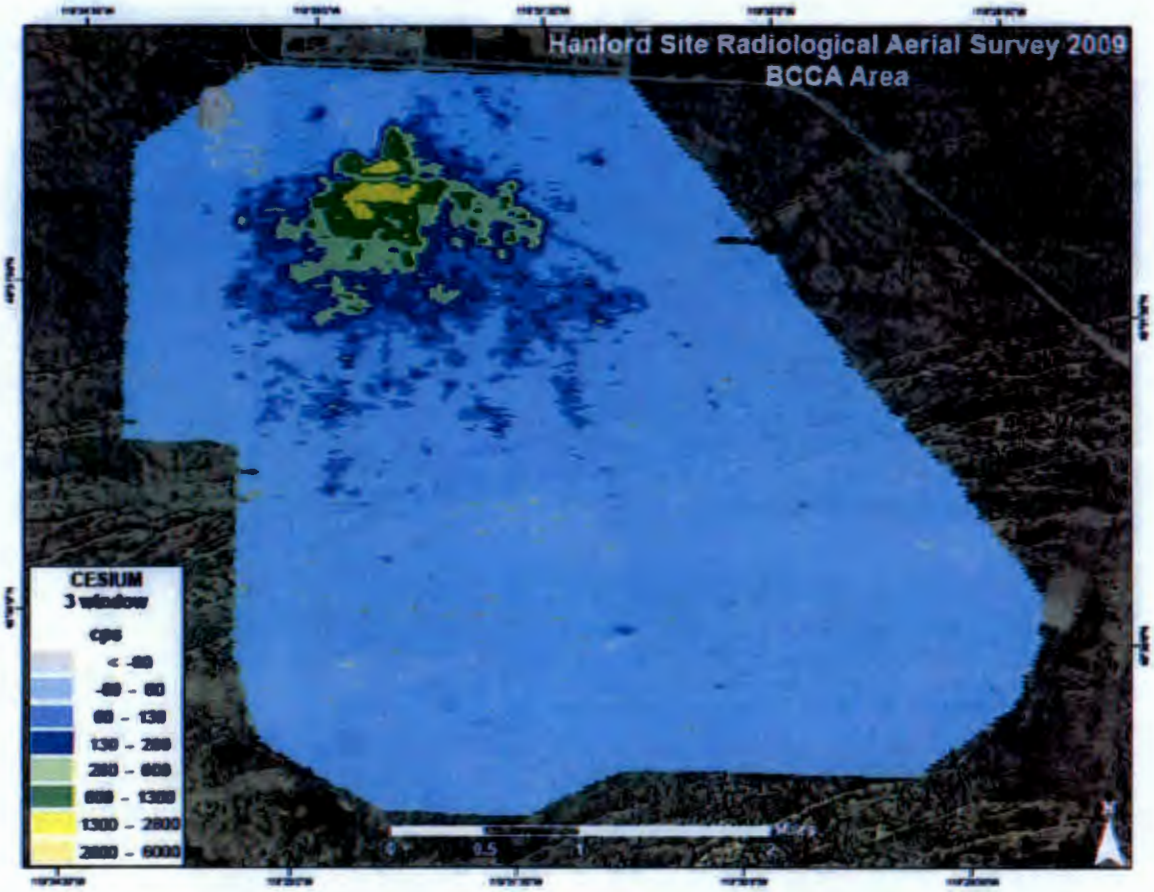


Figure 14. BCCA Cesium-137 Net Counts Contoured Data Results

5.5 Cesium-137 Volumetric Activity (pCi/g) Point Data and Contoured Data Maps (BCCA)

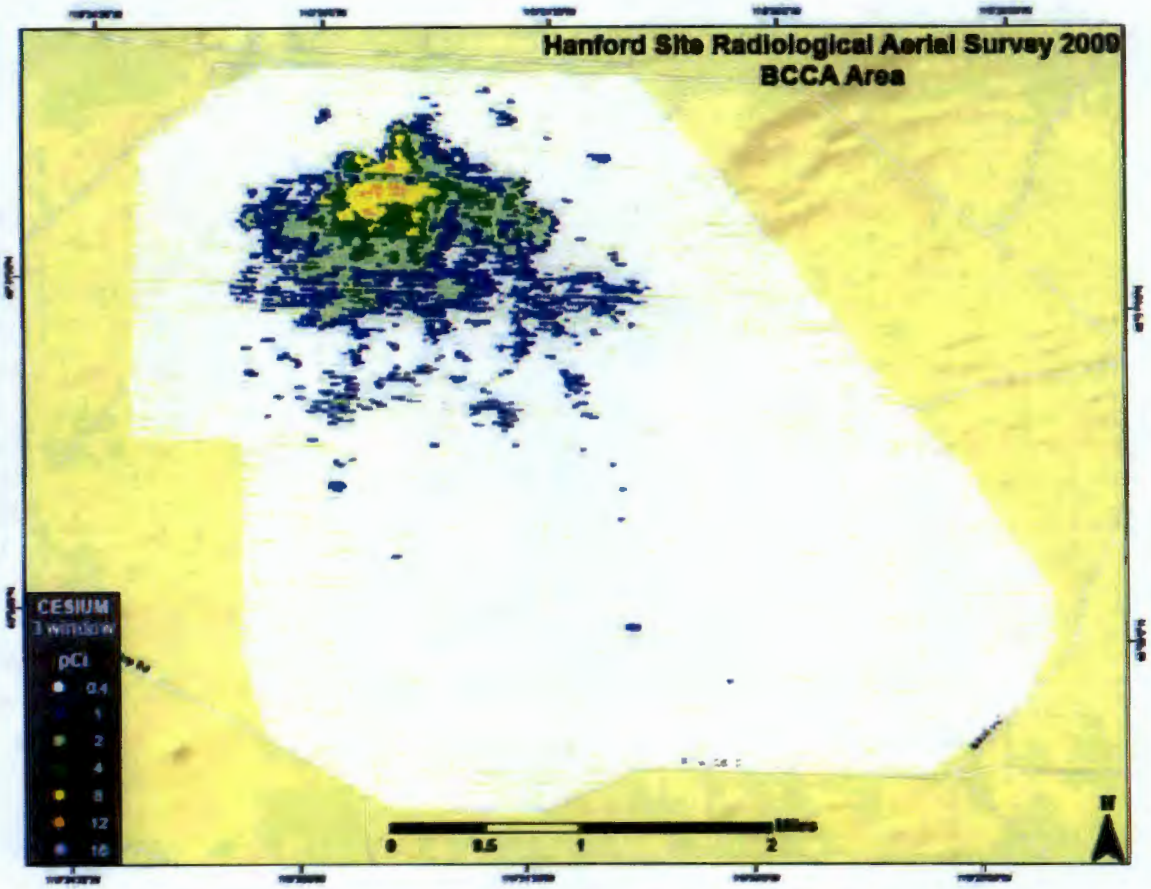


Figure 15. BCCA Cesium-137 Volumetric Activity (pCi/g) Point Data Results

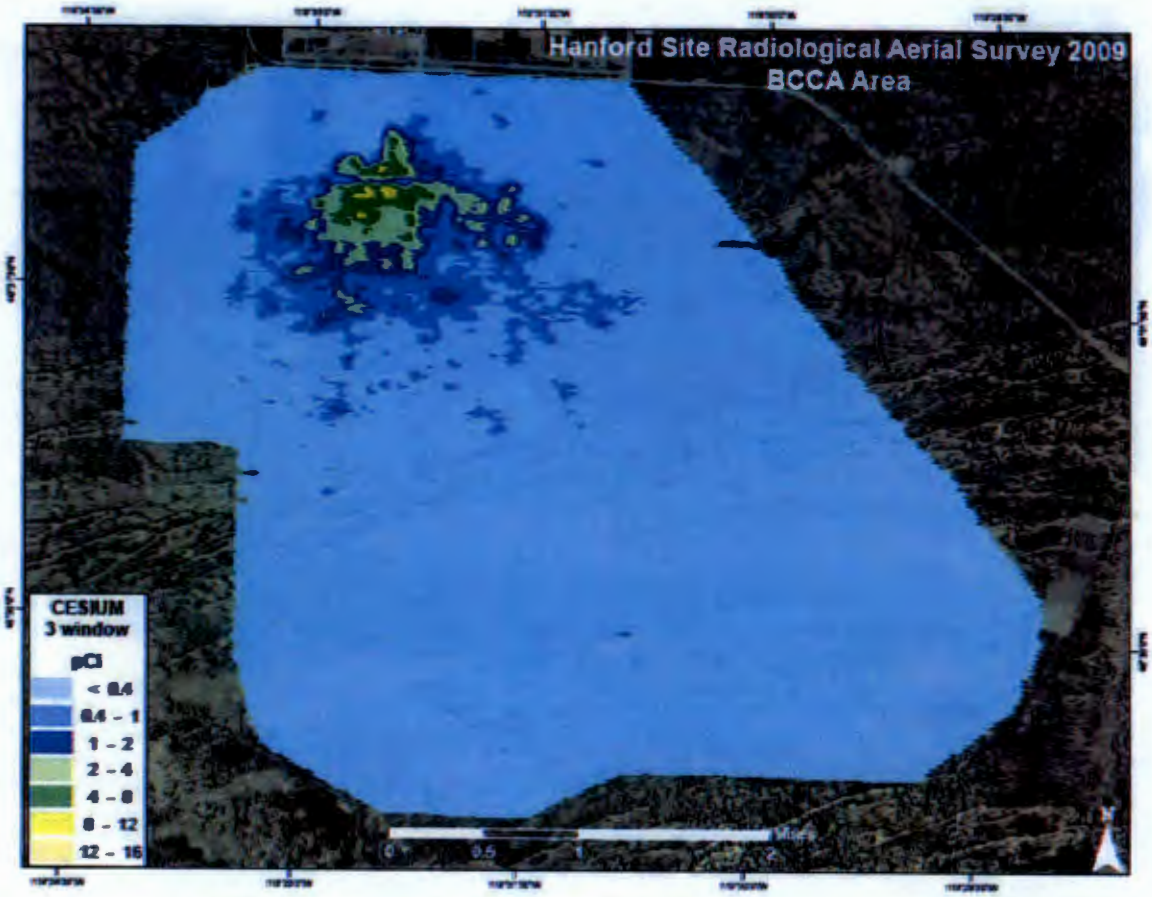


Figure 16. BCCA Cesium-137 Volumetric Activity (pCi/g) Contoured Data Results

5.6 Man-Made Gross Count Point Data Map (West Lake and Gable Mountain Pond)

The MMGC algorithm (discussed in the Section 4.1.2) was used to study the aerial data for man-made radionuclides in the survey area. The MMGC map (Figure 17) shows the activity that is attributable to gamma radiation from man-made radioisotopes with the variable natural background component removed. The figure shows the results as point data rather than contour data at the customer's request.

