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Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

12-AMCP-0010

OCT 25 2011

Mr. D. A. Faulk, Program Manager
Office of Environmental Cleanup
Hanford Project Office
U.S. Environmental Protection Agency
309 Bradley Boulevard, Suite 115
Richland, Washington 99352

Dear Mr. Faulk:

ON SCENE COORDINATOR REPORT FY 2010 AND FY 2011: BC CONTROLLED AREA (WASTE SITE UPR-200-E-83) LOCATED IN THE 200-OA-1 OPERABLE UNIT ON THE HANFORD SITE, DOE/RL-2011-101, REVISION 0

This letter transmits the approved On Scene Coordinator Report FY 2010 and FY 2011: BC Controlled Area (Waste Site UPR-200-E-83) Located in the 200-OA-1 Operable Unit on the Hanford Site, DOE/RL-2011-101, Revision 0. During August 2009 through July 2011 of the Fiscal Year 2009 through 2011 period, approximately 483,000 tons of contaminated soil was removed from an area of 140 acres (comprising Zone A and numerous spots in Zone B) of Waste Site UPR-200-E-83, also known as the BC Controlled Area.

If you have any questions, please contact me, or your staff may contact, Al Farabee, of my staff, on (509) 376-8089.

Sincerely,

Jonathan A. Dowell

Jonathan A. Dowell, Assistant Manager
for the Central Plateau

AMCP:FMR

Attachment

cc: See Page 2

RECEIVED
NOV 02 2011
EDMC

cc w/attach:
G. Bohnee, NPT
L. Buck, Wanapum
L. C. Buelow, EPA
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N. M. Menard, Ecology
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D. Rowland, YN (4) plus 2 CDs
Administrative Record
Environmental Portal

cc w/o attach:
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R. M. Hermann, CHPRC
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J. G. Vance, MSA

DOE/RL-2011-101
Revision 0

On Scene Coordinator Report FY2010 and FY2011: BC Controlled Area (Waste Site UPR-200-E-83) Located in the 200-OA-1 Operable Unit on the Hanford Site

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

U.S. DEPARTMENT OF ENERGY Richland Operations Office

P.O. Box 550
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

DOE/RL-2011-101
Revision 0

On Scene Coordinator Report FY2010 and FY2011: BC Controlled Area (Waste Site UPR-200-E-83) Located in the 200-OA-1 Operable Unit on the Hanford Site

Date Published
September 2011

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

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Executive Summary

During August 2009 through July 2011 of the fiscal year 2009 through 2011 period, approximately 483,000 tons of contaminated soil were removed from an area of 140 acres (comprising Zone A and numerous spots in Zone B) of Waste Site UPR-200-E-83, also known as the BC Controlled Area. This area is located south of the 200 East Area near the center of the U.S. Department of Energy Hanford Site.

Radiological surveys in the excavated area of Zone A and the peripheral areas of Zone B demonstrate that the removal effort eliminated radiological contamination above posting criteria established in 10 CFR 835.[1] Zone B is approximately 3,600 acres that contains more dispersed spots of contamination. Over 1,500 acres of the periphery of Zone B have been characterized and confirmed through field radiological soil surveys to be free of contamination above *Comprehensive Environmental Response, Compensation and Liability Act of 1980*[2] cleanup levels and radiological posting requirements. Zone C is the 4,700 acre southern half of the waste site. No removal efforts were conducted in Zone C, although a number of suspect areas of contamination were investigated and confirmed for surface contamination.

The excavated footprint of Zone A and the 1,500 acres of Zone B do not contain contamination above the preliminary remediation goals for cesium-137 and strontium-90 set forth in DOE/RL-2008-21.[3] DOE/RL-2008-21 authorized removal of shallow, radiologically contaminated soil for the selected areas in the northern part of the BC Controlled Area that was above preliminary remediation goals for the 200-UR-1 Unplanned Release Waste Group Operable Unit.

The removal action has been suspended as a result of competing funding priorities. Applications of soil fixatives and interim re-seeding to stabilize the excavated area were completed in February 2011. Removal activities were completed in Zone A during the month of July 2011. Dates for continuing the fieldwork activities for the BC Controlled Area outside of Zone A action have not been identified.

[1] 10 CFR 835, "Occupational Radiation Protection," *Code of Federal Regulations*. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2010-title10-vol4/xml/CFR-2010-title10-vol4-part835.xml.

[2] *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, 42 USC 9601, et seq., Pub. L. 107-377, December 31, 2002. Available at: http://epw.senate.gov/cercla.pdf.

[3] DOE/RL-2008-21, 2008, *Action Memorandum for the Non-Time-Critical Removal Action for the Northern Part of the BC Controlled Area (UPR-200-E-83)*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0806050037.

This on scene coordinator report has been completed as a requirement of DOE/RL-2008-22,[4] Section 5.5.2, which requires that an on scene coordinator report be developed after the completion of removal action activities and placed in the Administrative Record. Removal action activities have been completed in Zone A and have not been completed in Zone B. Because DOE/RL-2008-22 addresses Removal Action Objectives for the northern portion of the BC Controlled Area, which comprises Zones A and B, and contamination remains in Zone B, this report documents the current condition of Zones A and B. This document will be used to support future remedial actions and eventual deletion of the waste site from the National Priorities List.

[4] DOE/RL-2008-22, 2008, *Removal Action Work Plan for the Northern Part of the BC Controlled Area (UPR-200-E-83) Located Within the 200 UR 1 Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0904240157.

Metric Conversion Chart

Into Metric Units			Out of Metric Units		
If You Know	***Multiply By***	***To Get***	***If You Know***	***Multiply By***	***To Get***
	Length			**Length**	
Inches	25.4	millimeters	Millimeters	0.039	inches
Inches	2.54	centimeters	Centimeters	0.394	inches
Feet	0.305	meters	Meters	3.281	feet
Yards	0.914	meters	Meters	1.094	yards
Miles	1.609	kilometers	Kilometers	0.621	miles
	Area			**Area**	
Sq. inches	6.452	sq. centimeters	Sq. centimeters	0.155	sq. inches
Sq. feet	0.093	sq. meters	Sq. meters	10.76	sq. feet
Sq. yards	0.0836	sq. meters	Sq. meters	1.196	sq. yards
Sq. miles	2.6	sq. kilometers	Sq. kilometers	0.4	sq. miles
Acres	0.405	hectares	Hectares	2.47	acres
	Mass (weight)			**Mass (weight)**	
Ounces	28.35	grams	Grams	0.035	ounces
Pounds	0.454	kilograms	Kilograms	2.205	pounds
Ton	0.907	metric ton	Metric ton	1.102	ton
	Volume			**Volume**	
Teaspoons	5	milliliters	Milliliters	0.033	fluid ounces
Tablespoons	15	milliliters	Liters	2.1	pints
Fluid ounces	30	milliliters	Liters	1.057	quarts
Cups	0.24	liters	Liters	0.264	gallons
Pints	0.47	liters	Cubic meters	35.315	cubic feet
Quarts	0.95	liters	Cubic meters	1.308	cubic yards
Gallons	3.8	liters			
Cubic feet	0.028	cubic meters			
Cubic yards	0.765	cubic meters			
	Temperature			**Temperature**	
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
	Radioactivity			**Radioactivity**	
Picocuries	37	millibecquerel	Millibecquerel	0.027	picocuries

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Terms

BCCA	BC Controlled Area
BCG	biota concentration guidelines
CERCLA	*Comprehensive Environmental Response, Compensation and Liability Act of 1980*
CHPRC	CH2M HILL Plateau Remediation Company
COC	contaminant of concern
DCGL	derived concentration guideline level
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office
Ecology	Washington State Department of Ecology
EE/CA	Engineering Evaluation/Cost Analysis
ERDF	Environmental Restoration Disposal Facility
FY	fiscal year
GPS	Global Positioning System
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
MGA	Mobile Gamma Analysis
OU	Operable Unit
PRG	preliminary remediation goal
RCT	radiological control technician
RSL	Remote Sensing Laboratory
TPA-CN	Tri-Party Agreement Change Notice
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*

1 Introduction

This on scene coordinator report documents the contaminated soil removal activities performed during the period of September 2009 through July 2011 in the BC Controlled Area (BCCA) on the Hanford Site. The BCCA is a 3,480 ha (8,600 ac) waste site located immediately south of the 200 East Area on the Hanford Site, as shown in Figure 1-1. The BCCA is reported in the Hanford Waste Information Data Systems as an unplanned release site (UPR-200-E-83). During the discovery, characterization, and early remediation periods, the BCCA was part of the 200-UR-1 Operable Unit (OU). Therefore, regulatory requirements have been established for this removal action under the 200-UR-1 OU. However, during the time of remediation, the waste site was moved into the 200-OA-1 OU, a new OU with characteristics that more appropriately pertain to the BCCA.

The *Comprehensive Environmental Response, Compensation and Liability Act of 1980* (CERCLA) removal activities were performed as part of the removal actions identified in DOE/RL-2008-21, *Action Memorandum for the Non-Time-Critical Removal Action for the Northern Part of the BC Controlled Area (UPR-200-E-83)* (Action Memorandum). Prior to September 2009, removal activities were initiated in July of 2008 but suspended in September 2008 as a result of funding priorities, and the removal action was not completed. This report provides the status of the removal action in the *Hanford Federal Facility Agreement and Consent Order* ([Tri-Party Agreement] Ecology et al., 1989) administrative record until the removal action is completed or a final remedial decision for the BCCA and the 200-UR-1 Unplanned Release Waste Group OU has been made.

1.1 Location of Hazards

WMP-18647, *Historical Site Assessment of the Surface Radioactive Contamination at BC Controlled Area*, contains detailed information on the BCCA and a narrative of the contamination sources. As stated in WMP-18647, the BC Cribs and Trenches, located north of the BCCA, are known to be the source of the BCCA contamination, as the contamination in the BCCA was the result of animal intrusion and wind dispersion from the BC Cribs and Trenches. The BC Cribs and Trenches waste sites are part of the 200-BC-1 OU, separate from the 200-OA-1 OU. The BCCA waste site was divided into separate regions based on past historical information and analytical sampling events, as discussed in WMP-18647. The northern region of the BCCA is located north of the sand dunes that cross the controlled area from east to west. Animal intrusion and wind dispersion of contaminants originating in the BC Cribs and Trenches resulted in shallow soil contamination within the northern part of the BCCA, an area of approximately 1,500 ha (3,800 ac).

Within the northern part of the BCCA, the region that has the highest levels of contamination from cesium-137 and strontium-90 is referred to as Zone A. Zone A is approximately 57 ha (140 ac) and was identified in the Action Memorandum (DOE/RL-2008-21) as the area that presents the greatest risk to human health and the environment, with continuous radiological contamination over the preliminary remediation goals (PRGs). The remainder of the northern part of the BCCA, referred to as Zone B, contains some areas of detectable amounts of contamination in an irregular pattern; however, these areas are generally considered to be of lower risk. Figure 1-2 shows the diagram of the BCCA identifying the Zones A and B radiological contamination areas within the northern BCCA.

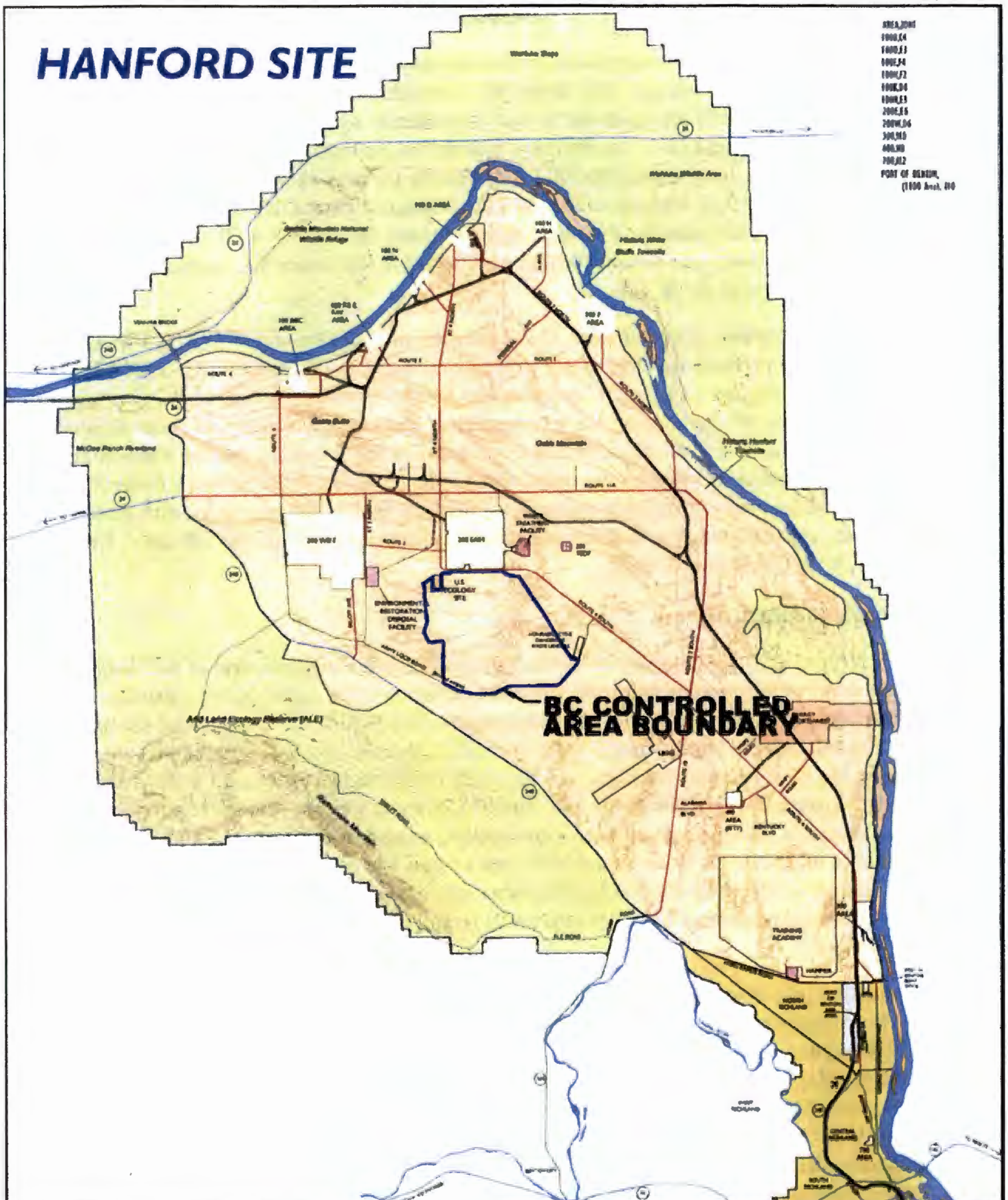


Figure 1-1. BC Controlled Area in the Hanford Site

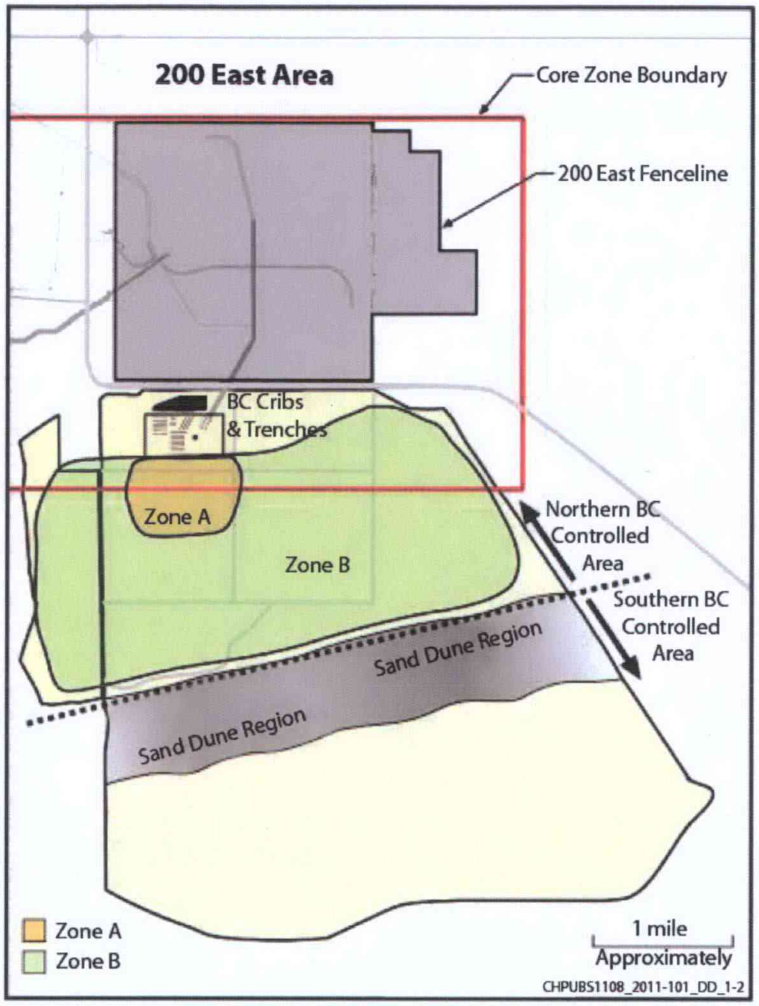


Figure 1-2. Diagram of the BC Controlled Area

Sampling in 1999 showed strontium-90 surface soil concentrations ranging from 0.32 to 3,420 pCi/g across the northern part of the BCCA. Cesium-137 surface soil concentrations range from 0.35 to 2,290 pCi/g across the area. Thus, the surface soil concentrations of cesium-137 and strontium-90—the two radionuclides likely to deliver the greatest dose to a recipient—vary widely across the northern part of the BCCA. According to WMP-18647, soil depth profiles of activity were expected to vary. Analytical data from calendar years 2005 and 2007 showed that the bulk of activity in areas with contamination caused by biological transport mechanisms (i.e., spread from animals) is primarily in the top 15 cm (6 in.) of the surface layer of soil, but is deeper in some areas.

For areas contaminated as a result of nonbiological transport mechanisms (i.e., windblown contamination), primarily in Zone B, the radionuclides are probably in the top 2.5 cm (1 in.) of the surface layer of soil, with the exception of strontium-90, which is distributed about 15 cm (6 in.) deep, based on sample results. The top 2.5 cm (1 in.) layer is expected to contain about 40 percent of the strontium-90. Depth profiles are discussed in greater detail in Section 3.5 of WMP-18647. No chemical contaminants of concern (COCs) had been identified during the BCCA characterization. Table 1-1 summarizes the results of the characterization efforts through 2007 for the known radionuclide COCs for the northern BCCA.