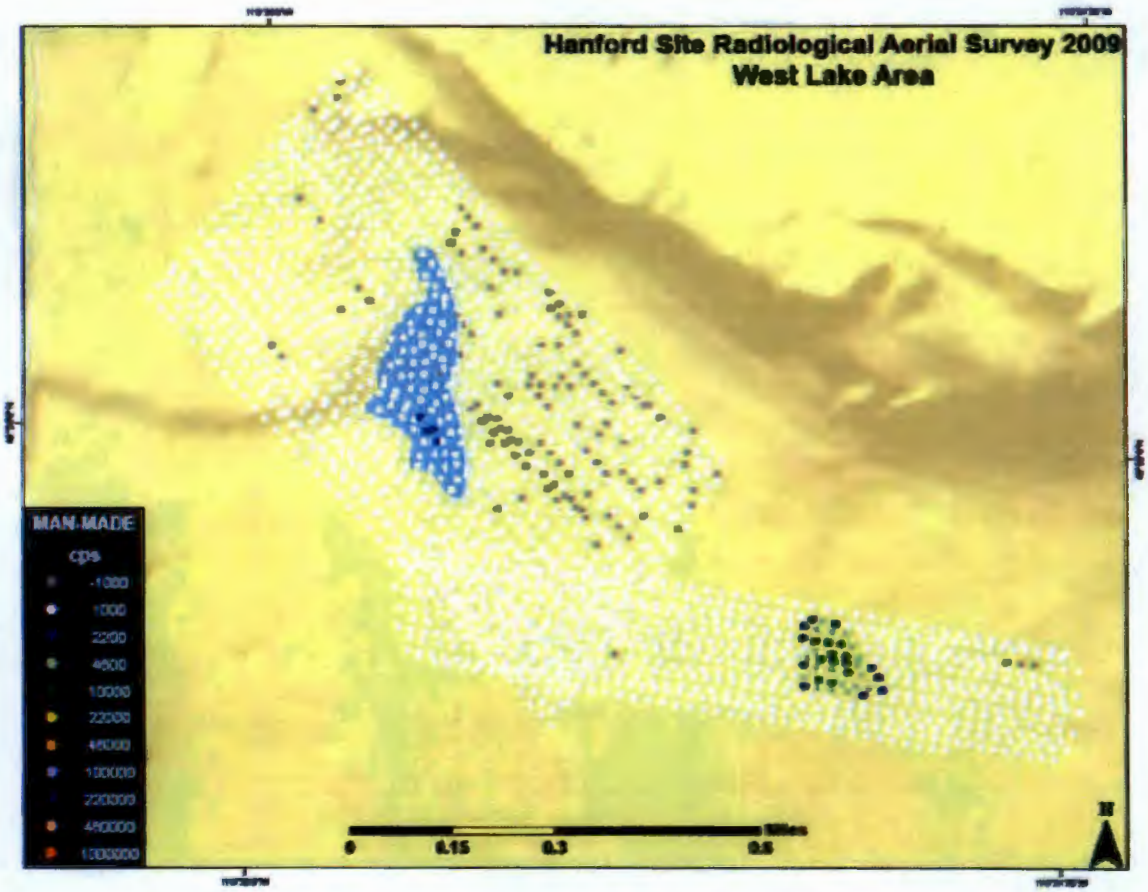


Figure 17. West Lake Man-Made Gross Count Map

5.7 Cesium-137 Extracted Isotope Counts Point Data and Contoured Data Maps (West Lake and Gable Mountain Pond)

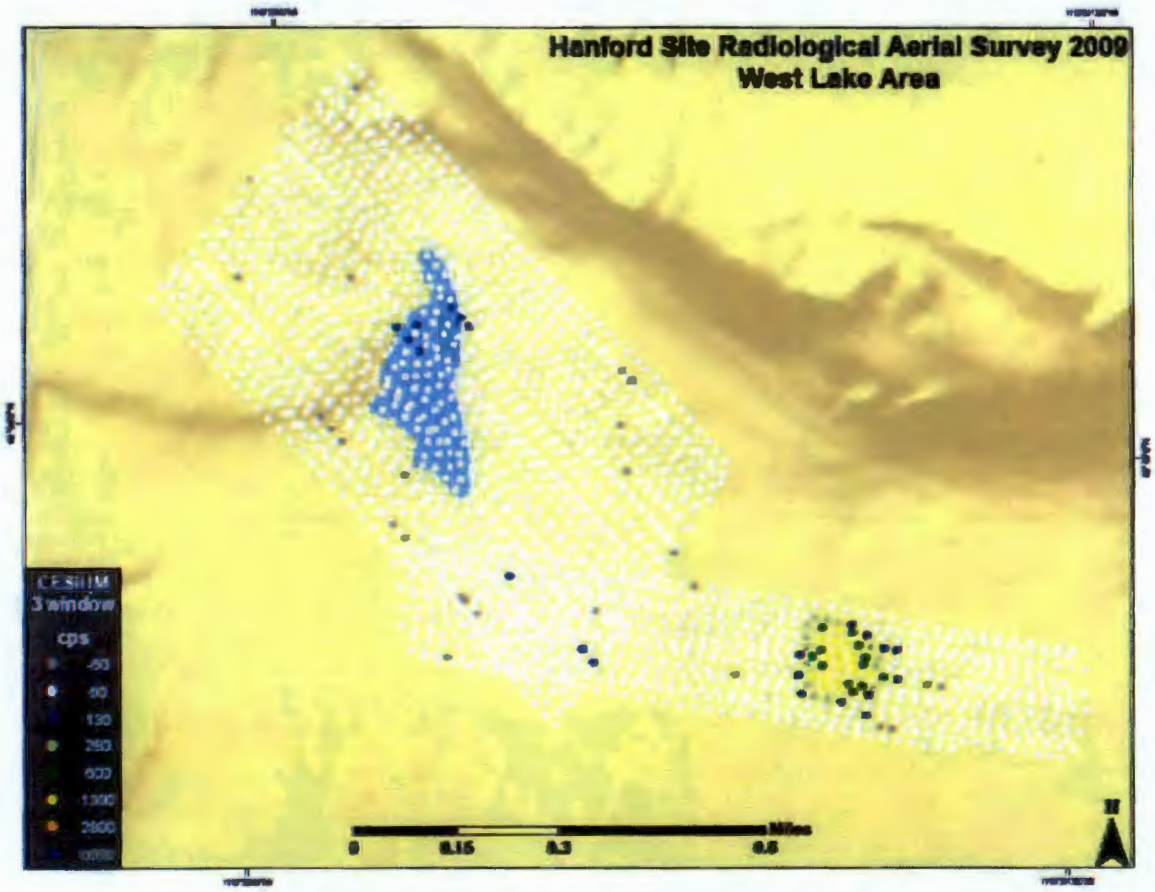


Figure 18. West Lake Cesium-137 Net Counts Point Data Results

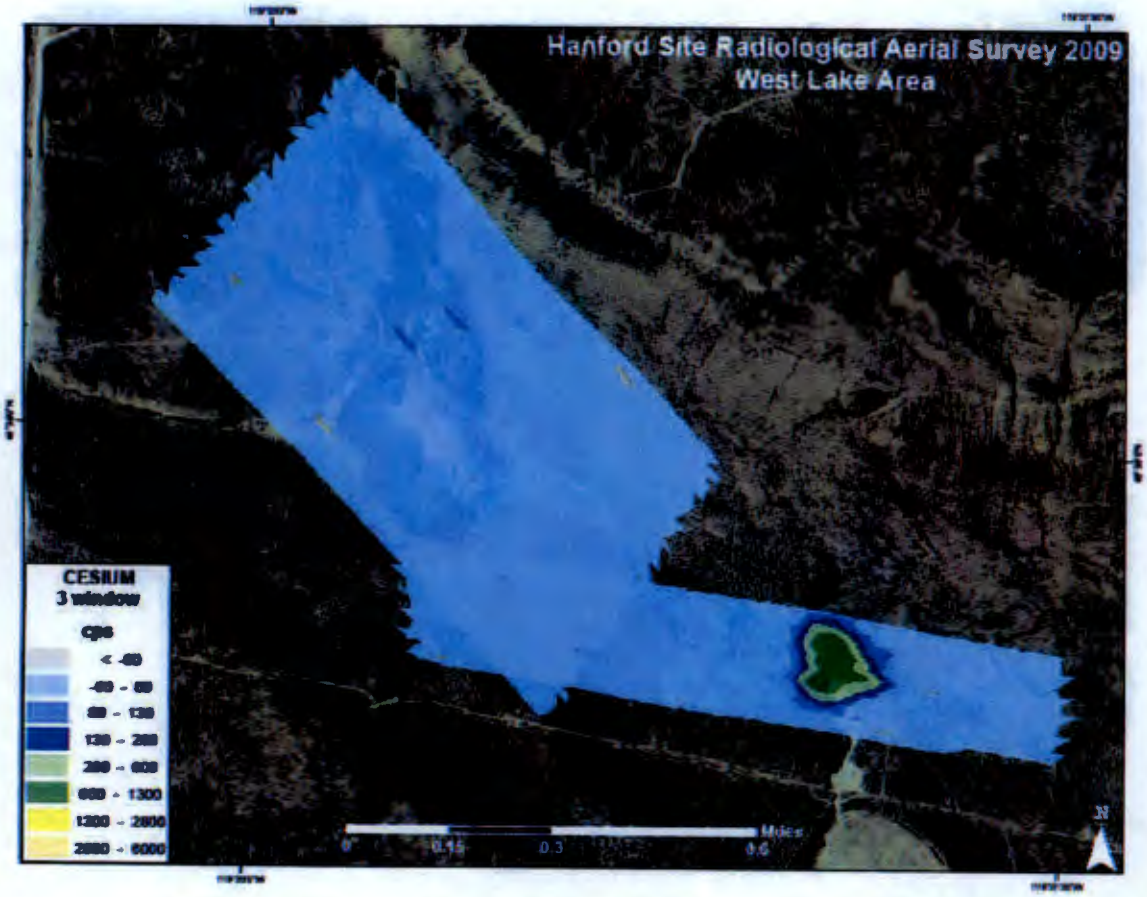


Figure 19. West Lake Cesium-137 Net Counts Contoured Data Results

5.8 Am-241 Extracted Isotope Point Data and Contoured Data Maps (BCCA)

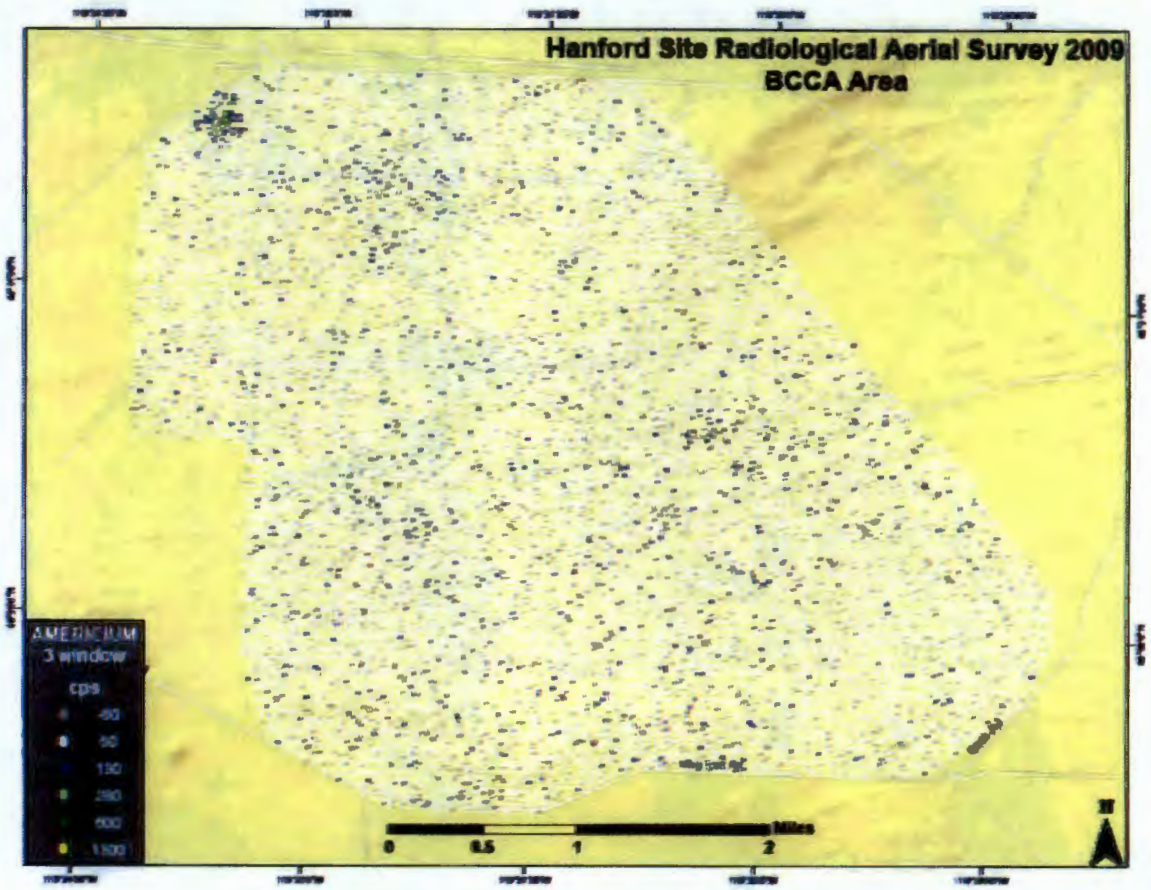


Figure 28. BCCA Am-241 Isotope Extraction Point Data Results

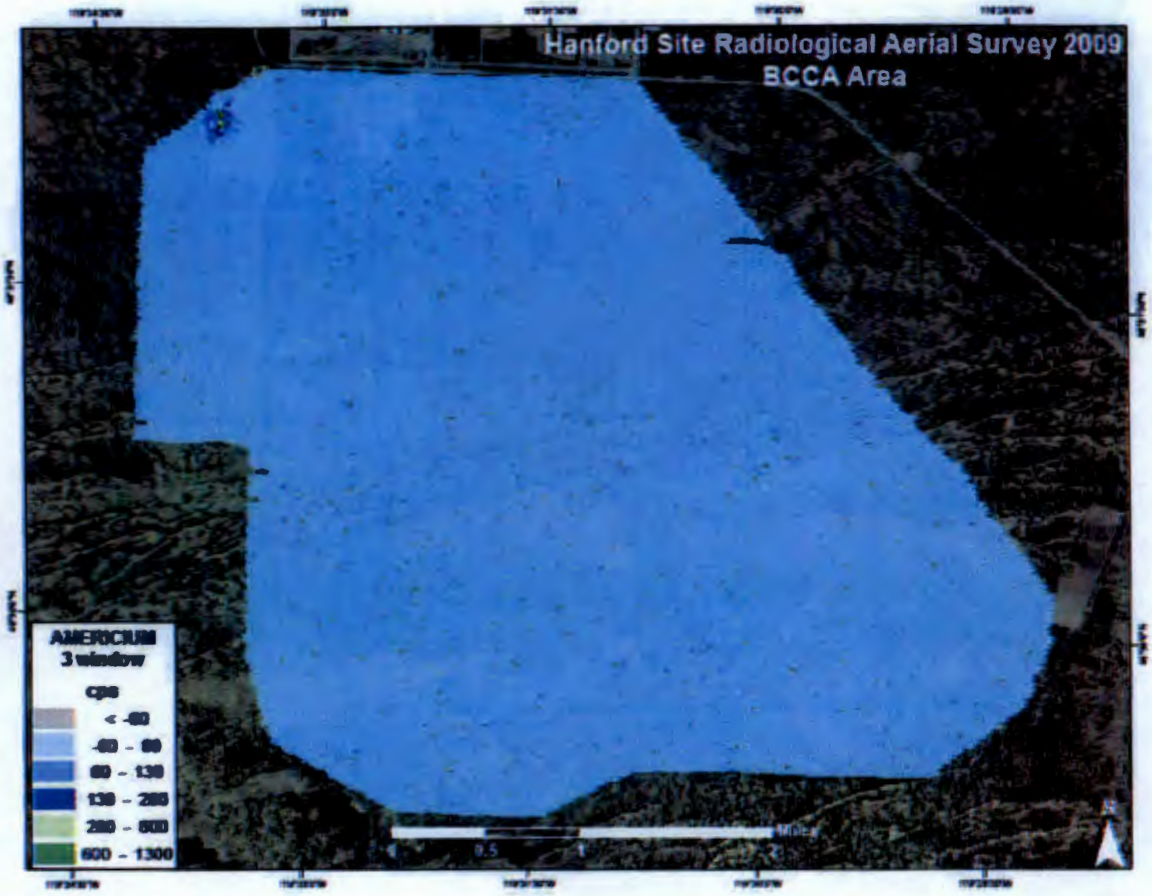


Figure 21. BCCA Am-241 Isotope Extraction Contoured Data Results