Table 1-1. Summary of 200-UR-1 OU BC Controlled Area Radioactive Contamination

Average and Maximum Detected Values for Radionuclides above 1 pCi/g in BC Controlled Area Zone A		
	Cs-137	**Sr-90**
Number of Detected Values	30	29
Average	164.5 pCi/g	303.2 pCi/g
Maximum	1,820 pCi/g	4,700 pCi/g

OU = operable unit

As aerial surveys of surface contamination previously conducted on the BCCA did not provide enough resolution to confidently identify and delineate spots of contamination characteristic of Zone B, the U.S. Department of Energy (DOE) requested the National Nuclear Security Administration, Nevada Site Office Remote Sensing Laboratory (RSL) to provide a low altitude survey of the BCCA. The data were collected by the Aerial Measuring System Radiation and Environmental Data Acquisition and Recorder, Version V, using an array of twelve 5 × 10 × 40 cm (2 × 4 × 16 in.) sodium iodide detectors flown onboard a twin-engine Bell 412 helicopter. The data were geo-referenced using a Differential Global Positioning System (GPS). Gamma-energy spectra were collected every second during the survey. Aerial survey parameters for an altitude of 15 m (50 ft) above ground level and parallel line spacing of 23 m (75 ft) were decided upon to maximize the man-made radiation sensitivity and reduce the effective footprint of the helicopter radiation acquisition system.

The surveys were performed in September 2009 to determine the nature and extent of contamination throughout the entire BCCA, and the results were reported in SGW-45563, *An Aerial Radiological Survey of the Hanford BC Controlled Area and West Lake Area*, presented as Appendix A of this document. The surveys updated the previous radiological surveys of the BCCA and provided a 100 percent gamma scan of the survey areas as per the Multi-Agency Radiation Survey and Site Investigation Manual ([MARSSIM] NUREG-1575) scoping and characterization survey objectives. Maps generated from the survey were used by the BCCA Soil Removal Project to determine the location and activity associated with radiological hot spots.

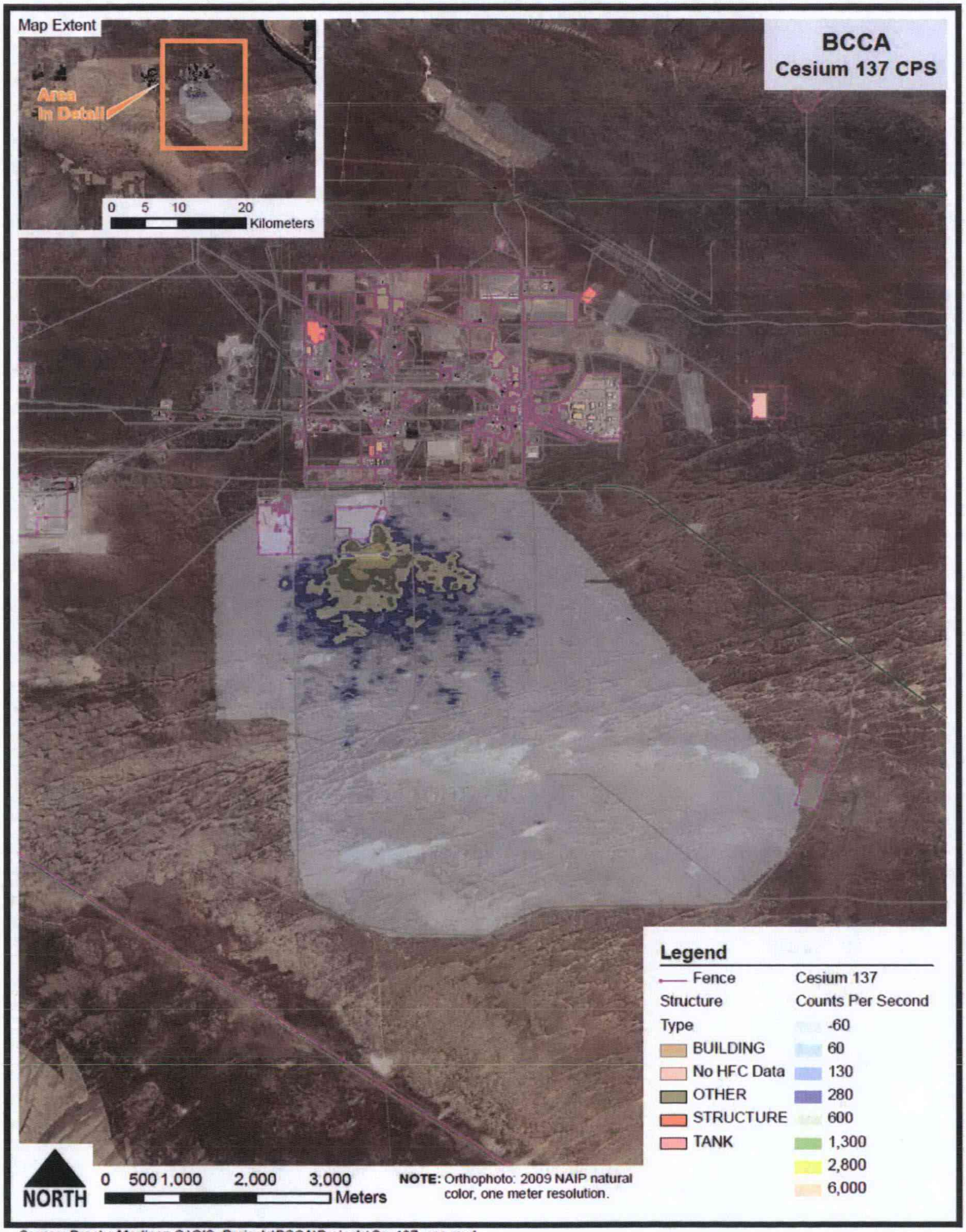
Gross counts of cesium-137 activity, as calculated from the aerial data, are presented as count per second (cps) intervals superimposed on imagery of the surveyed areas, as shown in Figure 1-3. The gross count and exposure rate results were comparable to the 1996 survey results. The BCCA deposition footprint was more complex than previously mapped due to the enhanced spatial resolution and detectability.

A final remedial decision for the 200-OA-1 OU has not been made. However, CERCLA radioactive hazardous substances[1] in the northern part of the BCCA present a potential threat to human health and the environment to the extent that a removal action[2] is warranted before a final remedial decision is documented. This removal action minimizes the potential for a release of hazardous substances from the northern part of the BCCA that could adversely impact human health and the environment, is protective

[1] "Hazardous substances" means those substances defined by CERCLA, Section 101(14), and include both radioactive and chemical substances.

[2] "Remove" or "removal" as defined by CERCLA, Section 101(23), refers to the cleanup or removal of released hazardous substances from the environment; actions if a threat of release of hazardous substances occurs; actions to monitor, assess, and evaluate the release (or threat of release) of hazardous substances; the disposal of removed material; or other actions that may be necessary to prevent, minimize, or mitigate damage to public health or welfare or the environment, which may otherwise result from a release or threat of release. If a planning period of at least 6 months exists before onsite actions must be initiated, the removal action is considered non-time critical and an engineering evaluation/cost analysis is conducted.

of site personnel and the environment, and contributes to the efficient performance of any anticipated long-term remedial actions, including any future soil remediation.



Source: Brooke Martinez C:\GIS_Projects\BCCA\Projects\Cs_137_cps.mxd

Figure 1-3. 2009 Helicopter Survey Map Showing Nature and Extent of Cesium-137 Contamination

1.2 Regulatory Documents

DOE/RL-2007-51, *Engineering Evaluation/Cost Analysis for the Northern Part of the BC Controlled Area (UPR-200-E-83)* (EE/CA), evaluated a removal action for the shallow contamination present in the northern part of the BCCA. A 30-day public comment and review period on the draft EE/CA (DOE/RL-2007-51) was held from February 25, 2008 through March 26, 2008. The comments and responses are contained in the Tri-Party Agreement (Ecology, et al., 1989) Administrative Record.

The Action Memorandum (DOE/RL-2008-21) implemented the remove, treat, and dispose alternative in the EE/CA (DOE/RL-2007-51) for removal of shallow, radiologically contaminated soil for the selected areas in the northern part of the BCCA that are above PRGs for the 200-UR-1 OU, and now the 200-OA-1 OU.

The removal action includes the removal of soil to approximately 15.2 cm (6 in.) or to the depth required to meet PRGs, to the extent practical, from Zone A and from select areas of elevated contamination in Zone B.

Table 1-2 summarizes the removal action goals for the radionuclide COCs identified in the Action Memorandum (DOE/RL-2008-21). These goals are based on the 200-UR-1 OU PRGs identified in DOE/RL-2004-39, *200-UR-1 Unplanned Release Waste Group Operable Unit Remedial Investigation/Feasibility Study Work Plan and Engineering Evaluation/Cost Analysis*, and DOE/RL-2006-50, *200-UR-1 Unplanned Release Waste Group Operable Unit Sampling and Analysis Plan* (200-UR-1 SAP).

Table 1-2. Summary of Radionuclide Soil Removal Action Cleanup Levels

Constituent	Hanford Site Background[a] (pCi/g)	RDL[b] (pCi/g)	Overall Removal Action Cleanup Levels[c] (pCi/g)
Cs-137	1.05	0.1	12.4
Sr-90	0.178	1	9.0

Note: The removal action cleanup levels are the same values specified in DOE/RL-2006-50, *200-UR-1 Unplanned Release Waste Group Operable Unit Sampling and Analysis Plan.*

a. Background values are based on DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, Table 5-1, lognormal distribution 90 percent.

b. The RDL is based on the current approved laboratory contractor RDL. The RDL is consistent with the practical quantification limits defined in WAC 173-340-200.

c. Listed values represent the most restrictive soil removal action cleanup levels, as identified in DOE/RL-2006-50. Values represented are for screening purposes. Site-specific evaluation and modeling will be performed to determine whether remedial action objectives have been attained in DOE/RL-2004-39, *200-UR-1 Unplanned Release Waste Group Operable Unit Remedial Investigation/Feasibility Study Work Plan and Engineering Evaluation/Cost Analysis.*

RDL = required detection limit

Final remedial action goals (cleanup levels) for the BCCA will be established in future 200-OA-1 OU remedial decision documents.

DOE/RL-2008-22, *Removal Action Work Plan for the Northern Part of the BC Controlled Area (UPR-200-E-83) Located Within the 200-UR-1 Operable Unit* (RAWP), identified the schedule for the removal action in fiscal year (FY) 2008 for the BCCA. DOE/RL-2008-22 proposed that a total volume of approximately 181,000 m^3 (237,000 yd^3) of contaminated soil, estimated to weigh 327,000 tons, be removed over a period of roughly 4 years to accomplish the following:

- Reduce the areas of contamination at the Hanford Site by removing the principal threat at the BCCA, Hanford's largest surface waste site
- Support the Hanford cleanup mission by providing the Environmental Restoration Disposal Facility (ERDF) with contaminated soil to meet its operating requirements
- Contribute to the long-term cleanup goal for the Hanford Site 200 Area

The 200-UR-1 SAP (DOE/RL-2006-50) was appended specifically to address PRGs for the BCCA, in Appendix A – BC Controlled Area Post Removal Action Verification Sampling and Analysis Plan. The 200-UR-1 SAP (DOE/RL-2006-50), Appendix A, presented the following details of the cleanup verification strategy:

- Closure of Zone A will be accomplished via a combination of radiological surveys and soil sampling. Zone A is a documented surface contamination area with extensive areas exceeding established derived concentration guideline levels (DCGLs).
- Because BCCA Zone A has widespread contamination, the surveys will be performed by a mobile radiological survey system that consists of sodium iodide detectors, and a GPS. The surveys will be conducted in the roving mode, yielding continuous survey data.

The sodium iodide detectors effectively monitor the presence of gamma-emitting isotopes—the principal one being cesium-137. The detected cesium-137 activity will be used as a surrogate isotope to determine the residual strontium-90 activity present, based on the ratio of strontium-90/cesium-137 observed in characterization efforts. Characterization activities performed under the provisions of the 200-UR-1 SAP (DOE/RL-2006-50) revealed a range of ratios of strontium-90 to cesium-137 activity in the northern BCCA. From this range of values, the 84^{th} percentile ratio of 4:1 was selected for initial calculations of DCGLs. The DCGLs for cesium-137 and strontium-90 were developed using this ratio and adjusted to account for an institutional control period of 30 years, as presented in Table A.3-3 of the 200-UR-1 SAP (DOE/RL-2006-50). This approach, allowed in MARSSIM, simplifies the closeout survey methodology and reduces costs.

Through the data quality objectives process, it was determined that the radiological surveys would suffice for closure of the northern portion of the BCCA, given the 15 mrem/yr above-background remedial action objective, the ecological protection biota concentration guidelines (BCG), and institutional controls of the area for at least 30 years. Cesium-137 and strontium-90 have half-lives of approximately 30 years; thus, the institutional control period provides one half-life of radiological decay, which effectively doubles the established DCGLs.

The minimum detectable concentrations (MDCs) shown in Table 1-3 are the MDC levels for the sodium iodide detectors that will be used to support closeout verification. At the MDC value, and given the 4:1 ratio of strontium-90/cesium-137, the estimated surrogate activity for cesium-137 is 1.9 pCi/g. Assuming the ratio of 4:1 for strontium-90/cesium-137, measured cesium-137 values greater than the surrogate DCGL result in residual strontium-90 concentrations greater than the adjusted DCGL for strontium-90. The derivation of the surrogate DCGL values was developed with appropriate methodology.

The surrogate DCGL for verification surveys, which accounts for the 4:1 strontium-90/cesium-137 ratio, effectively reduces the PRG for cesium-137 from 12.4 to 1.9 pCi/g, plus background of 1.05 pCi/g, or 2.9 pCi/g.

Table 1-3. Cleanup Levels and DCGLs for BC Controlled Area Closeout Verification

COC	Hanford Site Background[a] (pCi/g)	BCG (pCi/g)	15 mrem/yr Cleanup Level (pCi/g)	DCGLs[b] (pCi/g)	Surrogate DCGL for Verification Survey[c] (pCi/g)	4 × 4 × 16 in. Sodium Iodide MDC (pCi/g)	2 × 2 in. Sodium Iodide MDC (pCi/g)
Cs-137	1.05	21	6.2	12.4	1.9	0.75	1.1
Sr-90	0.178	23	4.5	9.0	7.6	NA	NA

a. Background values based on DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*, Table 5-1, with lognormal distribution of 90 percent.

b. The DCGLs are adjusted for institutional controls.

c. Calculated based on NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM), Section 4.3.2).

BCG = biota concentration guidelines

COC = contaminants of concern

DCGL = derived concentration guideline level

NA = not applicable

MDC = minimum detectable concentrations

2 Chronological Narrative of the Removal Action

This chapter provides a chronological narrative of the removal activities performed to excavate and dispose of contaminated soil in the BCCA.

2.1 Field Implementation Chronology

The 2010 BCCA removal activity during FY 2010 and FY 2011 resulted in the removal of approximately 463,000 tons of contamination soil from Zone A and 20,000 tons of contaminated soil from Zone B of the BCCA, which were disposed in the ERDF. Figure 2-1 shows the excavation area of focus planned for the 2010 removal. Planning and mobilization for the excavation work was initiated in August 2010.

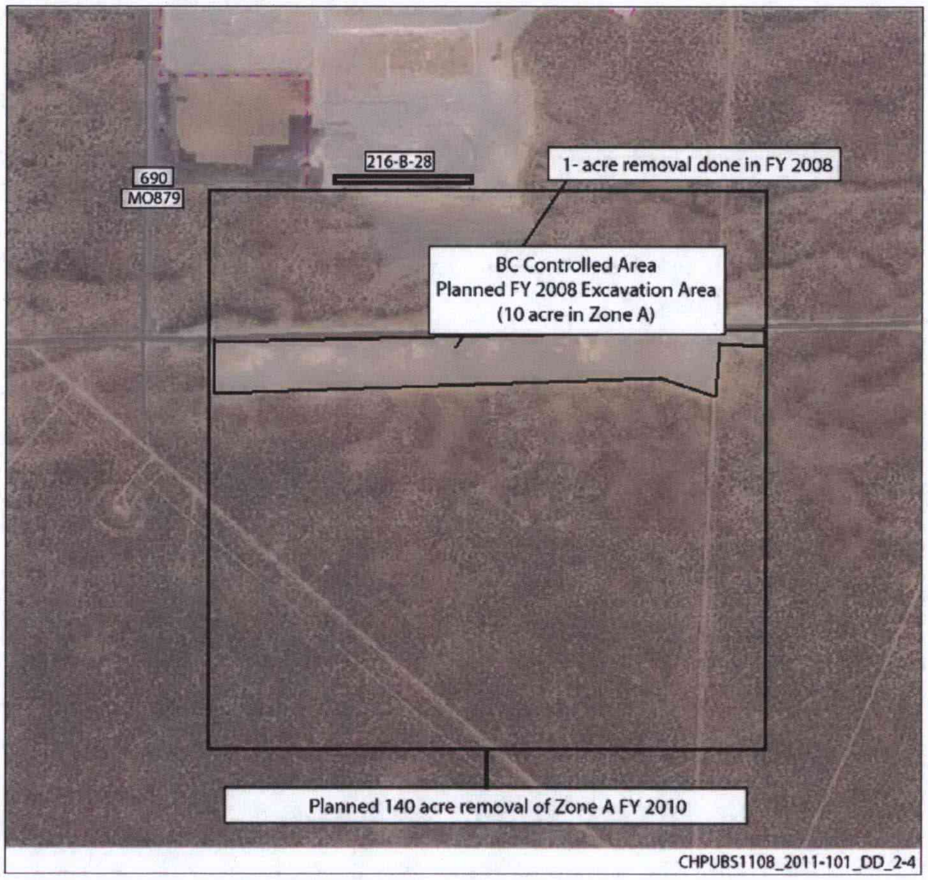


Figure 2-1. Planned FY 2010 BC Controlled Area Excavation Area of 140 Acres

Once personnel and equipment were mobilized, crews initiated removal of contaminated soil in a depression area south of the 216-B-28 trench. Simultaneously, a shallow load-out trench approximately 6 × 46 m (19.96 × 150.92 ft) long was established in this area. The purpose of the trench was to safely support loading of 25 ton super dump trucks, which could not be directly loaded at the point of excavation due to the sandy and undulating geology of Zone A.

As shown in Figures 2-2 and 2-3, excavation of contaminated material in Zone A was performed with John Deere and Hitachi 350- and 450-sized excavators pulling a 15 to 20 cm (6 to 8 in.) lift of material; the contaminated material was then loaded into a Cat 769 Rock Truck for transport to the load-out trench. Once at the load-out trench, material would be mixed and thoroughly wetted before being loaded into super dump trucks by a 350 excavator, as shown in Figure 2-4.

Figure 2-2. Zone A Excavation and Rock Truck Loading

Figure 2-3. Rock Truck Unloading in Load-Out Trench

Figure 2-4. 350 Excavator Filling a Super Dump Truck at Load-Out Trench

During July 2010, it was decided to begin stockpiling contaminated material from the Zone A excavation onto an adjacent contaminated area of Zone B for future shipment to the ERDF to increase efficiency, mitigate loss of production during ERDF closures, and reduce subcontractor costs and duration. During those times that the load-out trench became fully loaded, rock trucks would haul material from Zone A to the stockpile area and unload. Material was stockpiled from July 2010 through February 2011. During this time, the load-out trench was cleaned out, and all super dump truck loading was then transferred to the stockpile for the duration of the project.

Super dump trucks could be used because the nature of contamination was low level and the haul route to the ERDF had been previously established. Once loaded, super dump trucks would cross a calibrated scale (to ensure the shipment was below the maximum 25 ton payload), pass through a radiological survey tent, be automatically tarped, and then traverse a gravel back road to the ERDF and onto a disposal ramp for dumping.

The direct haul method of waste disposition via super dump trucks allowed for increased safety and efficiency:

1. No container transfer area construction was required.
2. Waste boxes did not have to be rolled on and off at every evolution of the ERDF container transportation process, which decreased labor efforts and hazards.
3. Waste quantities per load were increased: 24 to 25 tons per super dump truck in comparison to 18 to 20 tons per ERDF container.
4. Decreased labor was required at the ERDF, as the trucks dumped directly into the landfill without any staging.
5. Automatic tarping systems reduced labor efforts and lowered elevated work hazards.

The excavation depths were guided by radiological control technicians (RCTs) who monitored residual contamination after each 15 to 20 cm (6 to 8 in.) lift of material was removed until survey measurements were below radiological posting criteria. This observational approach resulted in the removal of contaminated surface soils from the BCCA Zone A over an area of approximately 140 ac. The excavated area was shallow enough that the remaining footprint followed the natural contour of the existing surface formations. It was reseeded with native grass seed mixtures after conclusion of the FY 2010 removal activities.

The following monthly activity review documents the scope of work performed in FY 2009 through FY 2011.

2.1.1 Pre-excavation Mobilization and Startup

August 2009: Mobilization for the BCCA began on August 10, 2009. Equipment, supplies, and boundaries were established. Improvements were begun on back haul roads for the intended transfer route of to the ERDF. CH2M HILL Plateau Remediation Company (CHPRC) and ERDF staff began discussions regarding the use of super dump trucks as a new technology at the ERDF. A super dump truck was brought onto the ERDF site for all interested parties to evaluate.

September 2009: On September 1, 2009, the subcontractor began clearing, compacting, and gravelling a site in the borrow pit that would be used by more permanent support facilities. On September 3, 2009, CHPRC and ERDF staff met to finalize a list of action items required prior to startup of super dump truck disposal at the ERDF. The first four super dump trucks arrived onsite and dry-runs were completed. However, lack of ERDF container availability delayed the start of excavation. On September 22, 2009, RSL began their aerial survey of the BCCA. Surveying took place September 22 to 29, 2009. Mobilization was completed and the worksite logistics were in place, as shown in Figure 2-5.

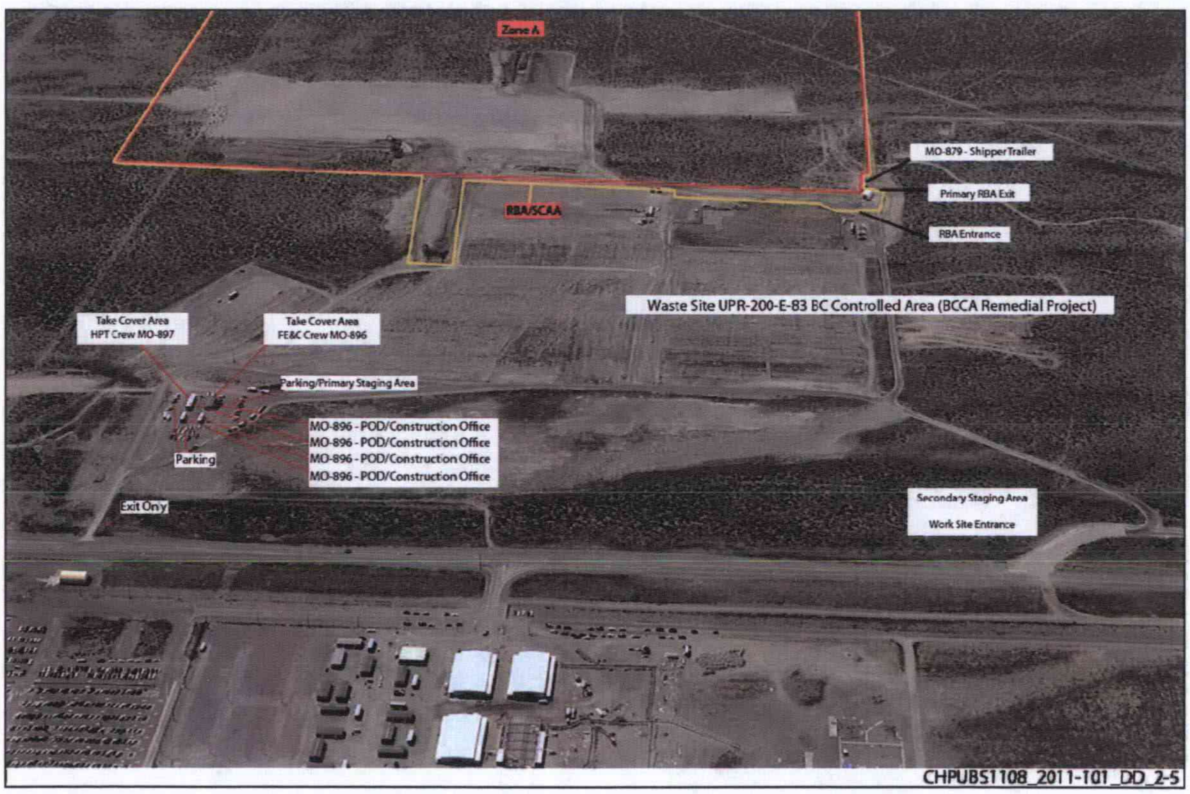


Figure 2-5. BC Controlled Area Removal Action Worksite Map

2.1.2 Excavation and Soil Disposal

October 2009: Excavation commenced on October 5, 2009. Approximately 4 ac at the north end of Zone A were surveyed and down-posted from a contamination area to a soil contamination area/ radiological buffer area. Clearing an area of this size allowed for increased traffic safety and enhanced excavation efficiency. Final driver training and revision to ERDF practices were completed the morning of October 7, 2009, followed by final approval and signature of the pre-startup review by the ERDF management. October 8, 2009, six super dump truck loads of material were hauled to and disposed of at the ERDF. With the use of three super dump trucks in service, 6 ac were excavated, as shown in Figure 2-6, and 3,800 tons were shipped to the ERDF.

Figure 2-6. BC Controlled Area Removal Action October 2009

November 2009: Excavation of contaminated soil in Zone A continued with the use of three super dump trucks in service. A survey tent was erected and scaffolding was being constructed. The lack of the additional super dump trucks impacted the completion schedule. On November 30, 2009, CHPRC provided DOE Richland Operations Office (DOE-RL) preliminary data from the helicopter aerial survey conducted from late September 2009 to early October 2009. As shown in Figure 2-7, 2 ac were excavated this month, and 7,600 tons were shipped to the ERDF.

December 2009: Excavation of contaminated soil in Zone A continued with the use of three super dump trucks in service. Work was impacted for a total of 4 days in December 2009, due to extreme cold weather, as indicated by Figure 2-8. Contract award for the procurement of six more super dump trucks was issued on December 10, 2009. The lack of the additional super dump trucks impacted the completion schedule. In Zone A, 1 ac was excavated this month, and 5,500 tons were shipped to the ERDF.

Figure 2-7. BC Controlled Area Removal Action November 2009

Figure 2-8. Removal of Frozen Soil from the Bed of a Super Dump Truck

January 2010: Excavation of contaminated soil in Zone A continued with the use of three super dump trucks in service. A draft report from the helicopter aerial survey was provided to DOE-RL for review. The lack of the additional super dump trucks impacted the completion schedule. In Zone A, 1 ac was excavated this month, as shown in Figure 2-9, and 13,730 tons were shipped to the ERDF.

Figure 2-9. BC Controlled Area Removal Action January 2010

February 2010: Excavation of contaminated soil in Zone A continued with the use of six super dump trucks in service. Work in Zone B was initiated with hot spot excavation conducted over approximately 2 ac. On February 11, 2010, CHPRC notified DOE-RL (via correspondence) of a contract change condition associated with the waste characterization of the southern half (Zone C) of BCCA (roughly 10.5 km^2 [6.52 mi^2]), based on the survey. The presence of elevated radiologically contaminated soil in Zone C was not anticipated and will require remediation. CHPRC received the final report of the aerial survey from the subcontractor on February 19, 2010. In Zone A, 3 ac were excavated this month, and 19,715 tons were shipped to the ERDF.

March 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. Work in Zone B continued; activities included radiological down-posting, MARSSIM confirmatory surveys, and hot spot remediation. Hot spot excavation was continued on an area of approximately 5 ac in Zone B, and approximately 680 ac of Zone B were down-posted this month. Cultural resource surveys were completed for Zone C. A total of 3.5 ac of Zone A were excavated this month, as shown in Figure 2-10, and 27,630 tons were shipped to the ERDF.

Figure 2-10. BC Controlled Area Removal Action March 2010

April 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. On April 1, 2010, CHPRC submitted a Request for Equitable Adjustment corresponding to a nominal increase in depth of contamination to DOE-RL. On April 15, 2010, CHPRC provided DOE-RL the final (cleared) report of the aerial survey. On April 21, 2010, CHPRC presented a briefing of the aerial survey results to DOE-RL and the regulators to support determinations of the nature and extent of potential remediation. Work in Zone B continued; activities included radiological down-posting, MARSSIM confirmatory surveys, and hot spot remediation. Approximately 2 ac equivalent of soil volume was removed from Zone B, and approximately 850 ac of Zone B were down-posted this month. As shown in Figure 2-11, 4.5 ac of Zone A were excavated this month, and 22,178 tons were shipped to the ERDF.

Figure 2-11. BC Controlled Area Removal Action April 2010

May 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. A draft report from the helicopter aerial survey was provided to DOE-RL for review. Hot spot excavation was continued on an area of approximately 8 ac in Zone B, and approximately 1,000 ac of Zone B were down-posted through May 2010. Excavation of vegetated areas of Zones A and B was temporarily discontinued while a field work mitigation plan to protect migratory birds' habitat and nesting, in compliance with the *Migratory Bird Treaty Act of 1918*, was completed. On May 20, 2010, DOE-RL approved the mitigation plan, which outlined an avoidance strategy that allowed field work to resume. As an outcome of an April 21, 2010, report briefing of the September 2009 aerial survey of the BCCA, DOE-RL contacted the Washington State Department of Ecology (Ecology) requesting a meeting with the U.S. Environmental Protection Agency and CHPRC to discuss a proposed regulatory approach (and rationale) for the contaminated soil cleanup (removal action) work that, along with CERCLA and other regulatory documents, will be required for Zone C. In Zone A, 3 ac were excavated this month, as shown in Figure 2-12, and 17,552 tons were shipped to the ERDF.

Figure 2-12. BC Controlled Area Removal Action May 2010

June 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. The migratory bird avoidance strategy was implemented in Zones A and B, resulting in approximately 5 ac of Zone A and 5 ac of Zone B being deemed areas where excavation activities would not adversely impact migratory birds. Approximately 1,100 ac of Zone B were down-posted through June 2010. An ecological field survey of Zone C was completed on June 30. In Zone A, 4 ac were excavated this month, as shown in Figure 2-13, and 25,340 tons were shipped to the ERDF.

Figure 2-13. BC Controlled Area Removal Action June 2010

July 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. The migratory bird avoidance strategy was implemented in Zones A and B, resulting in approximately 5 ac of Zone A and 5 ac of Zone B being deemed areas where excavation activities would not adversely impact migratory birds. Removal of elevated hot spots in an area of 4 to 5 ac on the western side of the BCCA was completed. Hot spot excavation was continued on an area of approximately 10 ac in Zone B, and approximately 1,300 ac were down-posted through July. In order to recover schedule lost to the lack of super dump trucks at the project's conception, constraints during the migratory bird nesting season, and shutdowns due to weather, two changes in operation were made:

1. Due to the nontransferable nature of the contamination at BCCA, excavators were placed on the contaminated material, while all rock trucks and water trucks remained on clean material, reducing logistical constraints on equipment.
2. Location and controls were selected to allow the subcontractor to begin stockpiling large quantities of contaminated material, alleviating the constraints on material transport to the ERDF.

The 30-day review of the Zone C cultural resources review report by the State Historic Preservation Offices, the Tribes, and others, which DOE-RL transmitted on June 14, 2010, was completed, and no comments were received. In Zone A, 5.5 ac were excavated this month, and 19,704 tons were shipped to the ERDF.

August 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. With guidance from consulting ornithologists (and given the general end of the nesting season as described in the ecological review for Zone A), a large area of 50 to 60 ac was grubbed of vegetation with a team of graders to maintain field operations in anticipation of the coming high fire danger. Zone B hot spot removal was concluded with excavation over an area of approximately 15 ac, and approximately 1,500 ac were down-posted through August. Zone B resources were shifted to focus on completing remediation of Zone A. Optimum excavation rates in Zone A were realized with three excavators in the field, supported by three rock trucks hauling to the load-out trench and stockpile, as well as six supporting water trucks controlling dust suppression. One excavator remained to continue loading super dump trucks from the load-out trench. In Zone A, 7 ac were excavated this month, as shown in Figure 2-14, and 30,016 tons were shipped to the ERDF.

Figure 2-14. BC Controlled Area Removal Action August 2010

September 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. Through system review, it was determined that the pedigree of the data acquisition system required to accurately quantify residual contaminant quantities was not found in the onsite Gator Utility Vehicles mounted system,™ which had been used in the previous removal action. Therefore, a new detector, crystal, and vehicle was procured, characterized, and tested offsite at DOE's RSL in Las Vegas, Nevada. The detector and acquisition system will be used to make real-time volumetric measurements in pCi/g of cesium-137; the measurements will be used as cleanup verification data under CERCLA closure. The mobile detector will also be used in characterizing large parcels of land, locating contamination, and assisting in radiological down-posting. On September 21, 2010, CHPRC submitted to DOE-RL a change proposal that identified additional *American Recovery and Reinvestment Act of 2009* funded work for removing approximately 1,131,000 tons of additional soil in Zone B. Radiological characterization of a number of scattered hot spots in Zone C continued. In Zone A, 12 ac were excavated this month, as shown in Figure 2-15, and 31,964 tons were shipped to the ERDF.

October 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. On October 12, 2010, DOE-RL was provided a pre-decisional draft Tri-Party Agreement (Ecology, et al., 1989) Change Notice (TPA-CN), which proposed the addition of an appendix to the previously approved 200-UR-1 SAP (DOE/RL-2004-39) to address post-removal action verification sampling for hot spot contamination areas in the BCCA North. The draft TPA-CN was provided by DOE-RL to Ecology for their review at this time. However, it was later determined that, due to the non-time critical nature of this removal action, hot spot removal verification criteria would be established in a sampling and analysis plan under development addressing the 200-OA-1 OU, and the TPA-CN would be cancelled.

In Zone A, 15 ac were excavated this month, as shown in Figure 2-16, and 26,292 tons were shipped to the ERDF.

™ Gator Utility Vehicles is a trademark of John Deere & Company, Moline, Illinois.

Figure 2-15. BC Controlled Area Removal Action September 2010

Figure 2-16. BC Controlled Area Removal Action October 2010

November 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. CHPRC and RSL staff conducted the final field performance testing of a Kubota utility vehicle mounted with a large crystal sodium iodide (gamma) detector. The testing involved performing a side-by-side survey of the remediated portion of Zone A using the Kubota and an equivalent mobile vehicle and detection system (the "Kiwi") owned by RSL. The results of this test will be used for both verifying cleanup of cesium-137 and validating performance of the Kubota. Ecology continued review of the draft change notice addressing post remediation cleanup verification of Zone B hot spots. In Zone A, 13 ac were excavated this month, and 20,552 tons were shipped to the ERDF.

December 2010: Excavation of contaminated soil in Zone A continued with the use of seven super dump trucks in service. A draft report from the helicopter aerial survey was provided to DOE-RL for review. The lack of the additional super dump trucks impacted the completion schedule. In Zone A, 15 ac were excavated this month, as shown in Figure 2-17, and 21,969 tons were shipped to the ERDF.

Figure 2-17. BC Controlled Area Removal Action December 2010

January 2011: Excavation of contaminated soil in Zone A continued with the use of nine super dump trucks in service. In Zone A, 14 ac were excavated this month, as shown in Figure 2-18, and 24,803 tons were shipped to the ERDF. CERCLA post-soil removal verification measurements were continued with the large crystal sodium iodide (gamma) detector mounted on the Kubota utility vehicle. A vendor was selected for interim stabilization/revegetation of Zone A. The vendor mobilized materials and equipment to the site and began performing revegetation of the remediated portion of Zone A on January 28, 2011. The work was aligned with the draft Hanford Site-wide guidance plan on revegetation.

February 2011: Excavation of contaminated soil in Zone A continued with the use of eight super dump trucks in service. In Zone A, 13 ac were excavated this month, culminating in the completion of removal of 140 ac of Zone A, as shown in Figure 2-19; 19,294 tons were shipped to the ERDF. Residual hot spots identified during the Kubota surveys continued to be remediated. CERCLA post-soil removal verification measurements using a large crystal sodium iodide (gamma) detector mounted on a Kubota utility vehicle continued. Survey measurements were completed for approximately 80 percent of the area. Seeding of the initial 100 ac was completed.

March 2011: Removal of contaminated soil from the stockpile continued with the use of nine super dump trucks in service. As indicated by Figure 2-20, 29,740 tons were shipped to the ERDF. CERCLA post-soil removal verification measurements using a large crystal sodium iodide (gamma) detector mounted on a Kubota utility vehicle were completed for 100 percent of the area, while individual hot spots continued to be remediated and surveyed. The seeding of 140 ac was completed.