5.9 Am-241 Extracted Isotope Point Data and Contoured Data Maps (West Lake and Gable Mountain Pond)

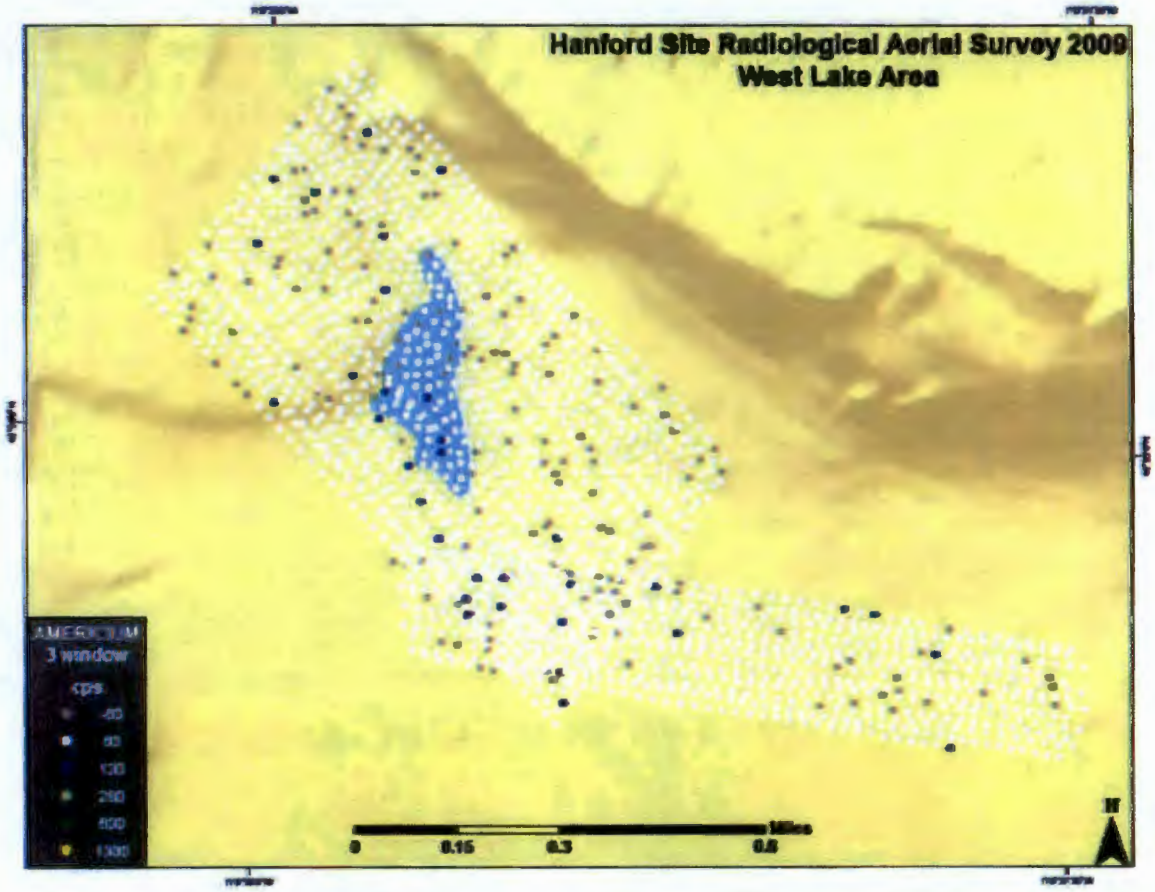


Figure 22. West Lake and Gable Mountain Pond Am-241 Isotope Extraction Point Data Results

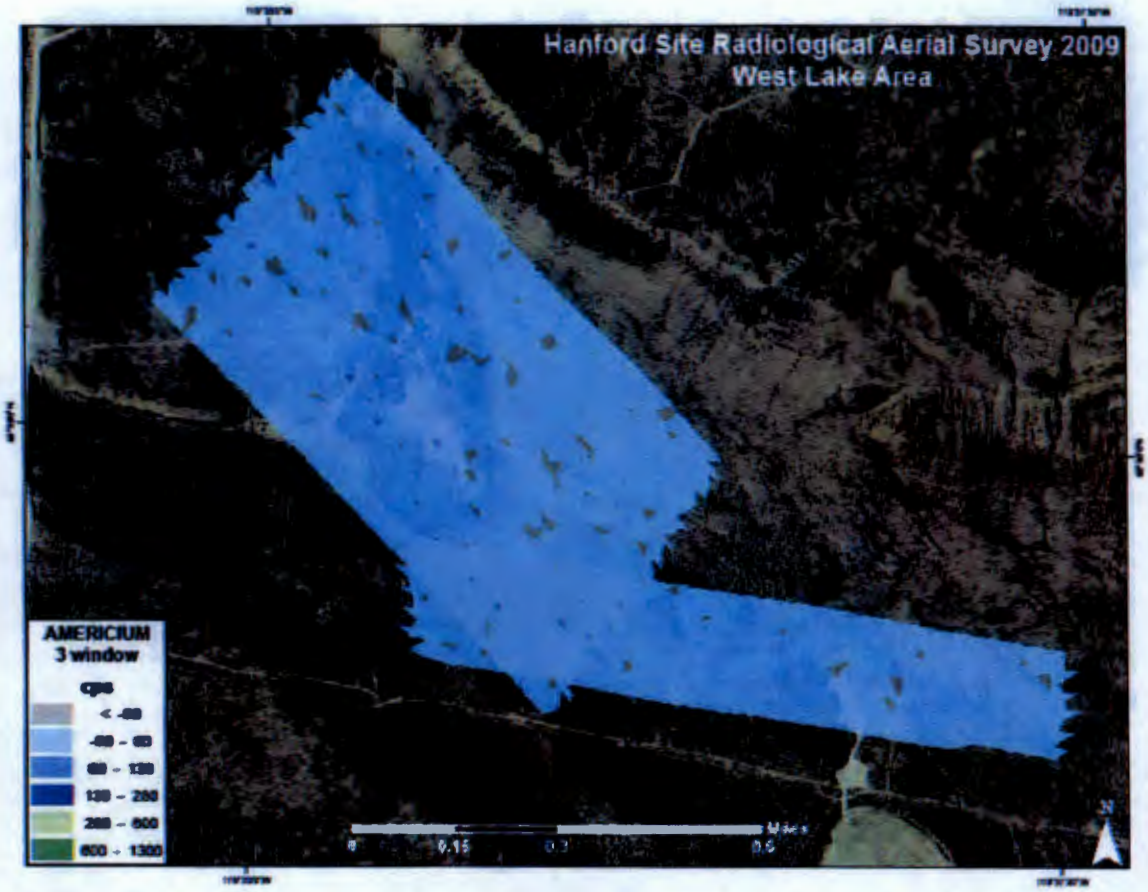


Figure 23. West Lake and Gable Mountain Pond Am-241 Isotope Extraction Contoured Data Results

5.10 BCCA Survey Area Flight Line Results

As discussed previously, one of the survey objectives was to provide a 100% gamma scan of the survey as close as practicable. Figure 24 shows all the flight lines over the survey area that was used for the data analysis. With a75-foot line spacing, the AMS pilots executed the survey with acceptable precision.