Figure 2-18. BC Controlled Area Removal Action January 2011

Figure 2-19. BC Controlled Area Removal Action February 2011

Figure 2-20. BC Controlled Area Removal Action March 2011

April 2011: Removal of contaminated soil from the stockpile continued with the use of nine super dump trucks in service. As indicated by Figure 2-21, 31,658 tons were shipped to the ERDF. Final down-posting surveys to release the land area from radiological controls were started on April 4, 2011. Residual contamination detected during any down-posting surveys that approached the posting criteria of 10 CFR 835, "Occupational Radiation Protection," was remediated and re-surveyed.

Figure 2-21. BC Controlled Area Removal Action April 2011

May 2011: Removal of contaminated soil from the stockpile continued with the use of ten super dump trucks in service. A total of 38,531 tons were shipped to the ERDF. Final down-posting surveys to release the land area from radiological controls continued. Residual contamination detected during any down-posting surveys that approached 10 CFR 835 posting criteria was remediated and re-surveyed.

June 2011: Removal of contaminated soil from the stockpile continued with the use of ten super dump trucks in service. As indicated by Figure 2-22, 32,400 tons were shipped to the ERDF. Final down-posting surveys to release the land area from radiological controls continued. Residual contamination detected during any down-posting surveys that approached 10 CFR 835 posting criteria was remediated in accordance with the RAWP (DOE/RL-2008-22).

Figure 2-22. BC Controlled Area Removal Action June 2011

July 2011: Removal of contaminated soil from the stockpile was completed on July 14, 2011, with the use of ten super dump trucks in service. As shown in Figure 2-23, 16 ac of Zone A were excavated this month, and 13,249 tons were shipped to the ERDF. Final down-posting surveys to release the land area from radiological controls were completed. The subcontractor demobilized all facilities and equipment from the site.

Figure 2-23. BC Controlled Area Removal Action July 2011

Monthly excavation and removal rates for October 2009 through July 2011 are shown in Table 2-1.

Table 2-1. Summary of 200-UR-1 OU BC Controlled Area Soil Removal

Month	Tons to ERDF*	Acres of Removal
October 09	3,881	6
November 09	7,562	2
December 09	5,526	1
January 10	13,730	1
February 10	19,715	4
March 10	27,630	5
April 10	22,178	7
May 10	17,552	4
June 10	25,340	6
July 10	19,704	6
August 10	30,016	10
September 10	31,964	17
October 10	26,292	15
November 10	20,552	13
December 10	21,969	16
January 11	24,803	14
February 11	19,294	13
March 11	29,740	-
April 11	31,658	-
May 11	38,531	-
June 11	32,400	-
July 11	13,249	-
Total	**483,286**	**140**

* One super dump truck averages 24 tons per load to ERDF.

2.2 Zone A Removal Action Surveys

A series of radiological surveys were conducted to support post-soil removal verification surveys and sampling of Zone A. Table 2-2 presents a summary of the Zone A survey and sampling design.

Table 2-2. Key Features of Zone A Survey and Sampling Design

Sampling Collection Methodology	Key Features of Design	Basis for Sampling Design	Sample Frequency	Instruments	Analytes
Pre-Excavation Confirmation of 2007 Radiological Survey Results					
Radiological survey	Survey before soil removal in two of the perimeter grids surveyed in 2007	Confirm radiological contamination status since the 2007 survey	Continuous survey in two of the 2007 survey grids	2 × 2 in. or 3 × 3 in. sodium iodide detectors	Cs-137
Zone A Soil Removal—Remove and Dispose of Zone A Radiologically Contaminated Soil					
Post-Excavation Radiological Survey					
Kiwi/Kubota radiological survey[a]	Radiological survey of all grids after soil removal	Radiological status of soil surface after soil removal lifts; identify hot spots	Continuous survey using 2007 survey grids	4 × 4 × 16 in. sodium iodide detector	Cs-137
Zone A Hot Spot Removal—Remove and Dispose of Residual Hot Spots in Zone A (radiological contaminated soil removal)					
Verification Radiological Survey					
Radiological survey	Radiological survey of hot spot locations after soil removal	Verify attainment of Cs-137 DCGLs	100% survey of excavated hot spots	2 × 2 in. or 3 × 3 in. or 4 × 4 × 16 in. sodium iodide detectors	Cs-137
Radiological survey	Static 100 cm^2 beta measurements of hot spot locations after soil removal	Confirm the absence of radiological contamination less than 10 CFR 835 levels[a]	95% confidence survey of selected locations[b]	Static 100 cm^2 beta measurements	Cs-137 and Sr-90

a. 10 CFR 835, "Occupational Radiation Protection."

b. Based on Visual Sampling Plan, using NUREG 1575, *Multi Agency Radiation Survey and Site Investigation Manual* (MARSSIM) methodology to calculate the number of survey points with a 95% confidence level.

DCGL = derived concentration guideline level

Excavation in Zone A was planned for total excavation of 140 ac to a minimum depth of 6 in. or until the depth required to reach PRGs. After the initial 6 in. removal, continued remediation was guided by field surveys for gamma radiation, typically with a sodium iodide and 4393 Rate Meter Dual Scintillation Detectors (or equivalent). Removal of contaminated soils was conducted to a depth necessary to result in contamination levels below radiological posting requirements in accordance with 10 CFR 835, followed by verification surveys and correlation to PRGs in accordance with the 200-UR-1 SAP (DOE/RL-2006-50).

Cleanup verification surveys of the an initial 70 ac were conducted in accordance with DOE/RL-2006-50, Appendix A, *BC Controlled Area Post-Removal Action Verification Sampling and Analysis Plan*, using a mobile vehicle mounted with a radiological survey system equipped with sodium iodide detectors, visual read-out controller, and GPS. During the survey of the first 70 ac, two mobile detection systems were used: the "Kiwi" owned and operated by NStech personnel out of DOE's RSL, and the Kubota owned and operated by CHPRC personnel. Each system is similar in detection capability, with each able to meet the minimum detectable activity required in the 200-UR-1 SAP (DOE/RL-2006-50), Appendix A. The Kiwi vehicle and RSL staff were used to obtain a 100 percent survey of 70 remediated ac and build a data set made up of cesium-137 concentrations based on a 6 m^2 (19.69 ft^2) field of view. The team from RSL was also contracted to analyze a parallel dataset obtained by a 100 percent survey of the area with the Kubota survey system and build a parallel data set of cesium-137 concentrations based on a 2 m^2 (21.53 ft^2) field of view. The parallel surveys were conducted as a final validation of capabilities for the Kubota, which was used to verify cleanup of the remainder of BCCA.

As remediation excavations continued across Zone A, the Kubota continued verification surveys until 100 percent of the 140 ac were surveyed. Areas above the cleanup criteria were remediated as localized spots of contamination and re-surveyed by the Kubota. Results of the verification surveys are further discussed in Section 2.5.

2.3 Zone B Spot Characterization and Removal Action Surveys

The following sections discuss the survey design, excavation guidance surveys, and removal action final status surveys used within Zone B.

2.3.1 Survey Design

A series of radiological surveys were conducted to support a post-soil removal verification decision on Zone B contamination spots. Table 2-3 presents a summary of the spot contamination area survey design.

Table 2-3. Key Features of Spot Contamination Radiological Survey Design

Survey Methodology	Key Features of Design	Basis for Sampling Design	Sample Frequency	Instruments	Analytes
		Nature and Extent Survey			
Helicopter fly-over radiological survey	Determine nature and extent of contamination and identify spot contamination in entire BCCA	Locate radiological hot spots to guide soil removal operations	100% survey (census)	Array of 4 × 4 × 16 in. sodium iodide detectors	Cs-137
		Excavation Guidance Survey			
Hand-held radiological survey	Confirm presence of radiological hot spot locations	Confirm the results of the helicopter survey	Survey 12 random locations in hot spot area	Static 100 cm^2 beta measurements	Cs-137 and Sr-90
		Define hot spot boundaries	Walk-around surveys to define perimeter of hot spot	2 × 2 in. or 3 × 3 in. sodium iodide detectors	Cs-137

Table 2-3. Key Features of Spot Contamination Radiological Survey Design

Survey Methodology	Key Features of Design	Basis for Sampling Design	Sample Frequency	Instruments	Analytes
Final Status Survey					
Hand held or mobile radiological survey	Radiological survey hot spot locations after soil removal	Verify attainment of Cs-137 DCGLs	100% survey of excavated hot spots	2 × 2 in. or 3 × 3 in. or 4 × 4 × 16 in. sodium iodide detectors	Cs-137
Hand-held radiological survey	Static 100 cm^2 beta measurements of spots post soil removal	Verify that gross beta measurements are less than 10 CFR 835 levels[a]	95% confidence survey of selected locations[b]	4393 Rate Meter Dual Scintillation detectors or equivalent and 2 × 2 in. or 3 × 3 in. or 4 × 4 × 16 in. sodium iodide detectors	Cs-137 and Sr-90
Confirmatory Survey—Confirm Clean Zones Between Hot Spots					
Hand-held radiological survey	Confirm the absence of radiological contamination in noncontaminated areas	Confirm the results of the helicopter survey	Survey 12 random locations in hot spot area	Static 100 cm^2 beta measurements	Cs-137 and Sr-90

a. 10 CFR 835, "Occupational Radiation Protection."

b. Based on Visual Sampling Plan, using NUREG 1575, *Multi Agency Radiation Survey and Site Investigation Manual* (MARSSIM) methodology to calculate the number of survey points with a 95% confidence level.

BCCA = BC Controlled Area

DCGL = derived concentration guideline level

Figure 2-24 depicts contaminated areas or spots identified by either the 2009 helicopter fly-over survey or nature and extent survey. Contamination is represented in counts of gamma energy from cesium-137 contributions per second. The lightest blue shade of 60 cps represents background levels. All areas showing levels at 130 cps or greater were investigated with field instrumentation as the first step in the excavation guidance survey process.

2.3.2 Excavation Guidance Surveys

Following analysis of the aerial survey conducted in September of 2009, field validation of the hot spots identified during the survey was initiated and a systematic approach for remediating the 3,600 ac Zone B was developed.

There are two classes of survey units for the BCCA spot contamination area, the first being the contaminated hot spot survey units, set as a Class I area under MARSSIM, with survey unit sizes no larger than 2,000 m^2 (0.49 ac). The second is the noncontaminated area survey units, called a MARSSIM Class III area, with survey unit sizes less than 0.647 km^2 (0.25 mi^2), which are shown in Figure 2-25.

Zone B contains firebreak roads established to protect roughly 1,200 ac of old growth sage habitat and the most densely contaminated portions of Zone B. Contamination outside of the firebreak roads appeared very sparse, based on the 2009 aerial survey. Therefore, it was determined appropriate to classify the land outside the firebreak roads as Class III. The approach for characterization of these units was to study the aerial survey and determine whether the survey unit contained spots of contamination.

If contamination was identified in the aerial survey, then the characterization process proceeded as follows:

1. Obtain coordinates of all identified hot spots inside the 0.647 km^2 (0.25 mi^2) survey unit
2. Confirm the presence or absence of contamination through field surveys with hand-held devices
3. Determine the extent of contamination and post contamination area boundaries

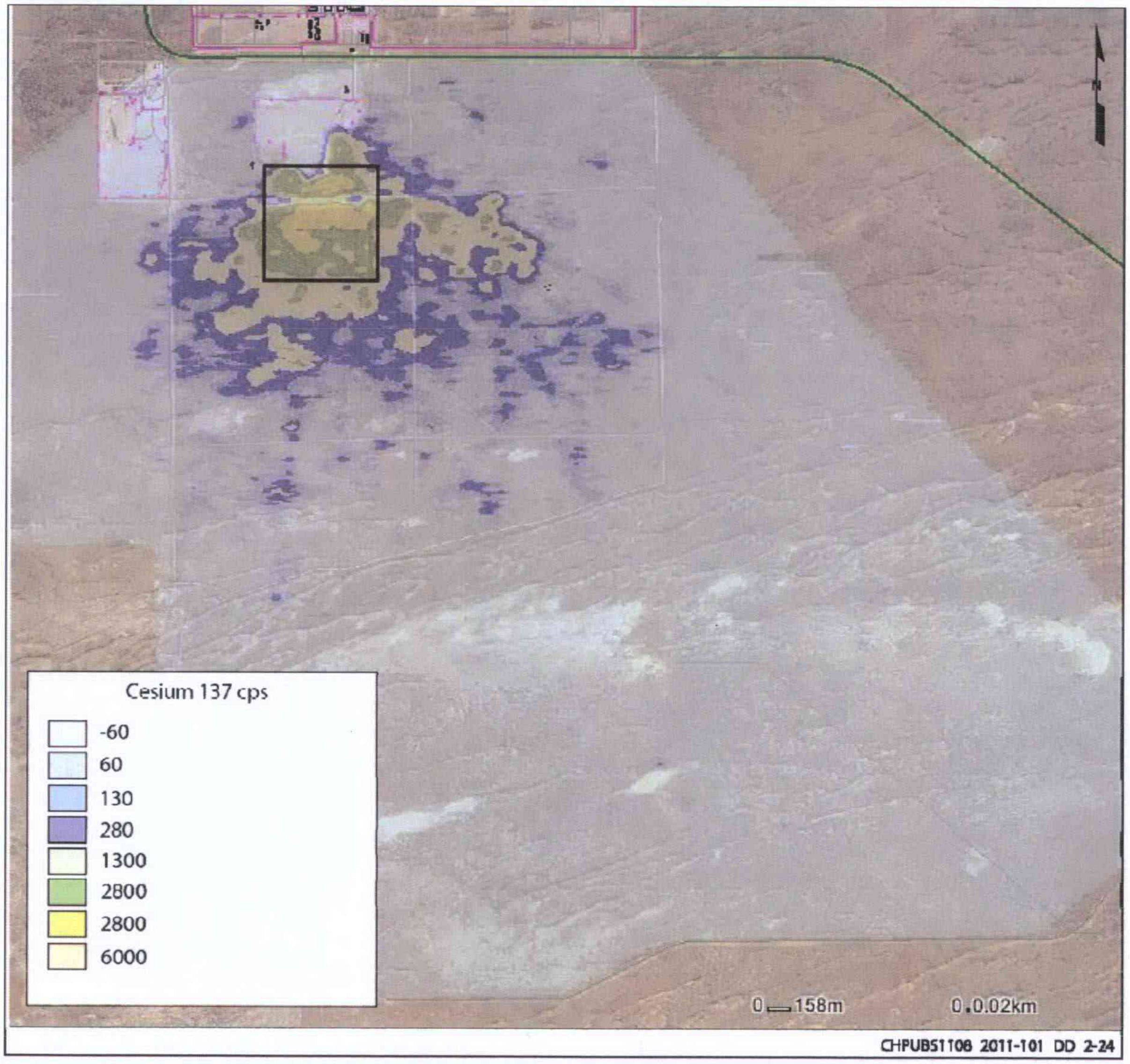


Figure 2-24. BC Controlled Area September 2009 Aerial Survey—Cesium-137 Contamination

Once it was determined that there were no contaminated spots in a survey unit, or that spots had been identified and posted correctly, then a confirmatory survey was conducted of the non-contaminated survey unit. Confirmatory surveys were conducted in accordance with DOE/RL-2006-50, Appendix B, *BC Controlled Area Post-Removal Action Verification Sampling and Analysis Plan for Spot*

Contamination Areas. When confirmatory surveys provided evidence of contaminated areas, those areas were investigated in accordance with the steps above, and the confirmatory survey process was re-started.

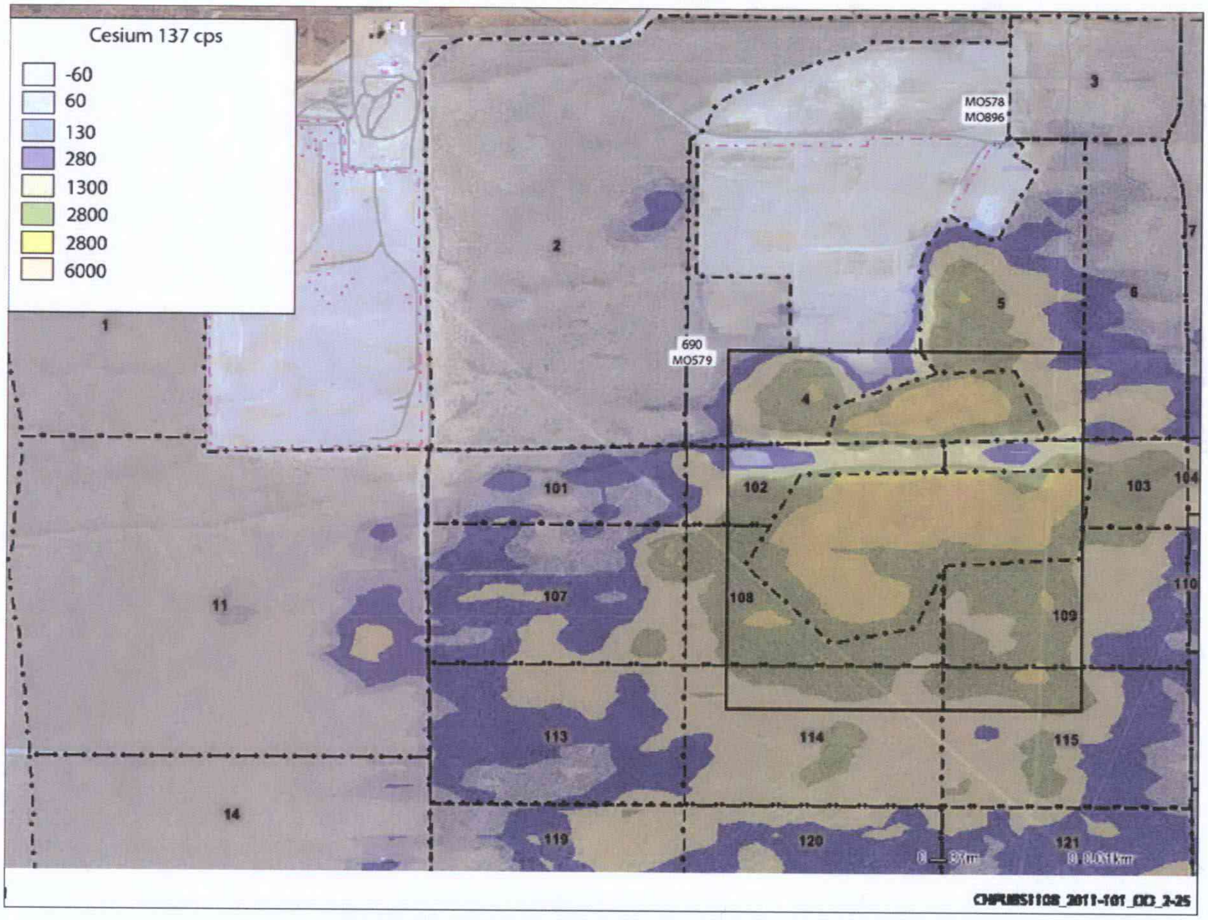


Figure 2-25. BC Controlled Area September 2009 Zone B Subunits

2.3.3 Removal Action Final Status Surveys

Contaminated spots in Zone B requiring removal were excavated using the same process as that for Zone A. The initial excavations were surveyed for residual contamination by both sodium iodide and 4393 Rate Meter Dual Scintillation Detectors (or equivalent), which provided results that would guide continued excavation depths. Once contamination was removed below radiological posting requirements, final status surveys were performed on the remediated hot spots. These surveys are also performed with both sodium iodide and 4393 Rate Meter Dual Scintillation Detectors (or equivalent). The sodium iodide survey provided 100 percent coverage of the excavated soil area. Twelve random survey locations per remediated spot were selected and measured by the rate meter detector to meet down-posting requirements.

The areas remediated in Zone B were not driven by the Kubota and, therefore, no verification survey has been completed in accordance with DOE/RL-2006-50, Appendix A. Though contaminants have been removed below radiological posting criteria, an evaluation of the residual contaminant concentrations in remediated hot spots in Zone B has not been completed.

2.4 Zone C Investigation

A number of areas of contamination identified by the 2009 Aerial survey were investigated in Zone C. Personnel performed field surveys for gamma radiation, typically with sodium iodide and 4393 Rate Meter Dual Scintillation Detectors (or equivalent), on spots of various sizes that had been identified by the aerial survey as having contamination above background levels. Some of the spots investigated were false positives, meaning field instruments were not able to locate detectable levels of contamination. However, larger spots were confirmed as having contamination levels that require radiological posting per 10 CFR 835 requirements. Figure 2-26 shows an example of Zone C contamination. No removal actions were performed in Zone C.

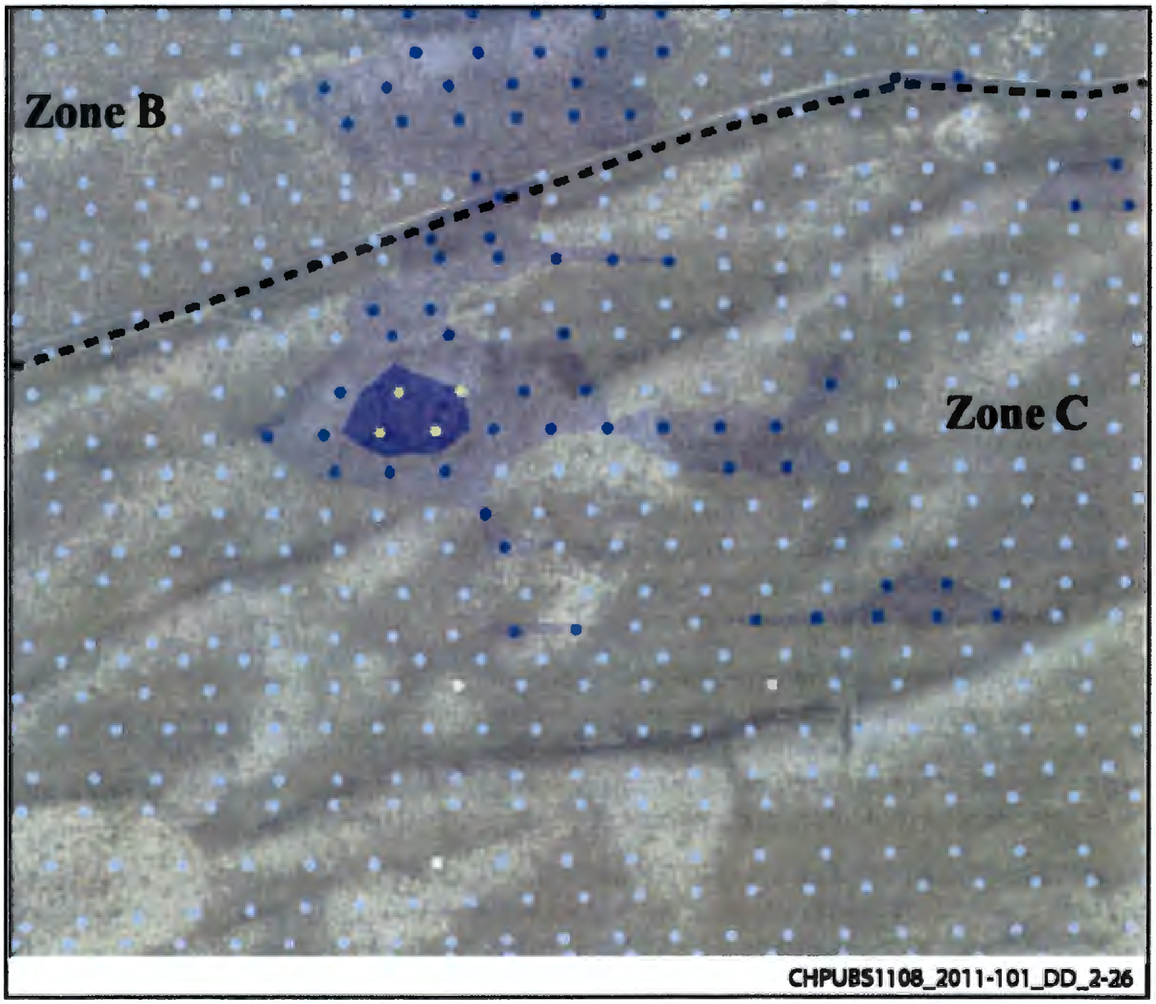


Figure 2-26. BC Controlled Area Zone B and C Contamination

2.5 Effectiveness of the Removal Action

The following sections discuss the outcomes of the removal actions and surveys performed in Zones A and B.

2.5.1 Zone A Removal

Approximately 483,000 tons of contaminated soil was removed from the BCCA during the period from October 2009 through July 2011. This represents considerably more than the original estimate of 327,000 tons of contaminated soil in the RAWP (DOE/RL-2008-22) for entire remediation of the BCCA.

A radiological survey of the excavated area that used two separate mobile gamma analysis (MGA) systems—the Kiwi and the Kubota systems—was conducted in November 2010 over approximately 70 ac of Zone A as an interim cleanup verification effort. MGA surveys were concluded on the remaining 70 ac in March of 2011.

The radiological survey process used in the BCCA is consistent with the guidance provided by the Ecology Memorandum (Price, 2008), "MARSSIM protocols for direct radiation measurements, to demonstrate consistency with chapter 173-340 requirements for compliance monitoring," The memorandum documents how specific direct measurements are consistent with monitoring requirements in WAC 173-340-740(7)(e) and discusses the use of MARSSIM site survey and investigative process as applied to the BCCA work activities. The following sections describe the process used for completing that survey and provide a summary of survey results.

2.5.1.1 Description of the Radiological Survey Process

The MGA system provides Gamma Energy Analysis data for surface soils to a depth of around 15 cm (6 in.). The Kiwi MGA system consisted of a bank of eight 10 × 10 × 41 cm (4 × 4 × 16 in.) sodium iodide detectors attached to Gamma Spectral System hardware. A GPS provided spatial coordinates in conjunction with the collected gamma spectral data. The equipment was mounted on a Ford F250 pickup, which allowed surveys of large areas of terrain. The MGA system was operated by driving the vehicle at a predetermined speed, nominally 2 m/sec (6 ft/sec) across the area of interest. As the vehicle progressed, spectral data and GPS coordinates were saved at a regular rate that was predetermined depending on the type of survey (i.e., scoping, characterization, or closure survey) being performed.

The Kiwi MGA system determined the presence of gamma emitters in surface soils by integrating collected signal data into 512 channels. The sodium iodide detector was mounted approximately 46 cm (18 in.) above the ground surface to minimize effects related to uneven terrain. At that detector height, the field of view (area scanned per data point) was about 1 m (3 ft) wide and 2 m (7 ft) long per data point, at a scan speed of 2 m/sec (7 ft/sec). Minimum detectable activity for the system was approximately 0.75 pCi/g for cesium-137 in the field of view.

Activity per energy channel was integrated between save points, with counts per second recorded for each of the 512 energy channels. At the end of the area scan, data points consisted of the energy spectral data as well as the GPS coordinates for the points where data were saved. Quantitative analysis of the spectral data was performed and plotted for specific gamma emitters of interest such as cesium-137 or for total gamma energy at each saved location, depending on the scope of the survey performed.

Results of the scan were plotted on a map of the area using the GPS coordinates collected during the survey process. A detailed description of the calibration and analysis methods for both the Kiwi and Kubota MGA systems was provided by the RSL in SGW-50939, *Kubota and Kiwi Ground Surveys of the BC Controlled Area Hanford Nuclear Reservation*, presented as Appendix B of this document.

2.5.1.2 Results of the Verification Survey

Figure 2-27 displays the radiological survey map for the first 70 ac excavated in Zone A, which was surveyed in the BCCA as of December 1, 2010. The radiological survey map displays cesium-137 contamination calculated from the survey data collected from the Kiwi system. The calculated cesium-137 concentrations were grouped into ranges (three ranges below the 2.9 pCi/g PRG for cesium-137, and three ranges above the PRG) for easier identification on the survey map. This information was reported by the RSL in SGW-50939, presented as Appendix B of this document. Information on COC strontium-90 contamination was not available from the MGA survey analysis software, but it is correlated from cesium-137 results in accordance with the 200-UR-1 SAP (DOE/RL-2006-50).

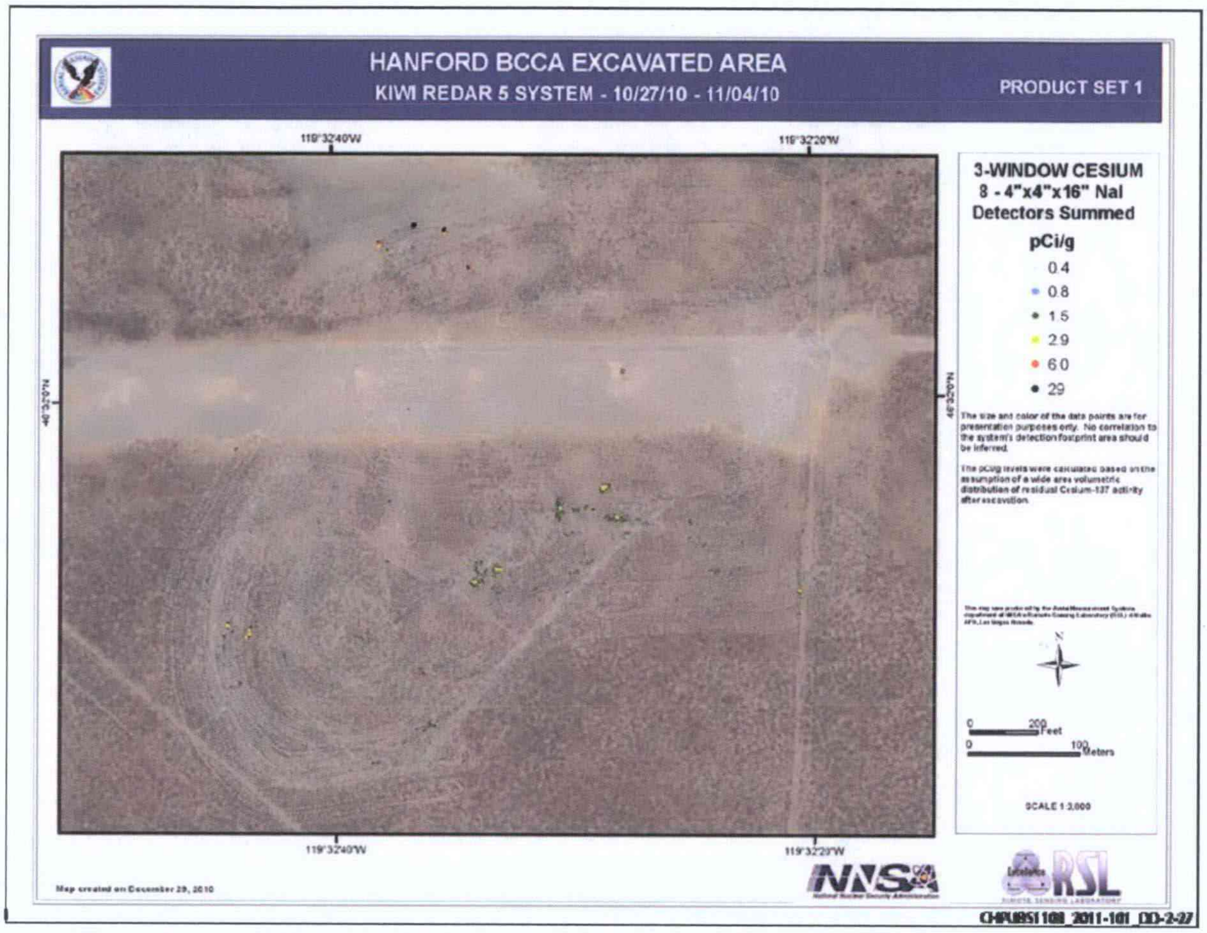


Figure 2-27. BC Controlled Area Zone A Verification Survey Map 70 Acres—Kiwi

Figure 2-28 displays the radiological survey map for the first 70 ac of Zone A, which was surveyed using the Kubota system in December 1, 2010. The two maps collected by the two systems, Kiwi and Kubota, show small areas of contamination above the cleanup criteria of 2.9 pCi/g, identified by the orange, black, or magenta markings.

Studying the point data collected during the Kubota surveys allowed a correlation to be made between the areas above the cleanup criteria of 2.9 pCi/g and areas with man-made, or net counts, of cesium-137 greater than 4,400 cps, as shown in Figure 2-28. Further explanation on the conversion from contaminant activity to volumetric contaminant concentrations is found in SGW-50939, presented as Appendix B of this document.

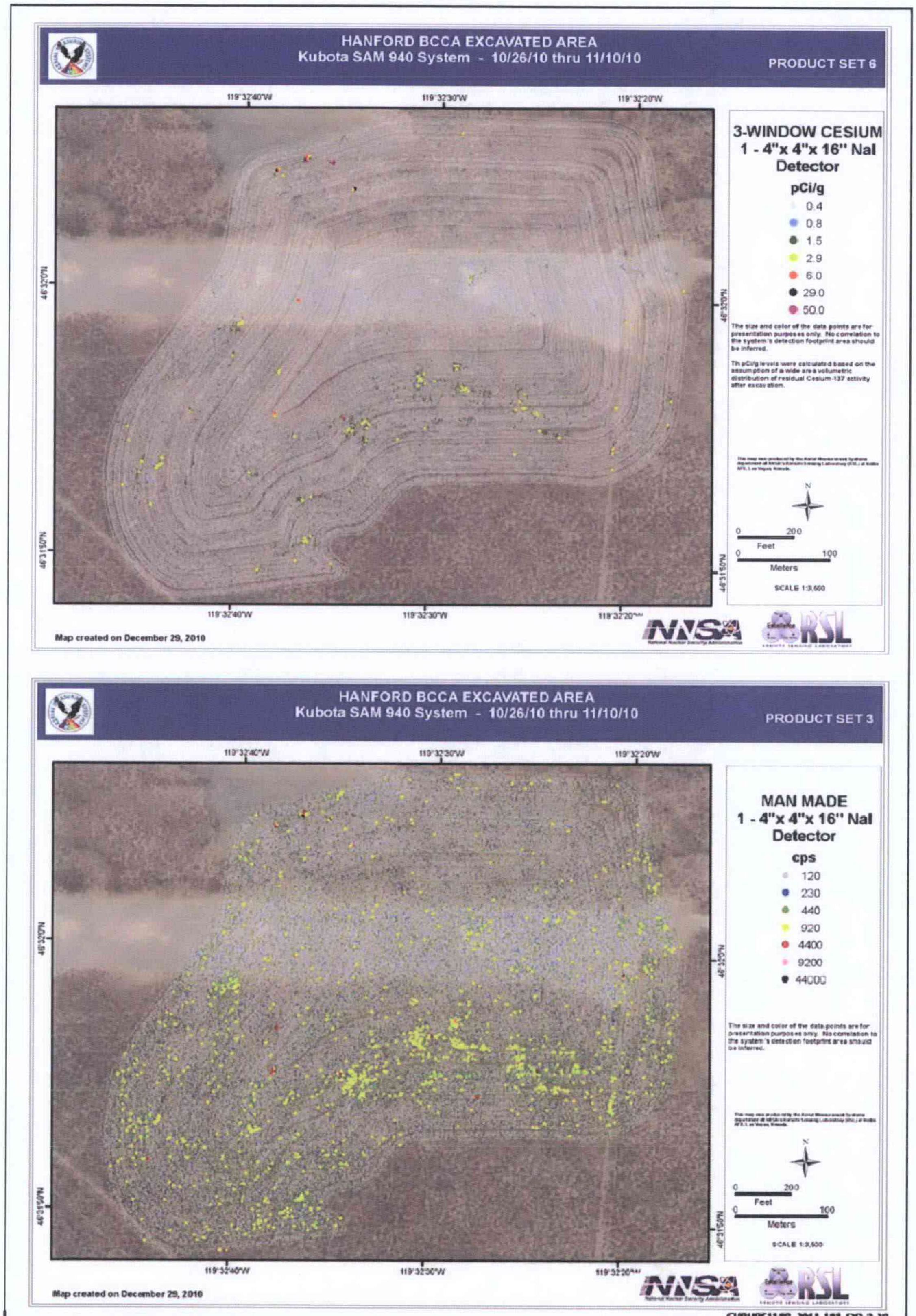


Figure 2-28. BC Controlled Area Zone A Verification Survey Maps 70 Acres—Kubota

During the early months of calendar year 2011, the remaining 70 ac of Zone A were surveyed by the Kubota system as excavations were completed. Given that the cleanup criteria were approached at 4,400 cps, localized hot spot remediation was conducted on areas greater than 2,500 cps. This lower level activity threshold also ensured there would be no need for occupational radiation protection postings, which are independent from the cleanup criteria. Investigative surveys determined that the radiological posting criteria, which is based on surface activity, was slightly more limiting than the volumetric cleanup criteria. Unlike the cleanup criteria, which factors in a 30-year decay period for institutional control, the radiological posting criteria apply to the as-left condition. In other words, if an area satisfied cleanup criteria but exceeded DOE radiological posting criteria, those controls would have to be maintained or additional remediation performed. The actual number of locations between 2,500 and 4,400 cps were limited to less than a dozen small hot spots. An example of a survey from remediated areas of localized contamination, which were used as *'fill-in'* surveys to be used in a consolidated final survey map, is shown in Figure 2-29. These efforts culminated in the final verification survey map for 100 percent of Zone A with no residual contamination greater than 2500 cps, shown in Figure 2-30.