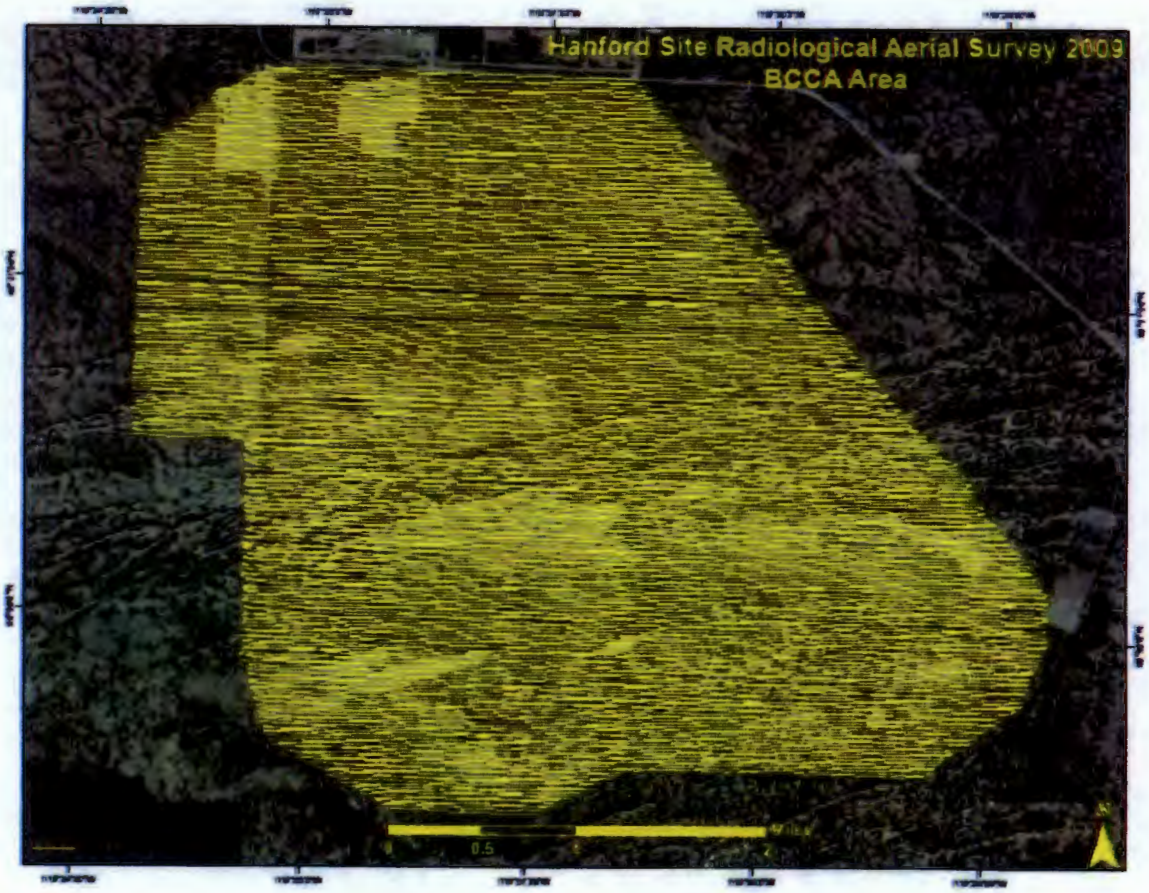


Figure 24. BCCA Flight Line Results

5.11 West Lake and Gable Mountain Pond Survey Area Flight Line Results

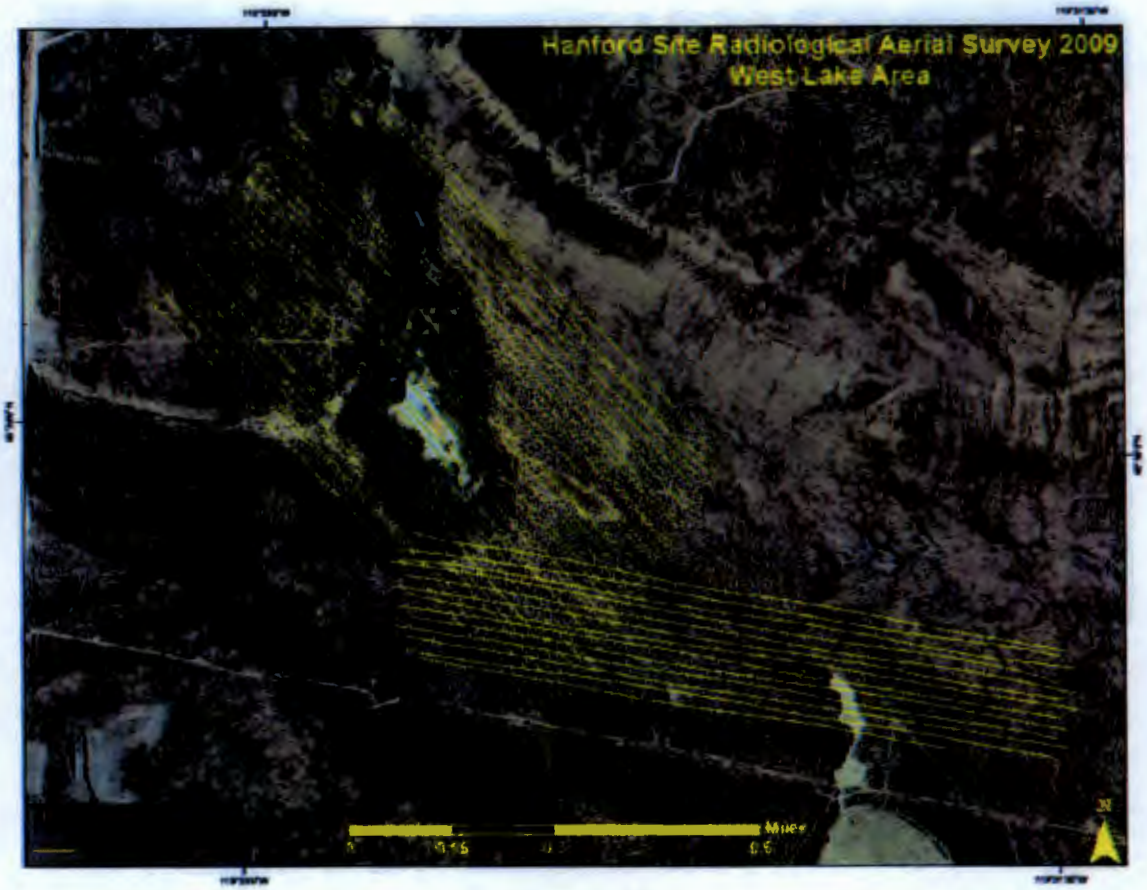


Figure 25. Example of Flight Line Precision over the West Lake and Gable Mountain Survey Areas

5.12 Gamma Spectral Analysis Results

Figure 26 shows the areas where the 1-second data results were combined for the net spectra analysis. Figures 27 and 28 show the "net" spectra results for portions of the survey area. The Cs-137 contour levels were used to determine the peak and background areas. The peak regions consist of the combined spectra contained within the boxes around each ground zero. The background region combined the spectra from the box outside the BCCA deposition footprint but within the survey area. This background spectrum represents the same geology as the ground zeros but also has some man-made activity present as well. This technique produces a net spectrum that has very little contribution from naturally occurring radionuclides and enhances any remaining peaks representing man-made radionuclides in the survey area.