2.5.1.3 Results of the Radiological Down-Posting Survey

Radiological posting requirements set forth in 10 CFR 835 and implemented through CHPRC radiological methods establish minimum safe activity levels for radiological contamination. Following the 100 percent scanning survey of Zone A by the Kubota with sodium iodide detection of gamma activity, a down-posting survey plan based on MARSSIM guidance for survey unit size and unit evaluation survey point frequency was followed. Initial field surveys were conducted by technicians at locations (gathered from the Kubota survey) that had the highest potential to exceed posting criteria. This evaluation led to the decision to include judgmental survey points at points with the highest activity detected with the Kubota system, along with the statistical survey locations gained from a MARSSIM design.

The plan resulted in 140 ac of Zone A broken into 84 survey units either 2,000 m^2 (0.49 ac) or 10,000 m^2 (2.47 ac), depending on the potential for activity based on the Kubota survey. In each survey unit, 12 random survey locations were established with Visual Sample Plan, and 4 judgmental locations were selected based on the four highest points from the Kubota survey, for a total of 16 survey points per survey unit. Locations that exceeded 10 CFR 835 posting criteria were remediated and re-surveyed. This process helped lead to the successful remediation and down-posting of 140 ac.

2.5.2 Zone B Removal

A total of approximately 20,000 tons of contaminated soil was removed from the BCCA during the spring of 2010. This resulted in the removal of approximately 15 ac of contaminated spots. Because the original funding was limited to accomplishing the removal of 15 ac of contaminated soil, soil removal in Zone B was suspended after the completion of this scope. Remediated spots were surveyed post remediation to ensure that residual levels were below posting requirements. Follow-on verification surveys with the Kubota MGA will be required.

Contaminated spots have been investigated and accurately posted in the majority of the area outside the firebreak roads. This resulted in the down-posting of more than 1,680 ac from Contamination Area or Soil Contamination Area postings to no radiological postings. Though the result was not reconfiguration of a CERCLA waste site boundary, land management area has been reduced and site hazards more precisely defined from a radiological standpoint. Contaminated spots are represented in Figure 2-31 by alpha numeric labels (e.g., ZB-2-6), the shapes for which represent actual radiological postings in the field.

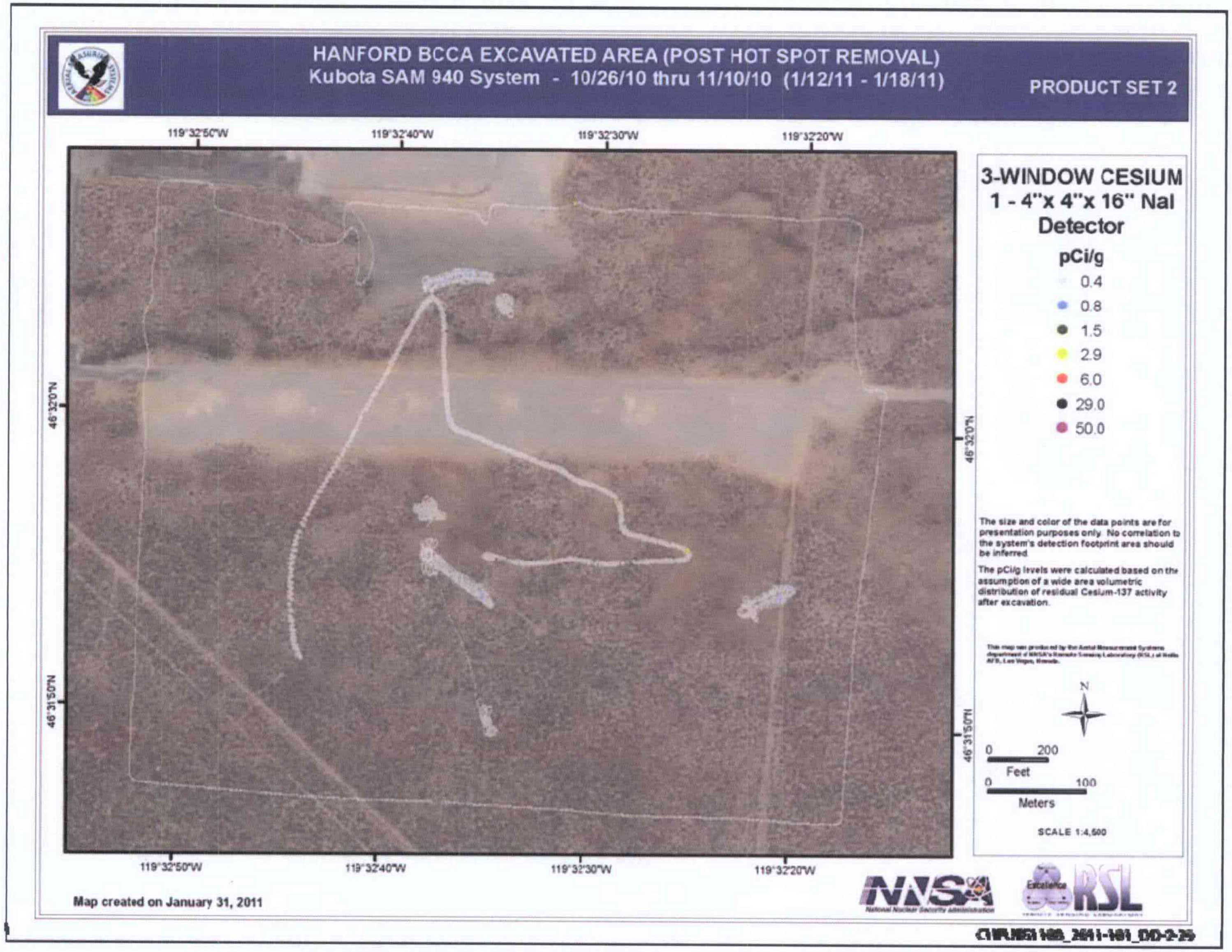


Figure 2-29. BC Controlled Area Hot Spot Removal Survey—Kubota

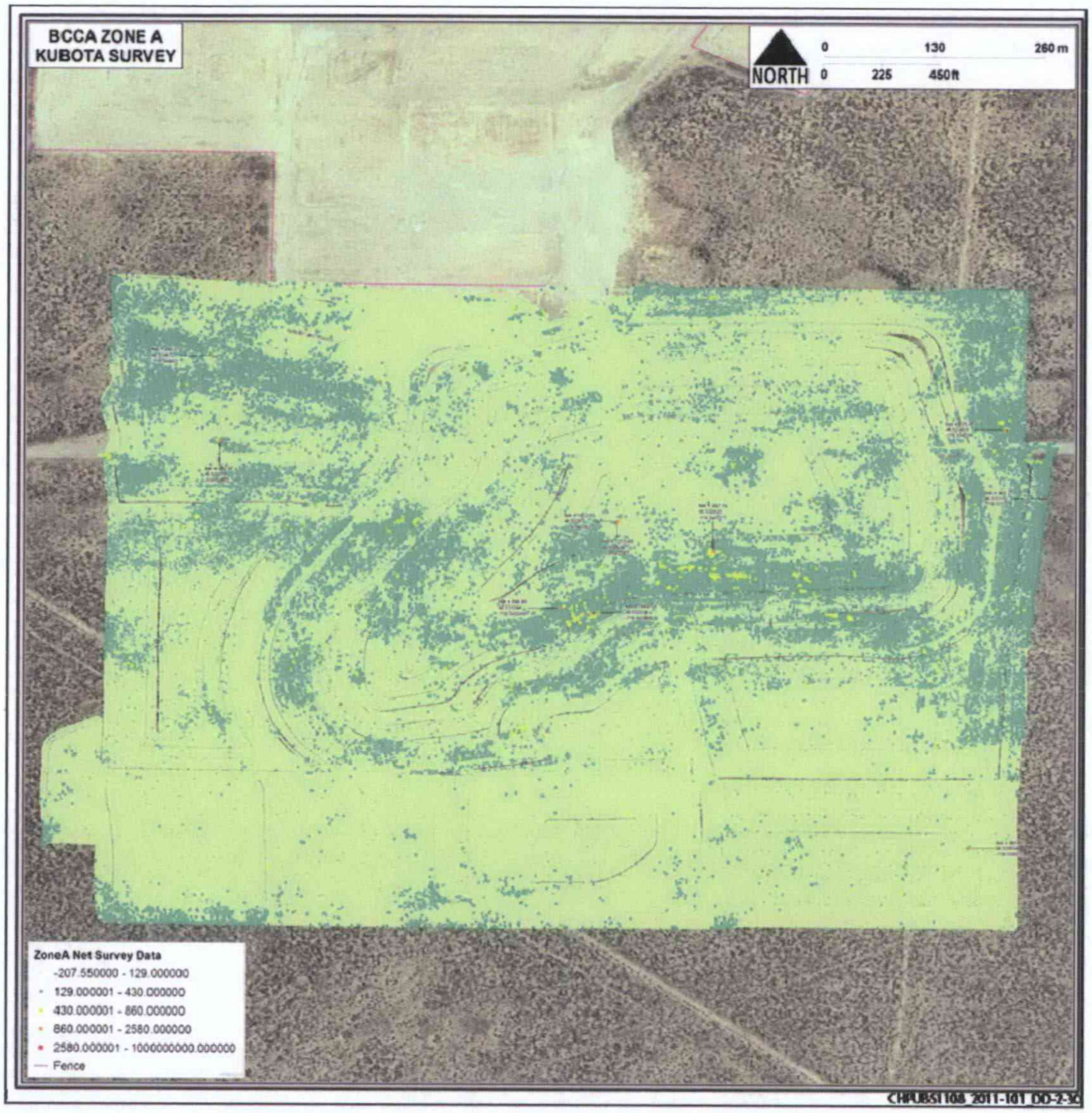


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Figure 2-30. BC Controlled Area Hot Spot Removal Survey—Kubota

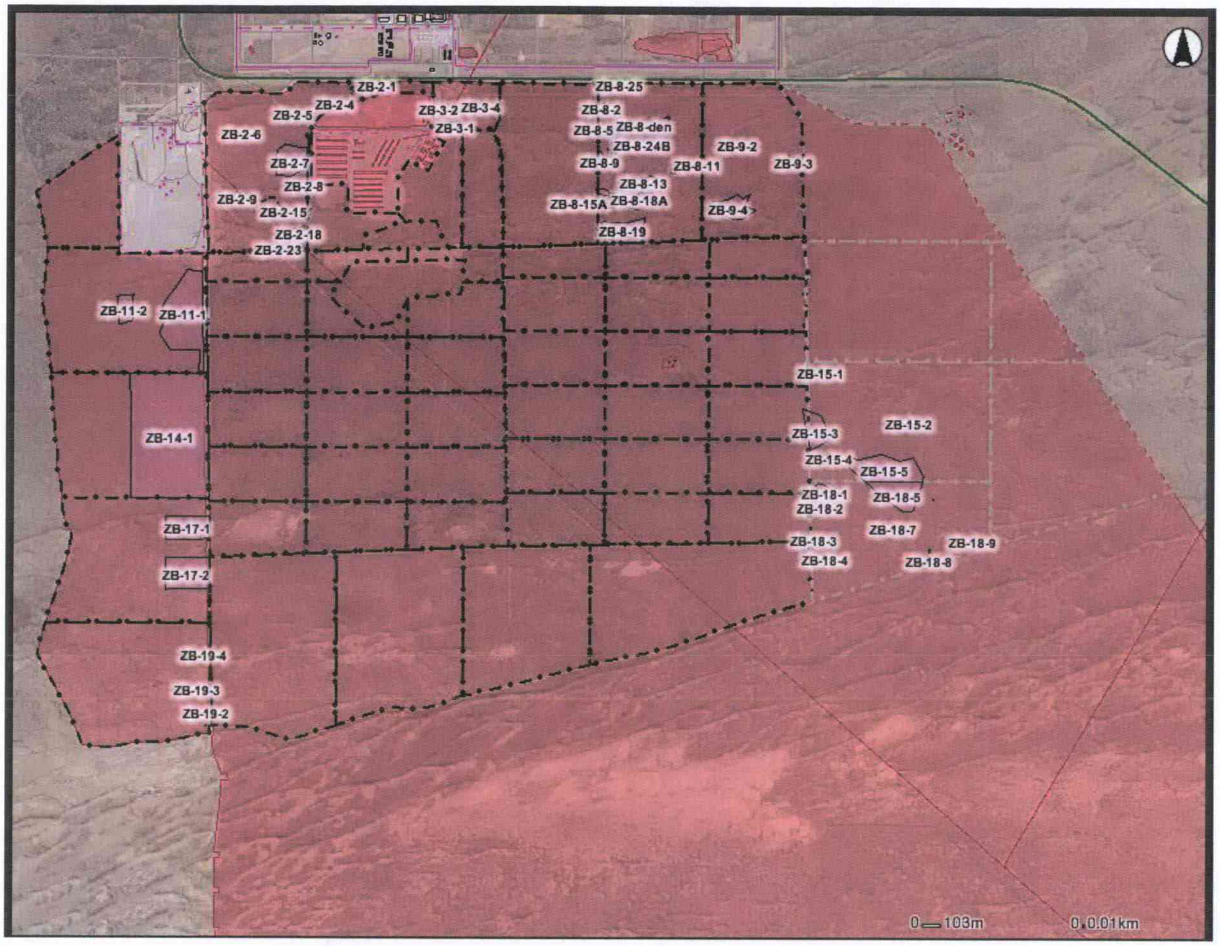

Figure 2-31. BC Controlled Area Zone B Hot Spots

3 Resources Committed to the Removal Action

This chapter summarizes the budgetary resources committed to the FY 2010 to FY 2011 contaminated soil excavation activities conducted in the BCCA. The scope of the FY 2010 to FY 2011 excavation activities was planned and budgeted for complete removal of 201,500 tons of contaminated soil. BCCA soil mass was estimated at a rate of 1,300 tons per ac at a 15 cm (6 in.) depth. From the 140 ac Zone A, 182,000 tons were planned for removal; 19,500 tons were planned for removal from 15 contaminated ac of Zone B. This work scope was completed on September 10, 2010. During the early stages of removal, field surveys, excavation depths, and mass shipped values were used to refine the plan for the Zone A removal action, where mass was re-calculated using a nominal 0.43 m (17 in.) excavation depth.

Tasks performed within the committed resources include the following:

- Mobilizing equipment and personnel
- Upgrading and maintaining gravel roadways up to 4,206 m (13,800 ft) long and 7 m (24 ft) wide
- Identifying the area within the BCCA, Zone A, for contaminated soil excavation
- Excavating contaminated soil in this area to levels below PRGs, nominally depth of 0.43 m (17 in.), and disposing of the contaminated soil at the ERDF
- Establishing equipment and protocols for conducting cleanup verification surveys aligned with Ecology's Memorandum (Price, 2008)
- Conducting cleanup verification surveys of the remediated area and compiling the data
- Applying soil fixatives to the excavated area

Scope exclusions from the committed resources include the following:

- Final remediation of the BCCA
- Completion of regulatory documents for the 200-UR-1 OU

Table 3-1 provides the calculated costs for the FY 2010 through FY 2011 BCCA excavation activities. These cost estimates were developed from actual contractor invoices, ERDF billing, and estimated labor hours. Table 3-1 includes the remove, treat, and dispose costs for the selected alternative in the Action Memorandum (DOE/RL-2008-21) for the removal of contaminated soil from Zone A and from select areas of elevated contamination in Zone B (approximately 293,000 tons of contaminated soil).

Table 3-1. BC Controlled Area Removal Project Calculated Total Cost Summary

Scope:	Costs ($)
Calculated Costs for FY 2009 to FY 2010 Removal Activities	$16,036,896.25
Calculated Costs for FY 2010 to FY 2011 Removal Activities	$18,158,577.92
Calculated Costs for FY 2009 to September 2011 Materials and Other Subcontracts	$284,298.21
Total Calculated Removal Activities Costs FY 2009 to September 2011	$34,479,772.38

Tables 3-2, 3-3, and 3-4 illustrate calculated costs according to fiscal year, including material purchases and miscellaneous subcontracts.