Hanford-BCCA Cesium

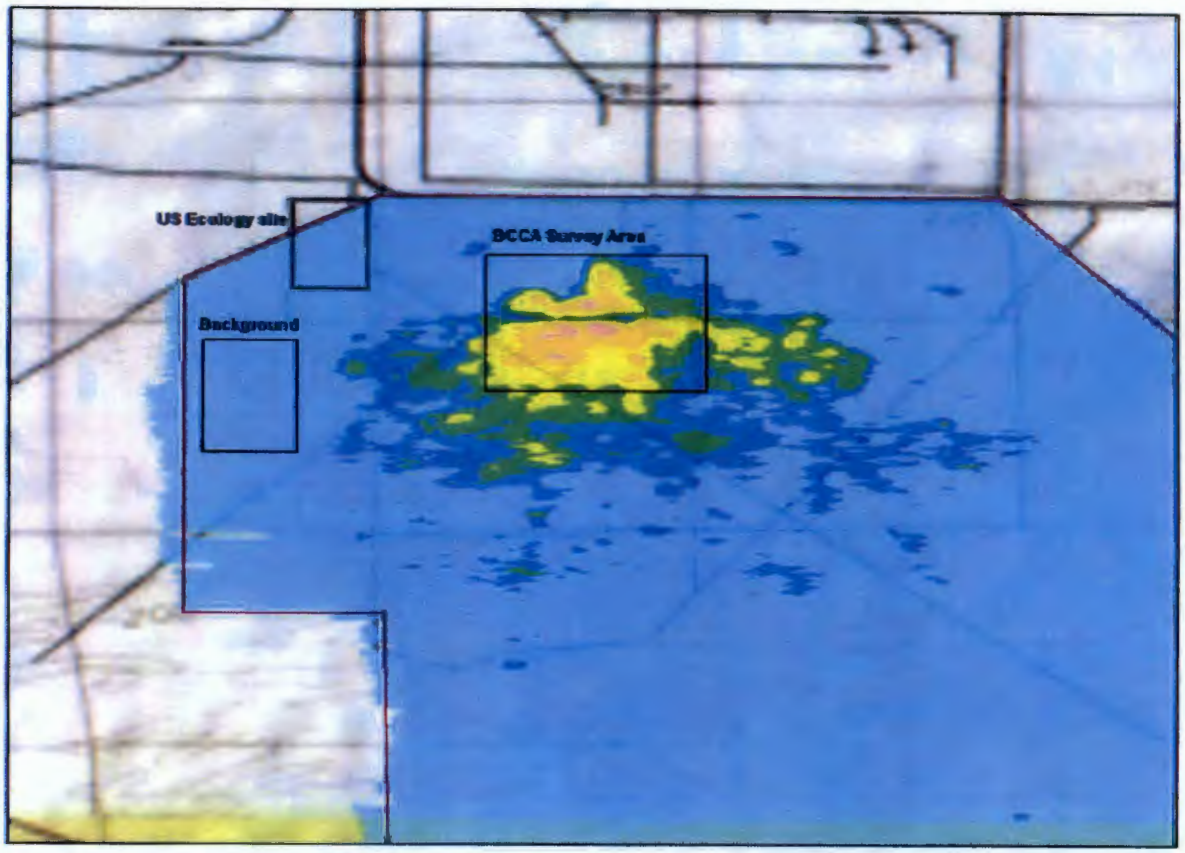


Figure 26. Gamma Spectra Analysis Locations

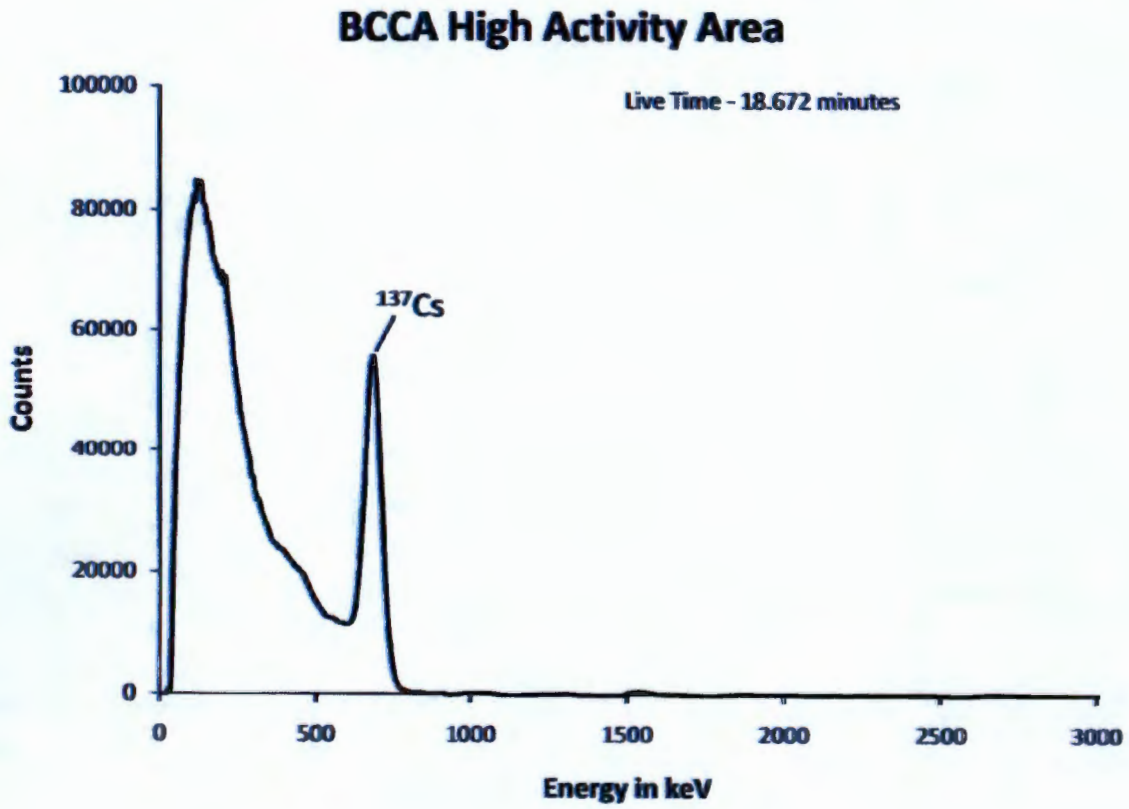


Figure 27. BCCA High Activity Area Net Spectrum

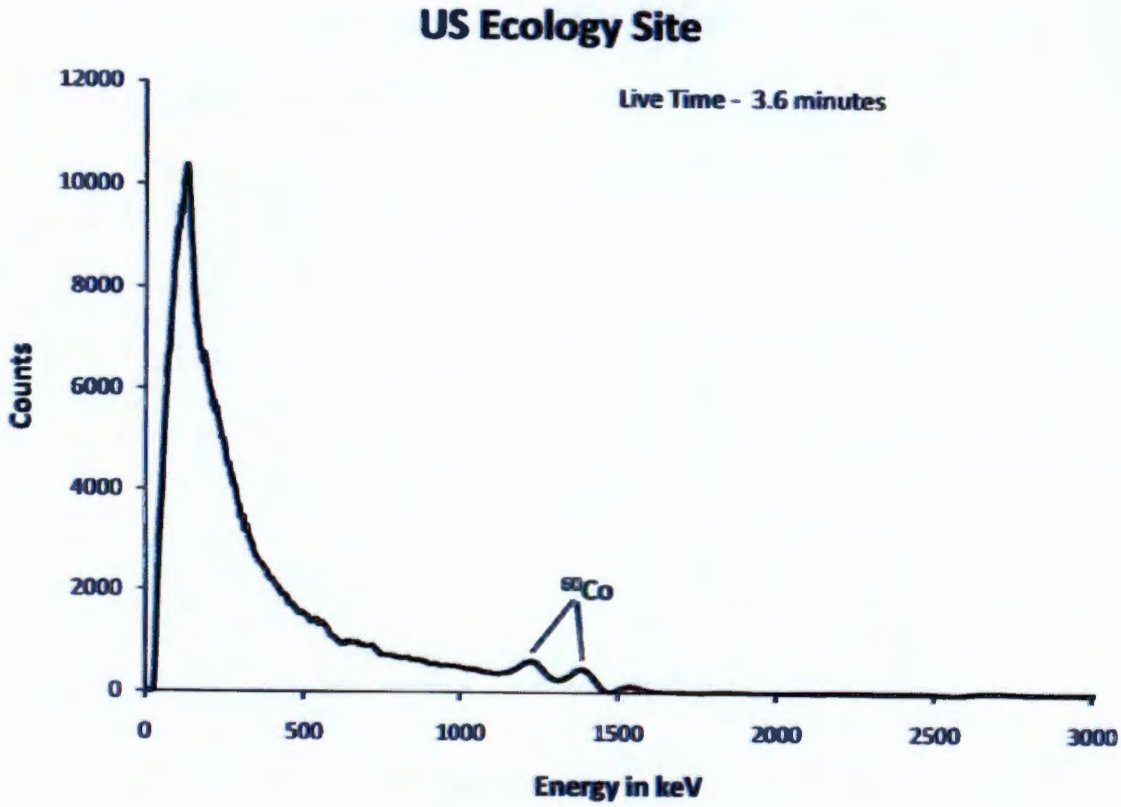


Figure 28. U.S. Ecology Site Net Spectrum

6. Discussion of Results

6.1 Comparison of Previous Survey Results to 2009 Survey Results

The aerial survey results depicted in Figure 2 from the 1996 survey are typical for the previous aerial surveys conducted at the HR. The previous survey objectives were limited to defining the man-made gamma footprints from all the facilities and operations within the HR. Due to the size of the reservation, the survey altitude and line spacing were designed for a reasonable deployment time. For the 1996 survey, the survey altitude was 200' AGL and the line spacing was set at 400'. The man-made gamma footprint depicted for the BCCA in 1996 is consistent with previous surveys. Similar to the Figure 29 example, the BCCA footprint has three count-rate ranges and relatively smooth boundaries between contour levels. In addition, the man-made gamma footprint from the adjacent US Ecology facility extends well beyond the facility boundaries. This is a result of a relatively small area of very high radioactivity detected on adjacent survey lines due to the higher altitude of the aircraft. For the 2009 survey, the project had identified Cs-137 as the only radionuclide of concern. With the reduction of altitude to 50' AGL and line spacing of 75', the raw data could be processed to include only the photopeak counts from Cs-137. The results are in Figure 14. Features to note include the complexity of the Cs-137 footprint within the BCCA and the absence of a competing man-made gamma footprint from the U.S. Ecology facility. The BCCA Cs-137 footprint is more complex than the typical example illustrated in Figure 29.

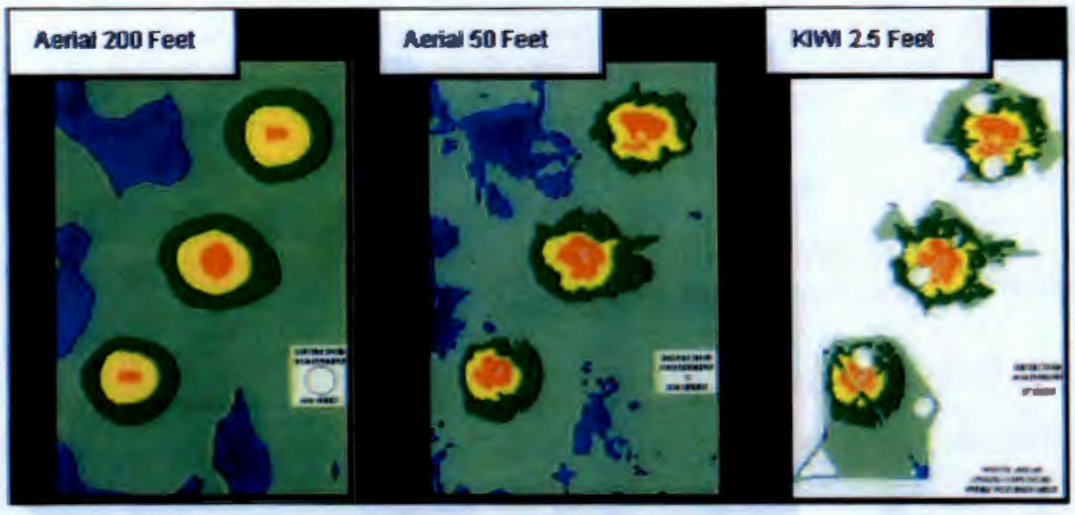


Figure 29. Example of Aerial Data Results From the NTS Due to Altitude

6.2 Point Data Comparisons to Contoured Data

As noted above, the 2009 survey results produced a BCCA Cs-137 footprint of similar dimensions to the 1996 survey but the complexity within the footprint due to the increased resolution and sensitivity are striking. Historically, large area radioactive material deposition on soil was the result of a single event or a process that released airborne material over a lengthy time period. Aerial survey results would produce maps similar to the Figure 29 example where the source of the release would produce the highest levels of radioactivity with deposition radiating outward or occurring downwind from the source. The source of the radioactive deposition for the BCCA has been documented as animal intrusions into the cribs and trenches with dispersal due to subsequent defecation or urination. Since the animals' movements would be random within the BCCA, the pattern of dispersal is more complex. In addition, all species have different size home ranges and may have traveled significant distances from the source of the radioactive salts within the cribs after ingestion.

At the start of the survey, the primary GIS product expected to be used was the Cs-137 contoured data in counts per second and converted to a preliminary pCi/g map. However, as draft products were being developed, the project personnel expressed great interest in the point data produced by the acquisition system. The GIS point data files have a number of attributes that are expected to improve site characterization efforts. In a comparison of Figures 13 and 14, the point data results in Figure 13 show potential Cs-137 activity in small, widely scattered areas outside the original Zone A and B areas. Due to the random nature of the animal movements within the site, these small "points" may require investigation by ground teams in the future. The GIS shape file contains specific latitude and longitude information for each data point. Ground teams can greatly improve their performance using this information to find the location. The point data products have been included in this report due to the value to the customer.

NOTE: The term point data is somewhat of a misnomer since each GIS data point actually represents an effective detection footprint circle of 100 foot (~30 meters) diameter.