Table 3-2. BC Controlled Area Removal Project Calculated Cost Summary FY 2009 to FY 2010

FE&C	Invoiced		$7,469,169.31			
ERDF	Total Tons	266,839				
	Total Cost	$7,625,700				
	Actual Rate	$28.58				
	BCCA Tons	224,798	$6,424,256.23			
Labor				Labor		
RCTs	Total Hours	28,143.4		RCTs		
	Total Cost	$1,408,300			FTE	16
	Actual Rate	$50.04			Total Hours	33,280
	BCCA Hours	33,280	$1,665,336.24			
Environmental Engineer						
	Total Hours	2,566		Environmental Engineer		
	Total Cost	$162,000			FTE	1
	Actual Rate	$63.13			Total Hours	2,080
	BCCA Hours	2,080	$131,317.23			
Plant Engineer				Field Engineer		
	Total Hours	1,313.5			FTE	0.25
	Total Cost	$71,300			Total Hours	520
	Actual Rate	$54.28		Plant Engineer (shipper)		
	BCCA Hours	2,600	$141,134.37		FTE	1
					Total Hours	2,080
Health Physicist						
	Total Hours	2,005				
	Total Cost	$128,300		Health Physicist		
	Actual Rate	$63.99			FTE	0.5
	BCCA Hours	1,040	$66,549.63		Total Hours	1,040
1st Line Supervisor						
	Total Hours	3,715		1st Line Supervisor		
	Total Cost	$248,500			FTE	1
	Actual Rate	$66.89			Total Hours	2080
	BCCA Hours	2,080	$139,133.24			
		Labor Subtotal	$2,143,470.71			
Total FY 2009 through 2010			**$16,036,896.25**			

FE&C = Federal Engineers and Constructors
BCCA = BC Controlled Area
ERDF = Environmental Restoration Disposal Facility
FTE = full time employee
RCT = radiological control technician

Table 3-3. BC Controlled Area Removal Project Calculated Cost Summary FY 2011

FE&C		Invoiced	$6,898,122.25			
	Actual Rate	$38.00				
	BCCA Tons	258,488	$9,822,544.00			
Labor				Labor		
RCTs	Total Hours	1,140.9		RCTs		
	Total Cost	$54,300			FTE	16
	Actual Rate	$50.04			Total Hours	24,320
	BCCA Hours	24,320	$1,216,972.80			
Environmental Engineer						
	Total Hours	301		Environmental Engineer		
	Total Cost	$20,600			FTE	1
	Actual Rate	$68.55			Total Hours	1,520
	BCCA Hours	1,520	$104,199.67			
Plant Engineer				Field Engineer		
	Total Hours	163			FTE	0.25
	Total Cost	$9,600			Total Hours	380
	Actual Rate	$58.90		Plant Engineer		
	BCCA Hours	1,900	$111,901.84		FTE	1
					Total Hours	1,520
Health Physicist						
	Total Hours	133				
	Total Cost	$9,000		Health Physicist		
	Actual Rate	$67.67			FTE	0.5
	BCCA Hours	760	$51,428.57		Total Hours	760
1st Line Supervisor						
	Total Hours	167.5		1st Line Supervisor		
	Total Cost	$12,800			FTE	1
	Actual Rate	$76.42			Total Hours	1,520
	BCCA Hours	1,520	$116,155.22			
		Labor Subtotal	$1,600,658.10			
Total FY 2011 through September 30, 2010			**$18,158,577.92**			

FE&C = Federal Engineers and Constructors
BCCA = BC Controlled Area
ERDF = Environmental Restoration Disposal Facility
FTE = full time employee
RCT = radiological control technician

Table 3-4. BC Controlled Area Removal Project Calculated Materials and Other Subcontracts, Cost Summary FY 2011

		FY 2009 to FY 2011
Materials	Description	Cost
	Utility vehicle (Kubota) for GPS-Assisted Gamma Spectrometry Equipment	$18,520.00
	GPS-Assisted Gamma Spectrometry Equipment	$76,760.00
	Design/Build and Mount Radiological Survey Equipment on Mobile Platforms	$30,159.93
	TOTAL	**$125,439.93**
Other Subcontracts	Description	Cost
	BCCA Ecological Reviews	$39,502.29
	BCCA Cultural Review	$99,519.74
	Electrical Utilities Support for BCCA-N	$16,997.15
	Provide Aviation Point of Contact for aerial survey	$2,839.10
	TOTAL	**$158,858.28**
	Total through September 30, 2010	**$284,298.21**

GPS = Global Positioning System
BCCA = BC Controlled Area

4 Difficulties Encountered

Difficulties encountered that impacted the BCCA removal action included the following:

- The lack of roll-on/roll-off containers delayed project startup.
- Procurement of an efficient number of direct haul super dump trucks delayed production rates through the first 4 months of the project.
- Excavation was temporarily suspended to prevent the spread of contaminated soil during periods of high wind on numerous occasions.
- Excavation was temporarily suspended on several occasions due to snow and ice conditions too hazardous for safe working conditions.
- Excavation was temporarily impacted during the migratory bird-nesting season.

5 Conclusion

Overall, the PRGs for the BCCA removal action have been met in Zone A, which has been surveyed by the mobile system, and surveyed and down-posted by RCTs. A total of 493,000 tons of contaminated soil was removed from the BCCA during the period from August 2009 through July 2011. This is 147 percent of the contaminated soil estimated in the removal action. The remainder of the contaminated soil has not been removed from Zone B and thus contamination remains within the BCCA in excess of the PRGs.

Contaminated spots in Zone B have been investigated and accurately posted in the majority of the area outside the firebreak roads. This resulted in the down-posting of more than 1,500 ac from Contamination Area or Soil Contamination Area postings to no radiological postings.

A number of suspect areas of contamination in Zone C, identified by the 2009 aerial survey, were investigated using field radiological instruments, which confirmed that these areas contained soil contamination at levels requiring radiological posting. No removal actions were performed in Zone C.

Radiological surveys with the mobile survey systems demonstrate that for the FY 2009 to FY 2011 excavation, the removal eliminated the direct contact exposure pathway for cesium-137, thereby preventing future releases of radiological contamination from this COC.

This on scene coordinator report documents the status of the removal action in the administrative record until the removal action is completed or a remedial decision for the BCCA is made.

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Appendix A

Reprint of SGW-45563, *An Aerial Radiological Survey of the Hanford BC Controlled Area and West Lake Area*, Rev. 0, published February 2010

SGW-45563
Revision 0

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

Survey Data - September 22 to 30, 2009

Document Type: TR Program/Project: S&GRP

C. Lyons
National Security Technologies, LLC

Date Published
February 2010

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

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AE Bratton 4/14/2010
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Approved for Public Release;
Further Dissemination Unlimited

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SGW-45563
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SGW-45563
Revision 0

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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Appendix

Figures

Table

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(T*l*)	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.

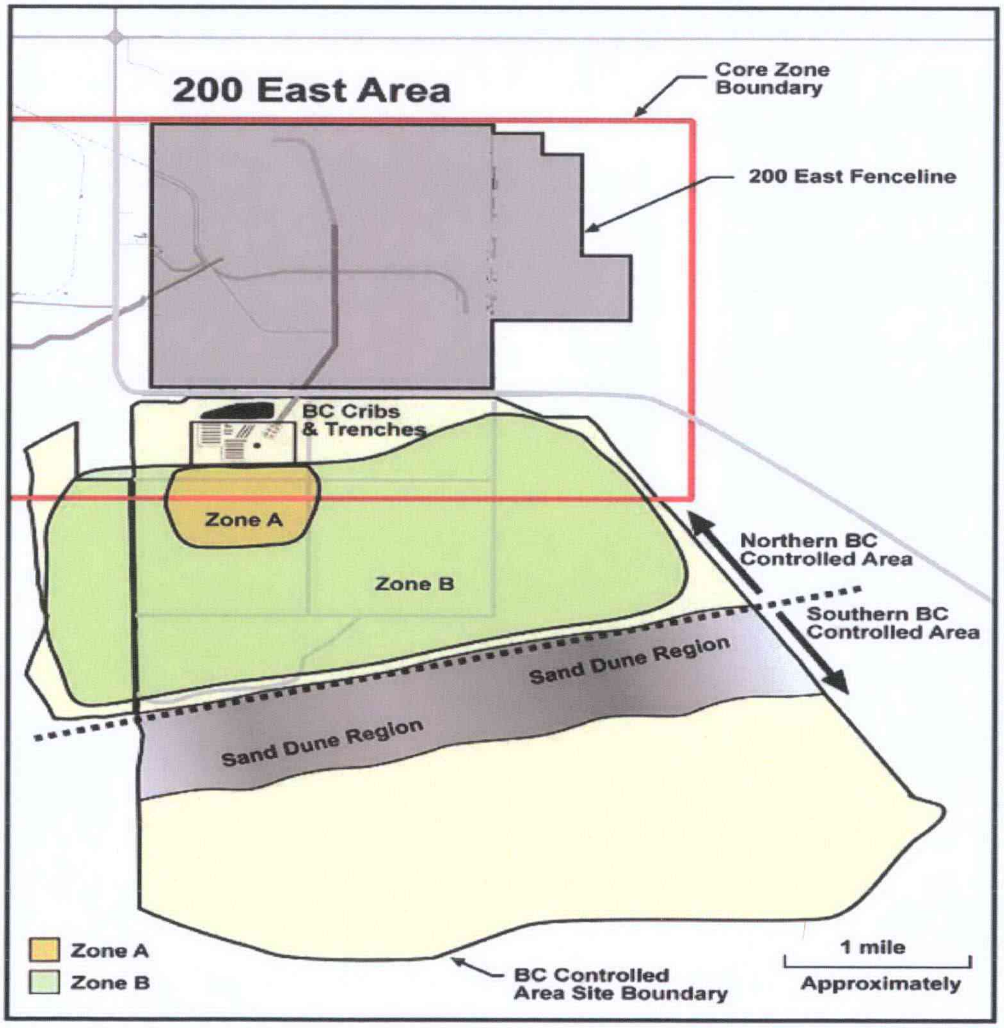


Figure 1. Map of BCCA and 200 East Area

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.

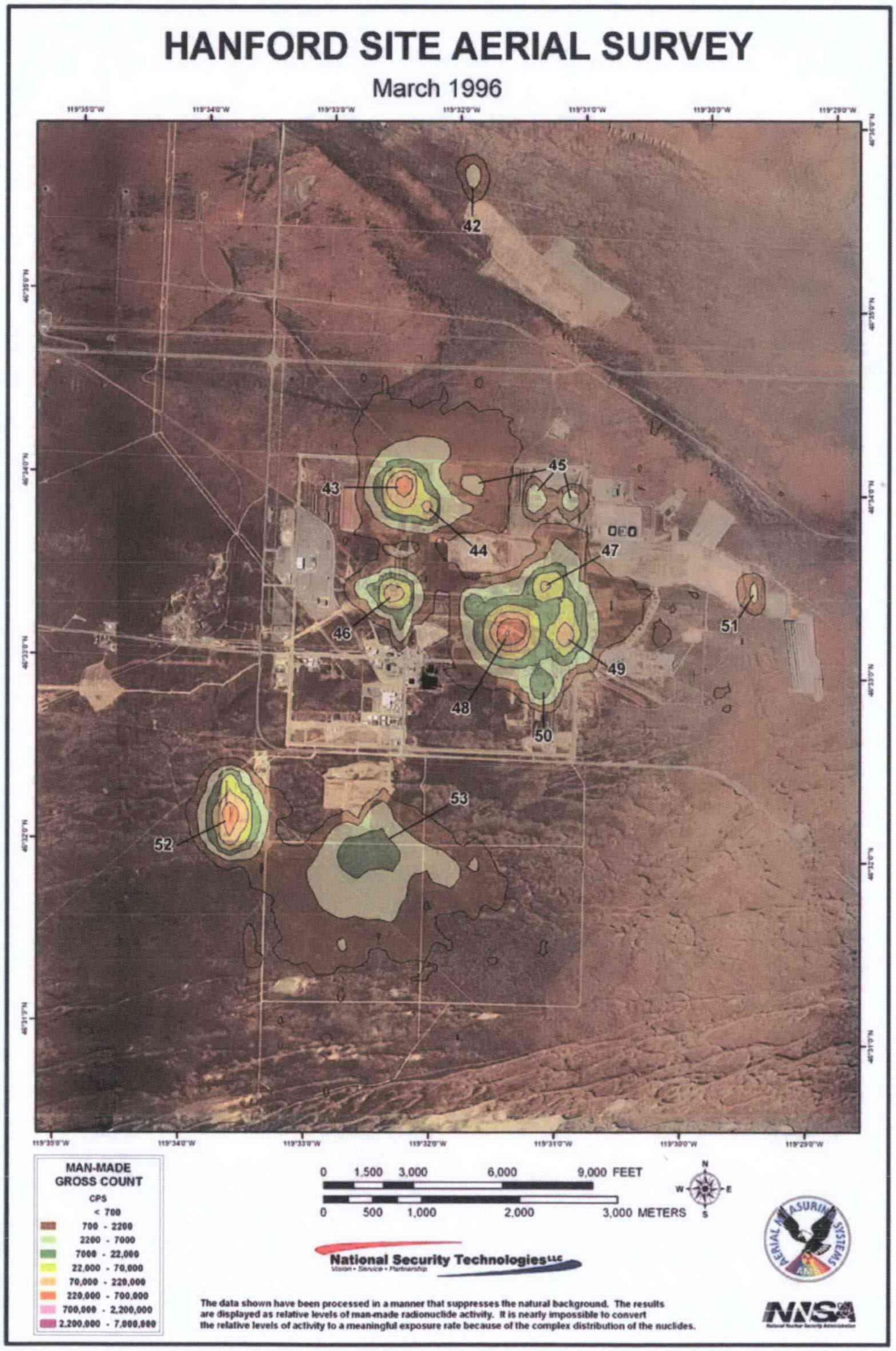


Figure 2. Man-made Gross Count Results from 1996 Survey

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.

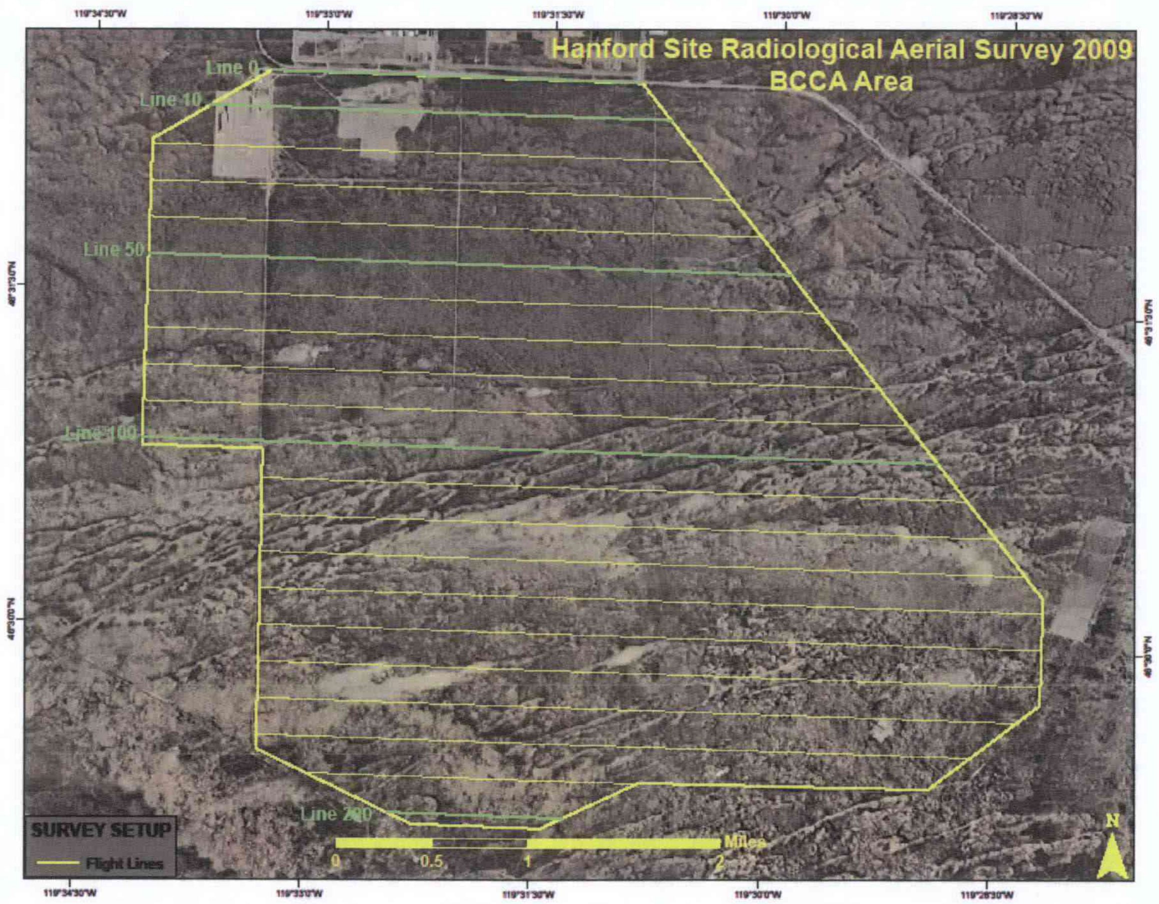


Figure 3. BCCA Planned Survey Lines

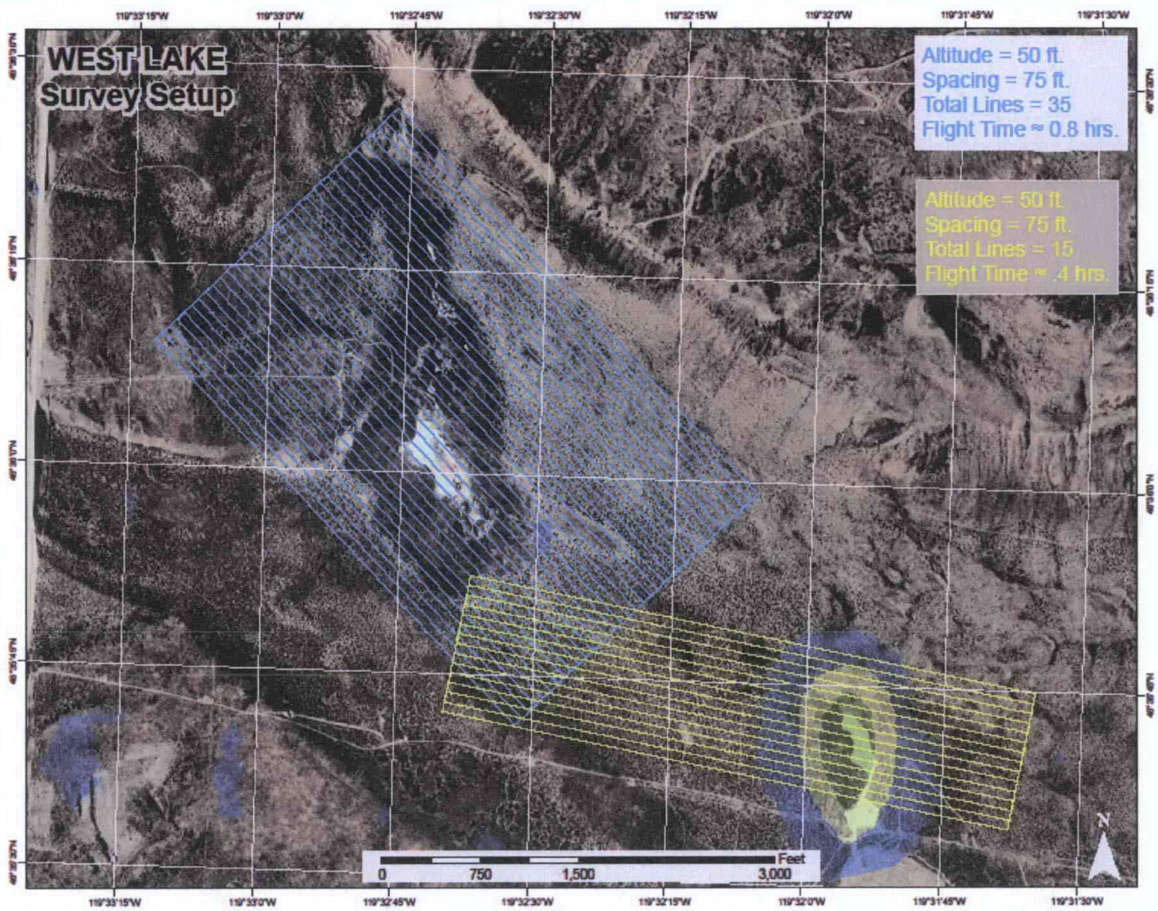


Figure 4. West Lake/Gable Mountain Pond Planned Survey Lines with 1996 Data

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.