6.3 Gross Counts and Exposure Rate Maps

The 2009 survey produced a gross map with results comparable to the 1996 survey results. As expected, the 2009 map has better detail of the higher gross count areas within the BCCA (Figure 7). The exposure rate map product in Figure 8 was normalized to the same exposure rate levels as presented in the 1996 report. The calculated terrestrial exposure rates between the two surveys are essentially identical. The value of these two products is for ground teams to know where to expect changes in count rate or exposure rate on non-spectral portable instruments. This can be invaluable where teams are investigating potential Cs-137 anomalies where terrestrial background levels are changing.

6.4 Man-Made Gross Count Point Data Maps

The man-made gross count point data maps (Figures 12 and 17) provide better spatial resolution of the man-made activity than the 1996 survey results. The results show that the original deposition has remained stable with no significant migration due to water or wind erosion. The data for both the BCCA and West Lake were not presented as contoured products since subsequent analysis has confirmed that all of the man-made activity in both survey areas is due to Cs-137 with the exception of the US Ecology facility. As such, the contoured data for the man-made products will be essentially identical to the Cs-137 contoured data provided.

6.5 Cesium-137 Extracted Isotope Counts and Volumetric Activity Maps

As discussed in Section 4.1.4 previously, the conversion of cesium photopeak counts to a soil volumetric activity (pCi/g) can be calculated with an existing software code used by AMS. For an initial scoping survey of a site, such as the BCCA, the map products produced should be used for remediation planning purposes only. Preliminary field investigations of cesium point data anomalies suggest that the initial deposition of the cesium salts by animals has not weathered sufficiently to meet the modeling assumptions in the software. Due to the apparent numerous point sources comprising the helicopter data results over the BCCA cesium footprint, subsequent conversions of cesium photopeak counts to a final volumetric activity map product should be delayed. Once remediation has been completed and the final cesium activity is expected to be low-level and uniformly distributed within the BCCA, a final data set conversion of cesium counts to volumetric activity can be completed for project and regulatory review.

6.6 Americium-241 Extracted Isotope Counts and Contoured Data Maps

As discussed in Section 4.1.5, the aerial data was analyzed for Am-241. Due to the history of the operations at the HR and the inclusion of Am-241 as a possible radionuclide of concern within the BCCA and West Lake sites, map products for Am-241 point data and contoured data were produced. Other than an obvious Am-241 footprint related to the US Ecology facility, only one small area within the BCCA produced a contoured area above the 3-sigma threshold. The anomaly had not been verified or investigated at the time of this report preparation.

6.7 Gamma Spectral Analysis Results

The net spectra results for both the BCCA and the adjacent U.S. Ecology site are very similar to the 1996 net spectra results. There does not appear to be any significant changes in the radioactive source term at either site.

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4. Proctor, A.E. *Aerial Radiological Surveys*. Report No. DOE/NV/11718-127, 1997; Bechtel Nevada, Las Vegas, Nevada.

5. Hendricks, T.J. "Radiation and Environmental Data Analysis Computer (REDAC) Hardware, Software, and Analysis Procedures," in *Remote Sensing Technology, Proceedings of a Symposium on Remote Sensing Technology in Support of the United States Department of Energy, 23-25 February 1983*. Report No. EGG-10282-1057, 1985; EG&G, Las Vegas, Nevada.

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Appendix A

Survey Parameters

Survey Site:	**BCCA**
Survey Coverage:	**13 square miles (~ 33.7 square kilometers)**
Survey Date:	**September 22-28, 2009**
Survey Altitude:	**50 feet (~15 meters)**
Aircraft Speed:	**70 knots (~36 meters per second)**
Line Spacing:	**75 feet (~23 meters)**
Navigation System:	**Trimble DGPS (WAAS corrections) differential**
Line Direction:	**East-West**
Detector Configuration:	**Twelve 2" × 4" × 16" NaI(Tl) detectors**
	1 High-Purity Germanium (HPGe) Detector (120%)
	ADC0= 6 NaI detectors
	ADC1= 1 NaI detector
	ADC2= 5 NaI detectors
	ADC3= 1 HPGe detector
Acquisition System:	**REDAR-V**
Conversion Factors:	**2055 cps/μR/h**
	0.004 pCi/g per 1-cps Cs-137 net photopeak
Air Attenuation Coefficient:	**0.001761/feet (0.005778/meters)**
Aircraft:	**Bell-412 Helicopter**
Federal Team Lead	**Joe Ginanni**
Project Management:	**Karen McCall**
	Elaine Hawkins
Project Scientist:	**Craig Lyons**
Data Scientist:	**Thane Hendricks**
Data Analyst:	**Jezabel Stampahar**
Electronic Technicians:	**Tom Stampahar**
	Dave Emory
Helicopter Pilots:	**Tom Selfridge**
	Tom McKissack
	Jeff LeDonne
Aviation Mechanic:	**Ed Zachman**

Survey Site:	**West Lake / Gable Mountain Pond**
Survey Coverage:	4.4 square miles (~ 11.4 square kilometers)
Survey Date:	September, 2009
Survey Altitude:	50 feet (~15 meters)
Aircraft Speed:	70 knots (~36 meters per second)
Line Spacing:	75 feet (~23 meters)
Navigation System:	Trimble DGPS (WAAS corrections) differential
Line Direction:	Northwest-Southeast
Detector Configuration:	Twelve 2" × 4" × 16" NaI(Tl) detectors 1 High-Purity Ge Detector (120%) ADC0= 6 NaI detectors ADC1= 1 NaI detector ADC2= 5 NaI detectors ADC3= 1 HPGe detector
Acquisition System:	REDAR-V
Conversion Factor:	2055 cps/μR/h 0.004 pCi/g per 1 cps Cs-137 net photopeak
Air Attenuation Coefficient:	0.001761/feet (0.005778/meters)
Aircraft:	Bell-412 Helicopter
Federal Team Lead	Joe Ginanni
Project Management:	Karen McCall Elaine Hawkins
Project Scientist:	Craig Lyons
Data Scientist:	Thane Hendricks
Data Analyst:	Jezabel Stampahar
Electronic Technicians:	Tom Stampahar Dave Emory
Helicopter Pilots:	Tom Selfridge Tom McKissack
Aviation Mechanic:	Ed Zachman

Appendix B

Cesium Three-Window Data Extraction

B.1 Gross Count Activity, Survey Line of Interest (LOI) Gable Mountain Pond Area

In addition to contributions from man-made activity, gross count activity observed by an aerial radiological measurement system is affected by a number of parameters. Some of these are altitude, aircraft speed, area geology, area topology, man made objects, detector configuration (size, shape, number of detectors), etc. A typical total count rate data subset taken from the 2009 Hanford data set is shown in Figure B-1. The example line of interest (LOI) was chosen from the Gable Mountain Pond data set. Unlike the BCCA, which has extensive spatial distribution of cesium, the activity in the chosen LOI is more isolated and provides a better data set for illustration purposes.

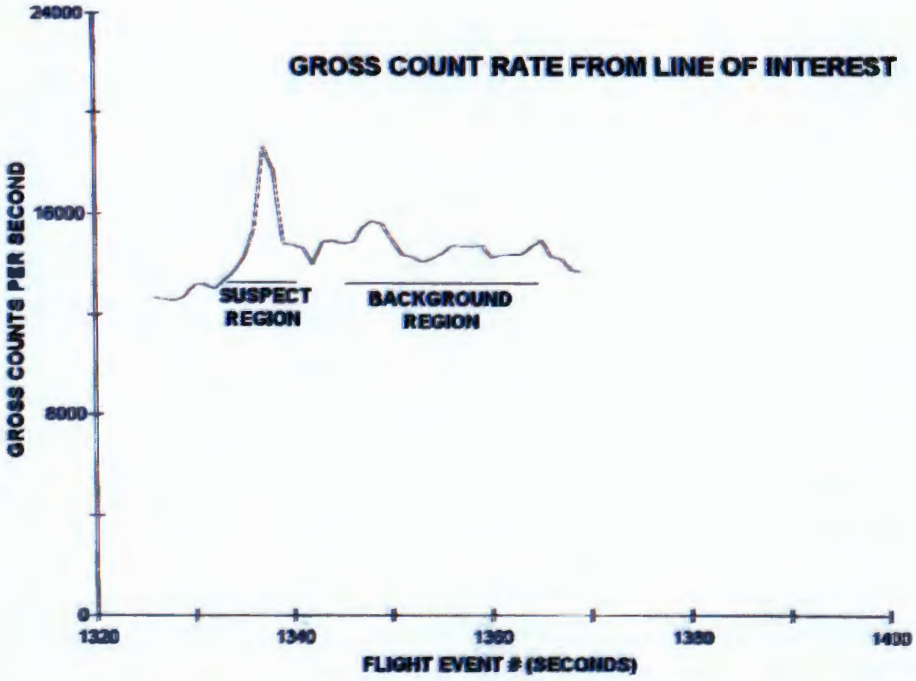

Figure B-1. Observed Total Gross Count Rate From Line of Interest

The gross count data shows appreciable variability throughout the entire LOI. Background and manmade activity regions are not well defined. The specific purpose of the Hanford survey was to separate, identify, and quantify specific contributions from the specific isotope cesium-137 (Cs-137). It is obvious that gross count data does not accomplish this task very well.

B.2 Isotope Extraction of Cesium by 3-Window Algorithm

Systems and procedures that utilize full gamma spectral information (not just gross count rate information) provide superior isotope extraction capability. Each specific radioactive isotope, whether natural or man-made, has distinct spectral properties. Exploiting these properties enables one to provide isotope specific processed data products. The cesium-only data set for the chosen LOI, processed by spectral extraction techniques, is shown in Figure B-2.

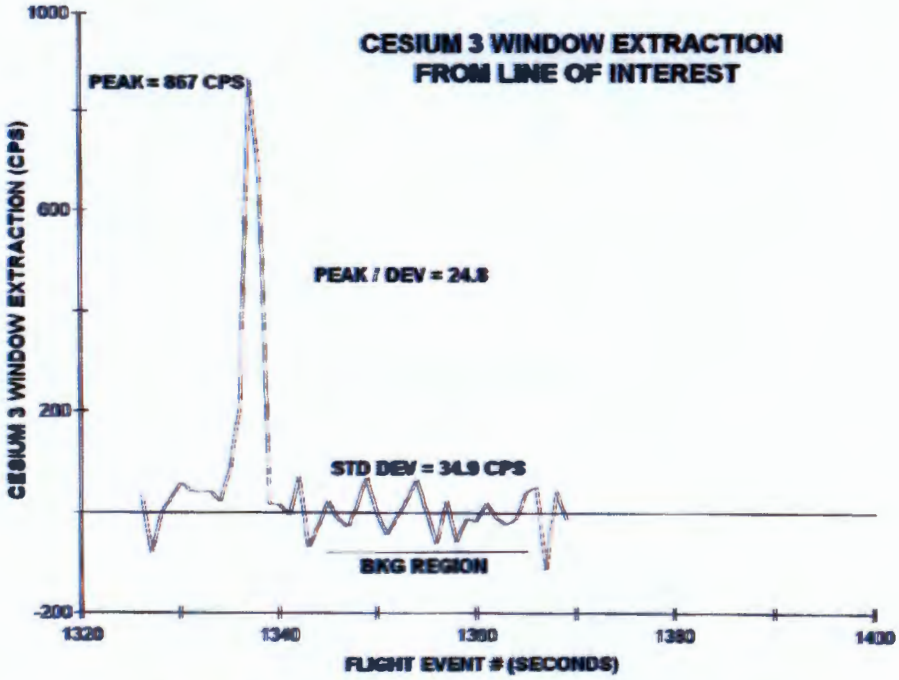

Figure B-2. Processed Cesium-137 Data Extraction

Note that the spectral extraction technique effectively separates the cesium data from the background data, providing a peak to background deviation ratio of 24.8.

The data of Figure B-2 was analyzed using a three window spectral energy extraction technique. A central window "A" (energy range of 594 to 730 keV) bounds the 662 KeV cesium photopeak. A background window "B1" (energy range of 526 to 594 keV is selected below the cesium photopeak and a background window "B2" (energy range of 730 to 798 KeV) is selected above the cesium photopeak. For typical background spectra, the ratio of counts in "A" to the sum of the counts in "B1" and "B2" is relatively constant. Mathematically:

$$K \text{ (typical per-flight extraction coefficient)} = A / (B1 + B2) \quad \text{(B-1)}$$

Where K is the average value from a typical background region; or the most likely value (from distribution analysis) taken in regions where non-cesium contributors dominate.

Using the survey-specific K value, the cesium extraction equation for a given flight on a point by-point basis then becomes:

$$CS(i) = A(i) - K * (B1(i) + B2(i)) \quad \text{(B-2)}$$

For reference, the K value for Figure B-2 was 1.128.

B.3 Additional Improvement of Detectability by Filtering

Figure B-3 shows additional detectability improvement is possible when a spatial filter is applied to the 3-window spectral extraction data.

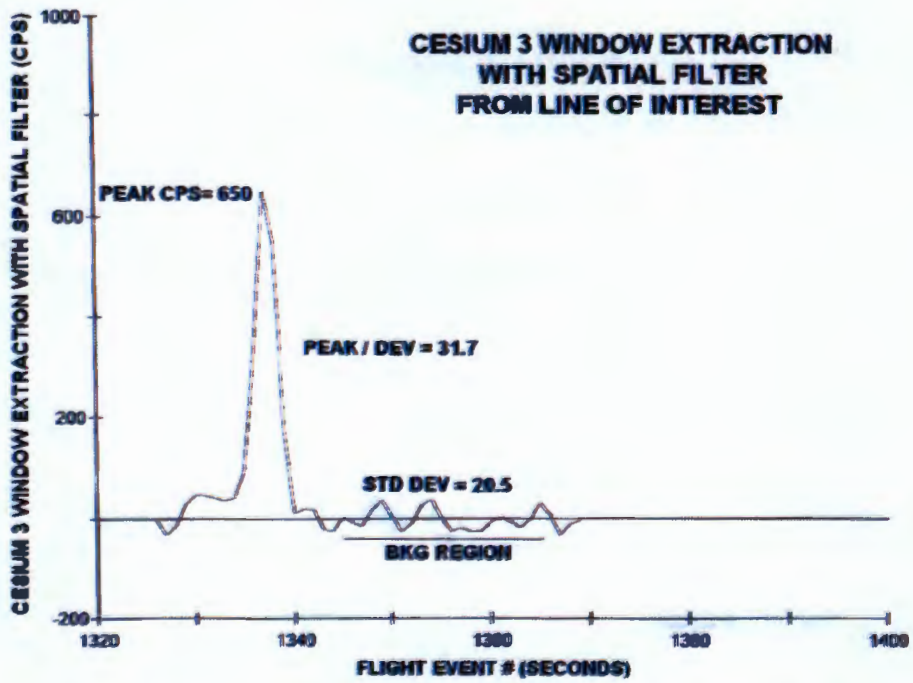

Figure B-3. Additional Improvement of Detectability by Spatial Filtering

Spatial filtering additionally improves the peak to deviation ratio from a factor of 20.8 to a factor of 31.7, a significant improvement. The spatial filter applies weights of one-quarter, half, and one-quarter to the three time-ordered points recorded before, during, and after the point of interest. This

filter is essentially optimum for this data set. The Hanford cesium data was processed utilizing both the described 3-window spectral extraction and the spatial filter.

B.4 Statistical Significance

The minimum detectability for a data set is usually expressed as a multiple of sigma (the standard deviation) determined from the data set. The term "detectable" is strongly dependent on the purpose for which a contour or point data map is generated. A common multiple of the standard deviation used for radiation counting statistics is 3-sigma. At the 3-sigma level, one will observe approximately 3 false positive points for every 1000 background points. A lower sigma level improves detectability for elevated man-made radioactivity above the background activity but also produces more false positives. For example, 2 sigma = 45 false positives per 1000 measurements, 1 sigma = 317 false positives per 1000 measurements. The choice of the multiple is obviously dependent on the number of individual possible false positives deemed acceptable for examination and resolution.

B.5 Spectral Data from Suspect Region of LOI

Figure B-4 shows the gross spectrum for the "suspect" region of the LOI.

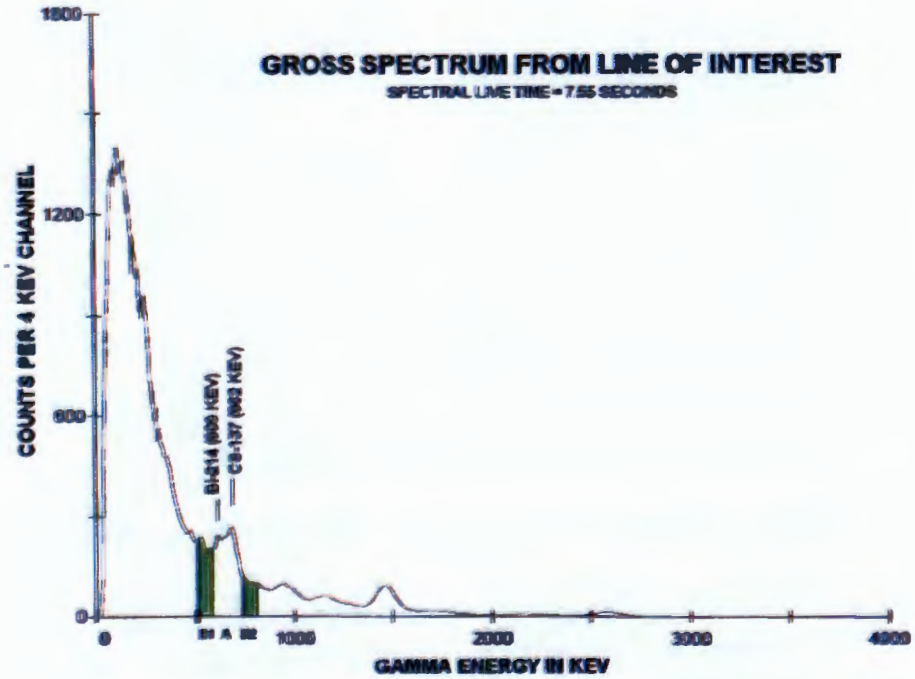

Figure B-4. Gross Spectrum from Suspect Area of LOI

The gross spectrum of the suspect region had a spectral live time of 7.55 seconds. The cesium photopeak (662 KeV) is visible in this gross spectrum but is only slightly larger than the adjacent natural bismuth-214 (Bi-214) photopeak (609 KeV). For reference, the three spectral window regions previously described are noted on the figure.

B.6 Spectral Data from "Background" Region of LOI

Figure B-5 shows the spectrum obtained from the nominal background region of the LOI. Visually, the spectrum does not look significantly different from Figure B-4. However, only the background bismuth photopeak is contributing counts to the 600-700 keV energy range.

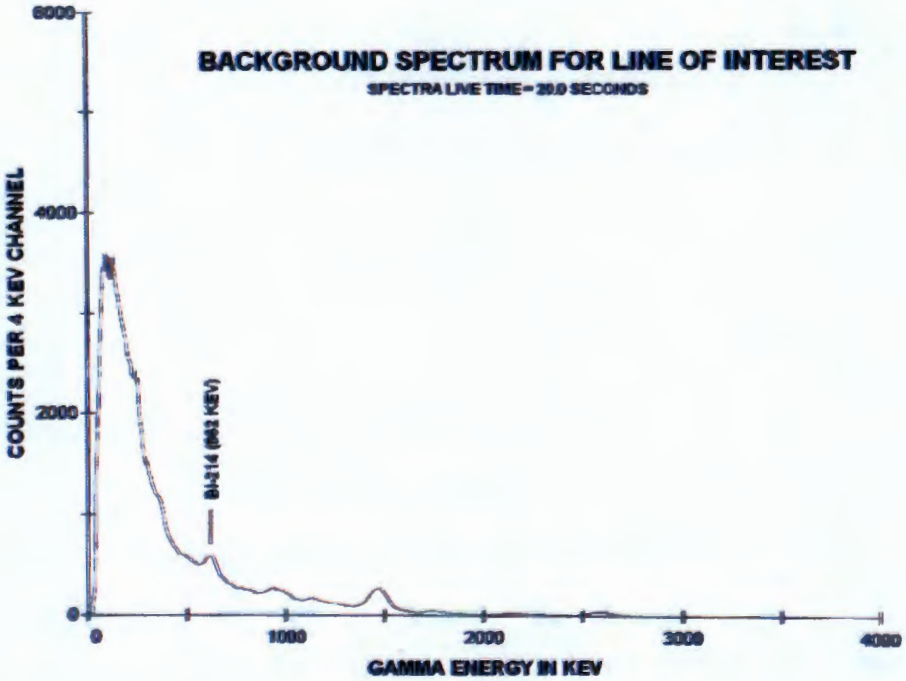

Figure B-5. Background Spectrum from LOI

B.7 Net Spectrum = Suspect Spectrum Less Background Spectrum

Figure B-6 confirms the presence of Cs-137 in the suspect area. The net spectrum was obtained by subtracting the live time-normalized background spectrum from the spectrum from the suspect area. The distinct spectrum for Cs-137 is now quite obvious despite a very low count rate at the peak energy. It should be noted that the 3-window algorithm can statistically recognize cesium levels appreciably lower than levels which would produce a satisfactory visual spectrum.

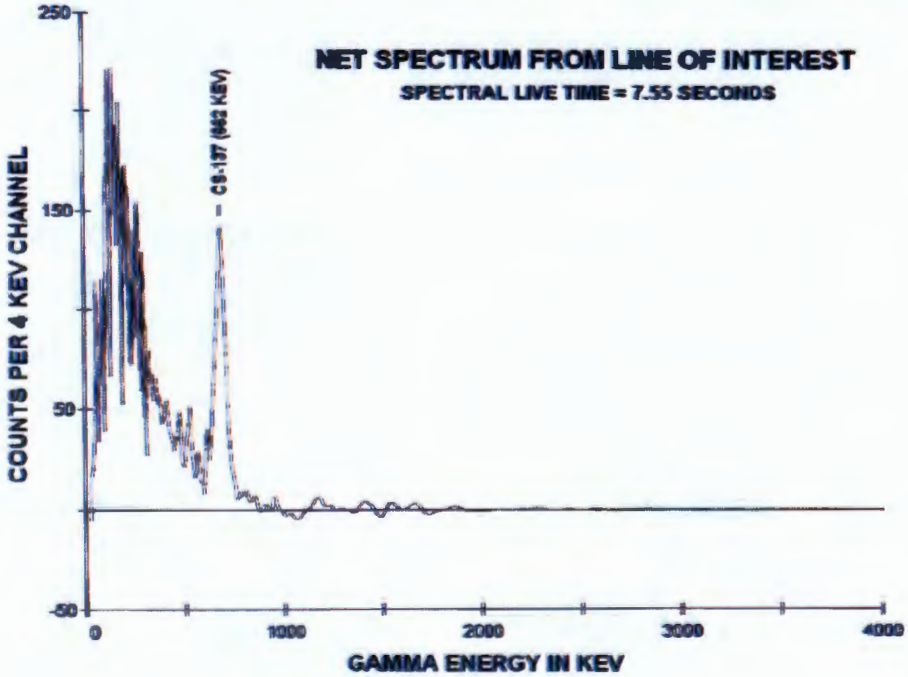

Figure B-6. Net Spectrum from Suspect Area

B.8 Conversion of Photopeak Extracted Count Rates to Volumetric Soil Activity (Picocuries per Gram)

Conversion of airborne count rate information to volumetric soil activity involves a number of parameters. These include detector type, number, and configuration; flight altitude and speed; isotope of interest; specific extraction algorithm; specific distribution of isotope in soil; soil density and moisture.

For estimation purposes, RSL utilizes a sensitivity estimation program written by Dr. Richard Maurer of the RSL. Provided with detector configuration, aircraft speed, and isotope of interest, the program estimates sensitivity conversion numbers for point source and infinite spatial extent

distributions including surface, uniform soil depth, and exponentially distributed soil depth. Resource materials from numerous technical references as well as a number of assumptions are embodied in the software.

Table 1 is a typical printout of information from the Maurer code. The 50 foot AGL data (highlighted) was used to estimate Hanford sensitivities.

Table 1. Estimated Conversion Factors (per Maurer)
Conversion Factors vs. Aircraft Altitude*

Aircraft Altitude (Feet)	Point Source mCi/cps(offset)	Soil Concentration (pCi/g/cps)		Surface Distribution ($\mu Ci/m^2/cps$)
		Uniform	Exponential	
50	.15E-02 / .63E-02	.435E-02	.369E-02	.584E-03
100	.44E-02 / .17E-01	.553E-02	.470E-02	.743E-03
150	.88E-02 / .26E-01	.695E-02	.590E-02	.933E-03
200	.15E-01 / .44E-01	.865E-02	.735E-02	.116E-02
300	.39E-01 / .12E+00	.132E-01	.112E-01	.177E-02
400	.94E-01 / .28E+00	.197E-01	.167E-01	.264E-02
500	.20E+00 / .60E+00	.290E-01	.247E-01	.390E-02
600	.39E+00 / .12E+01	.425E-01	.361E-01	.570E-02
700	.71E+00 / .21E+01	.617E-01	.524E-01	.828E-02
800	.12E+01 / .37E+-01	.890E-01	.756E-01	.120E-01
900	.21E+01 / .37E+01	.128E+00	.109E+00	.172E-01
1000	.35E+01 / .11E+02	.183E+00	.155E+00	.246E-01
1500	.35E+02 / .11E+03	.104E+01	.886E+00	.140E+00
2000	.28E+03 / .84E+03	.564E+01	.479E+01	.758E+00
2500	.19E+04 / .58E+04	.295E+02	.251E+02	.396E+01
3000	.12E+05 / .37E+05	.151E+03	.128E+03	.202E+02

* Isotope: Cs-137; Energy: 662 keV; Speed: 60 knots
12 – 2" x 4" x 16" Sodium Iodide detectors
Offset: Lateral distance = altitude; Statistics 3-sigma

For the Hanford survey, the value of 0.004 pCi per gram per 1 net photopeak count of Cs-137 was utilized. It is nominally the average of the infinite spatial distribution numbers for uniform and exponential soil distributions. The BCCA project has not verified all the parameters relating to distribution of the Cs-137 isotope in the soil. This distribution is very dependent on soil parameters,

weathering, ground cover, and a myriad of other items. Any initial estimates of volumetric concentration generated by this software have relatively large uncertainties.

B.9 Point Source Calibration Data Flown at Desert Rock

The applications covered by the Maurer code are too far extensive to be completely validated by actual measurements. However, some specific measurements have been made which are applicable to the Hanford survey data analysis. Aerial surveys have been conducted under controlled conditions at the Desert Rock Airstrip near the Nevada Test Site. One survey was flown at 50 feet AGL. Seven parallel lines were flown at 50-foot line spacing with the center line being directly over a 27 millicurie Cs-137 source. Figure B-7 shows the total cesium count (not just photopeak) contour map produced from this survey. The survey objective was to fly sufficient line lengths and enough lines to approximate the full footprint of the detector. While the along track distance was sufficient; the outermost lines did not quite cover the full footprint.

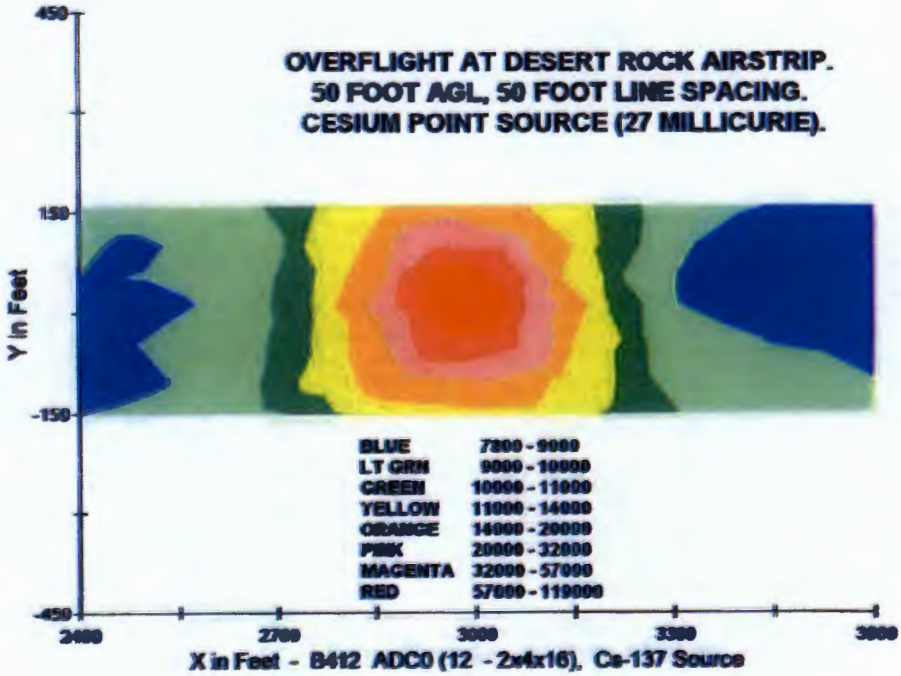

Figure B-7. Contour Map of Cesium Point Source Overflight

B.10 Notes on Detection System Footprint

It is standard practice to refer to the Full Width at Half Maximum (FWHM) spatial response to a point source as the footprint of the detection system. From inverse square calculations, the FWHM is nominally twice the detection system altitude. For the contour plot of Figure 7, the extent of the red contour is approximately 100 feet and contains all values from the peak value down to half the peak, complying nominally with the definition of detector footprint. Note, however, that the total effect of the point source reaches well beyond the 100 foot footprint, covering ~600 feet from 2700 feet to 3300 feet along the flight path. This spatial property can greatly disturb the ability to see small discreet sources in the presence of a large source.

B.11 Maurer Estimate and Desert Rock Data (Point Source)

As a first approximation (the maximum recorded data point may not have been exactly over the sealed source), the field measured point source sensitivity is just the point source strength divided by the net peak single point count. From data used to produce Figure B-7, with appropriate background corrections, and correction from gross cesium counts to photopeak cesium counts (required for the Maurer software code), the computation yields a point source photopeak sensitivity of:

$$\text{Point source sensitivity} = 27.0 / ((120169 - 8363) * 0.179) = 0.00135 \text{ mCi/cps}$$

(Compare to Maurer value of 0.0013)

where

27.0 = cesium point source strength in millicuries

120169 = peak observed counts per second

8363 = observed nominal background counts per second

0.179 = (Cesium photopeak cps) / (Cesium total cps)

The Maurer estimate and actual measurements are in good agreement

B.12 Maurer Estimate and Desert Rock Data (Infinite Surface)

Because the Desert Rock survey was flown at nominal constant speed and nominal constant line spacing, the infinite surface sensitivity can be estimated from the measured point source response. That is, the sum of all the spatially distributed contributions from a single point source is mathematically the same as the contribution would be at a single center point if identical sources were placed at each actual flown point.

The first order infinite surface sensitivity for the helicopter 12 detector system is then:

Surface sensitivity = 27.0 / ((1352623 – 854871) * 0.179 * 464)) = 0.000653
(Compare to Table 1 value of 0.000584)

where

1352623 = cps sum of the 100 measured points within the contour footprint

854871 = cps sum of nominal background of the 100 measured points

0.179 = ratio of peak to counts for cesium

464 = nominal square meters per point in the contour (100 foot × 50 foot)

The Maurer estimate and actual measurements are in reasonable agreement. Because the measured data did not quite capture all of the footprint counts (a denominator factor in the conversion calculations), one would expect the experimental value to be somewhat higher than reality.

B.13 Conversion of Distributed and Volumetric Activity at Hanford

Since the calculations done with point source data from Desert Rock determine point and surface coefficients which agree reasonably well with our current software, the calculations for distributed activity and soils predictions should also agree well with ground data measurements. In fact, if all the assumptions made in the computation agree with the actual field measurements and soil sample analysis results, there will normally be acceptable agreement. Unfortunately, such conditions do not always occur. Soil depth and source area uncertainties are the dominant contributors to aerial/ground disagreements. While the aerial systems gather very repeatable data, they do not have sufficient information to fully delineate spatial extent and depth for ground measurements.

For example, consider a soil volumetric measurement. If cesium is actually present only in the top one inch of soil, a collection of soil to a one inch depth is appropriate for determining soil concentration. If one homogenized the sample, determined the cesium activity and the gram weight of the sample, an accurate pCi/gram value would be obtained. Conversely, if the total amount of cesium activity in the top inch of the soil column is the same but the soil sampling method collects to a depth of ten inches, the calculated pCi/gram analysis result for the 10-inch sample is a factor of ten less than the earlier measurement.

A second source of error has to do with depositions which are not uniform within the detector footprint. The aerial measurement averages the activity over an area which is typically much larger than the area from which a surface or soil measurement is made. Preliminary field measurements within the BCCA by ground teams have documented numerous "hot spots" of Cs-137 within the

point data and contoured footprints of the helicopter system. It appears that the initial deposition of cesium activity by animals has not sufficiently weathered to produce a more uniform deposition as modeled by the RSL software code. The apparent discreet nature of the cesium deposition thus far measured severely limits the use of the preliminary Maurer volumetric constants.

As discussed, initial volumetric activity map products should only be used as aids for remediation planning efforts. Once an area has been remediated and only uniform low-level dispersed activity is expected, subsequent surveys by airborne, Kiwi, and other standoff radiation systems may produce net spectral photopeak counts that can be converted to a volumetric activity (pCi/g) map product. Any volumetric values derived from these instruments must be converted from measured count rate information. They do not directly measure pCi/g since they have no information about depth distribution.

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