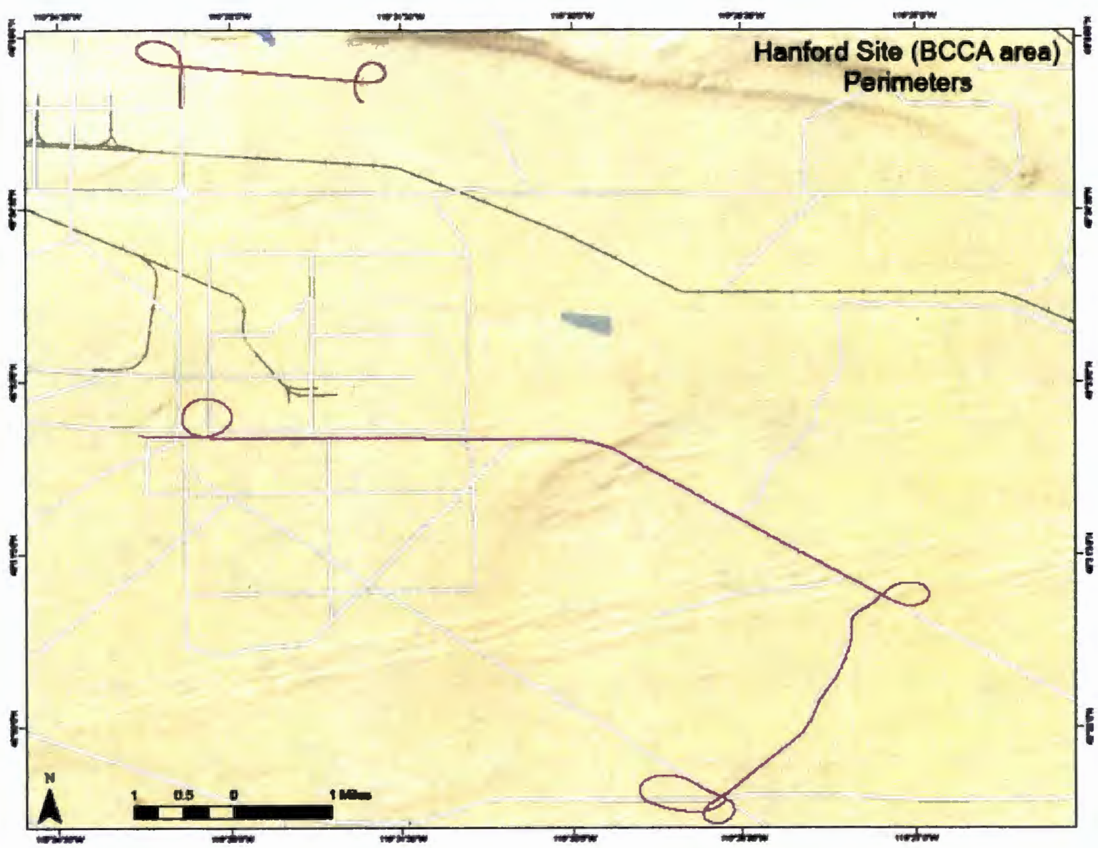


Figure 5. Example of Perimeter Line Results on a Map Layer

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:

$$ER\left(\frac{\mu R}{h}\right) = \frac{GC - B}{2088} \cdot e^{(A-300)\cdot C} \qquad (1)$$

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):

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

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

$$K_{mm} = \frac{\sum_{E=38}^{1394} S(E)}{\sum_{E=1394}^{3026} S(E)} \qquad (3)$$

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.

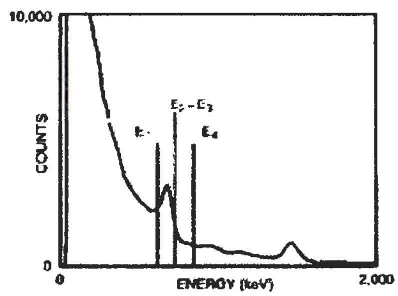
For a detailed description of the analysis techniques used to convert from spectra gross counts to an initial isotope-specific volumetric activity (pCi/g) estimate, Appendix B is provided.

4.1.5 Americium-Specific Isotope Extraction Algorithm

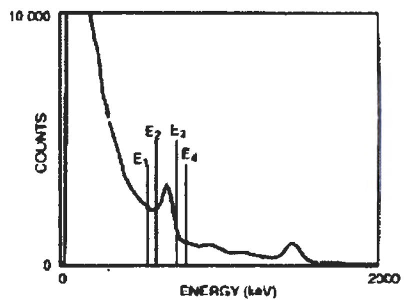
Although the project had identified Cs-137 as the only significant gamma emitter within the BCCA and West Lake survey areas, data analysis for americium was requested. The HR was the primary location for plutonium production since the 1940's. Since plutonium is a very weak gamma-ray emitter, the only 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:



2-Window



3-Window

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.

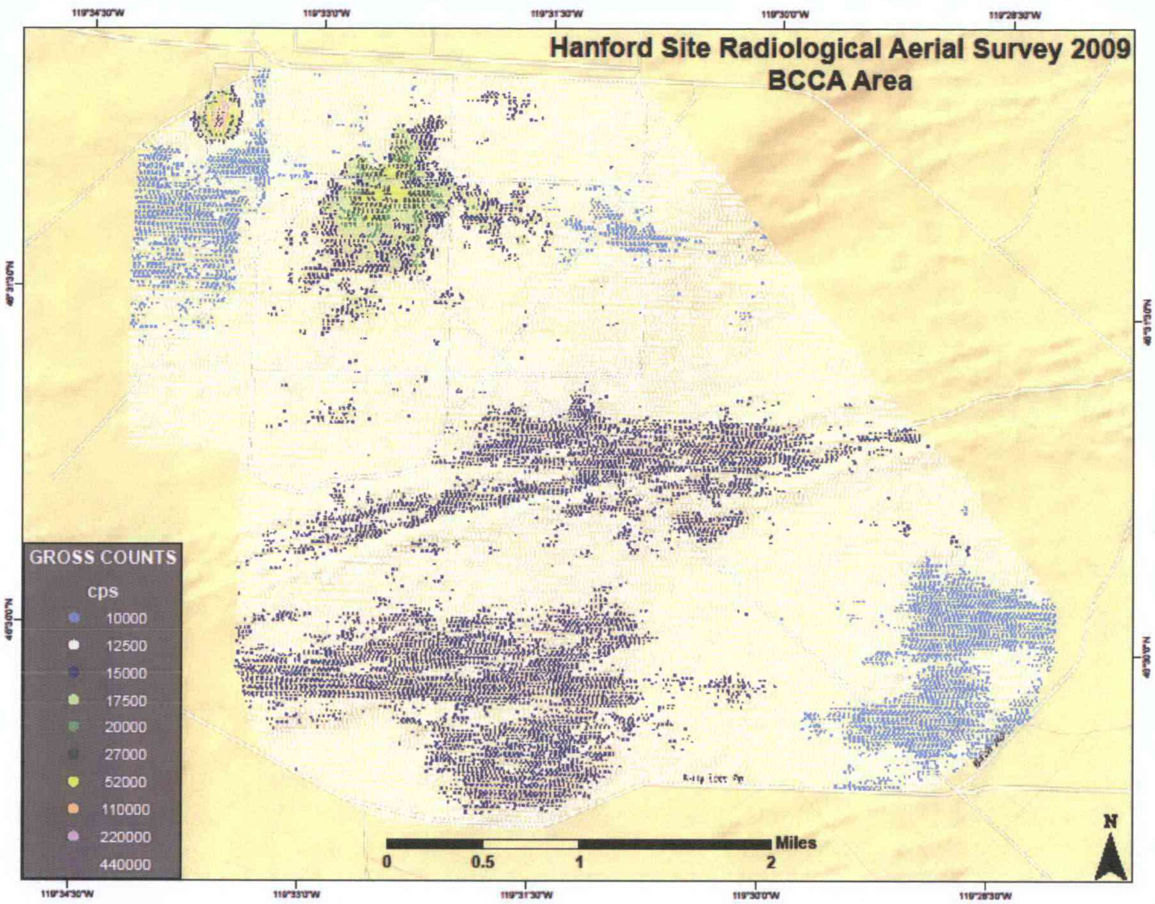


Figure 6. BCCA Total Energy Spectra Gross Count Point Data Results

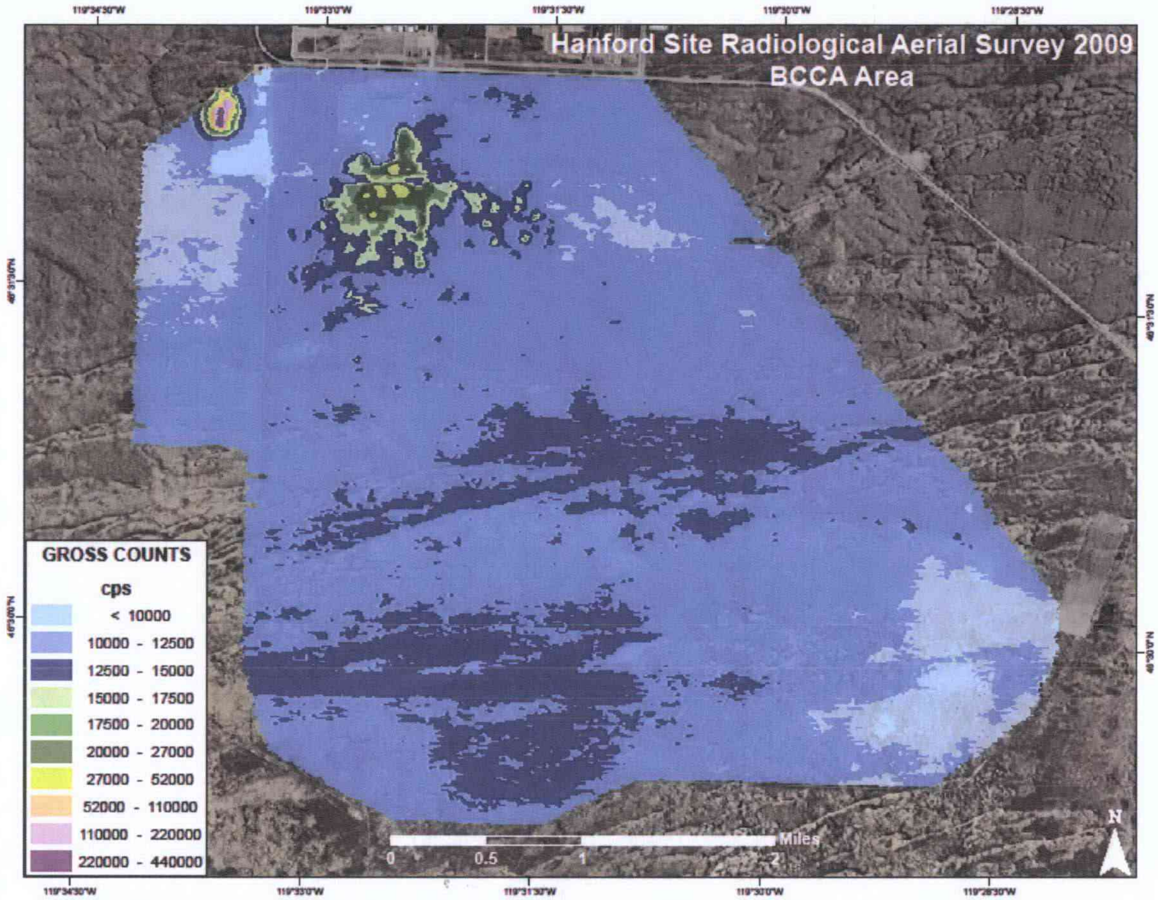


Figure 7. BCCA Total Energy Spectra Gross Count Contoured Data

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.

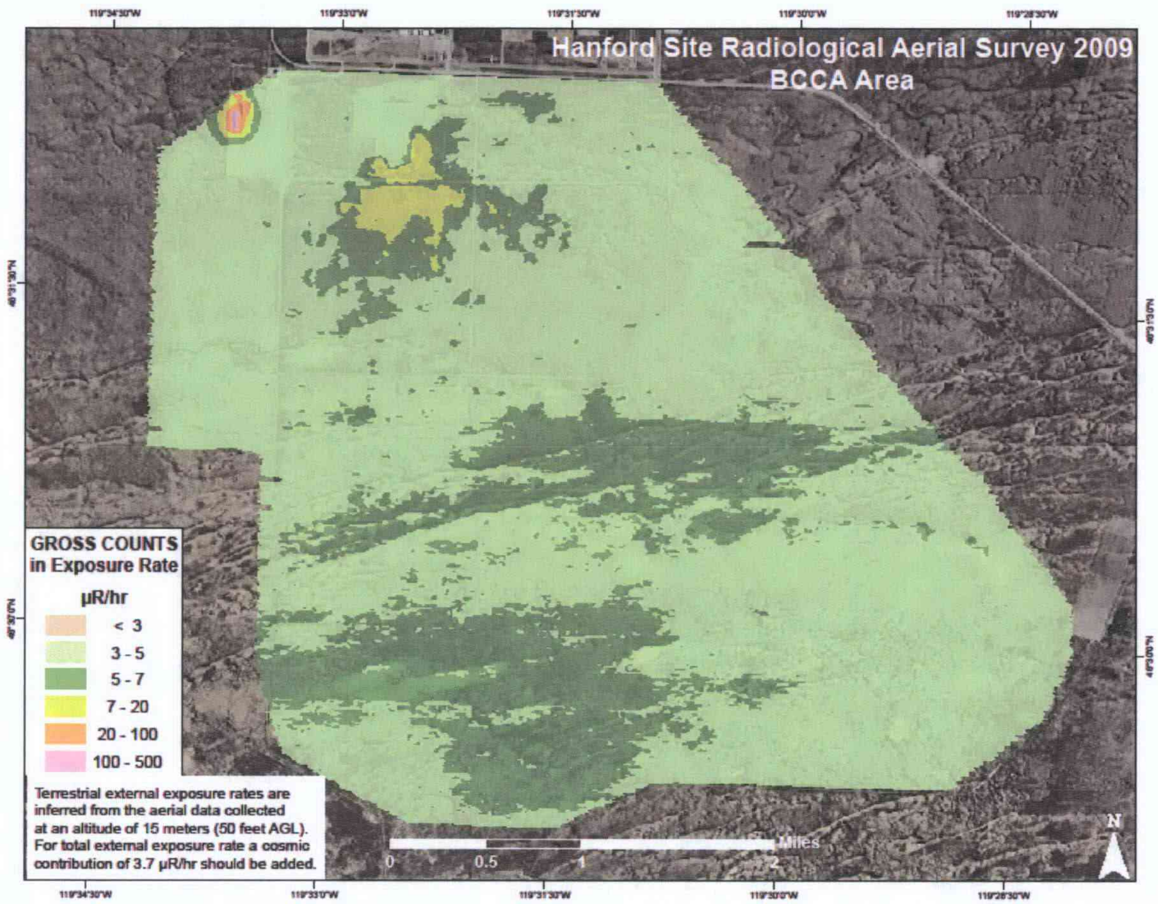


Figure 8. BCCA Inferred Gamma Exposure Rates

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.

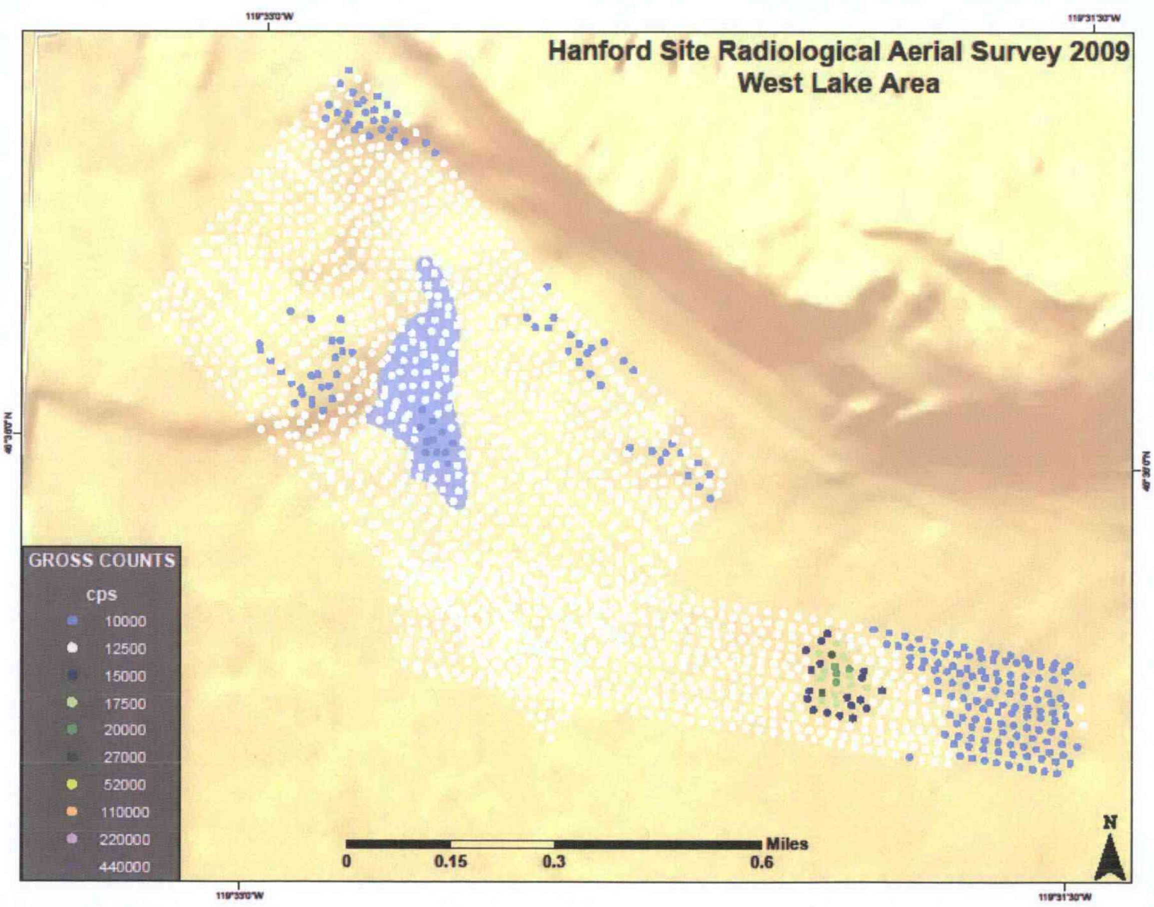


Figure 9. West Lake and Gable Mountain Pond Total Energy Spectra Gross Count Point Data

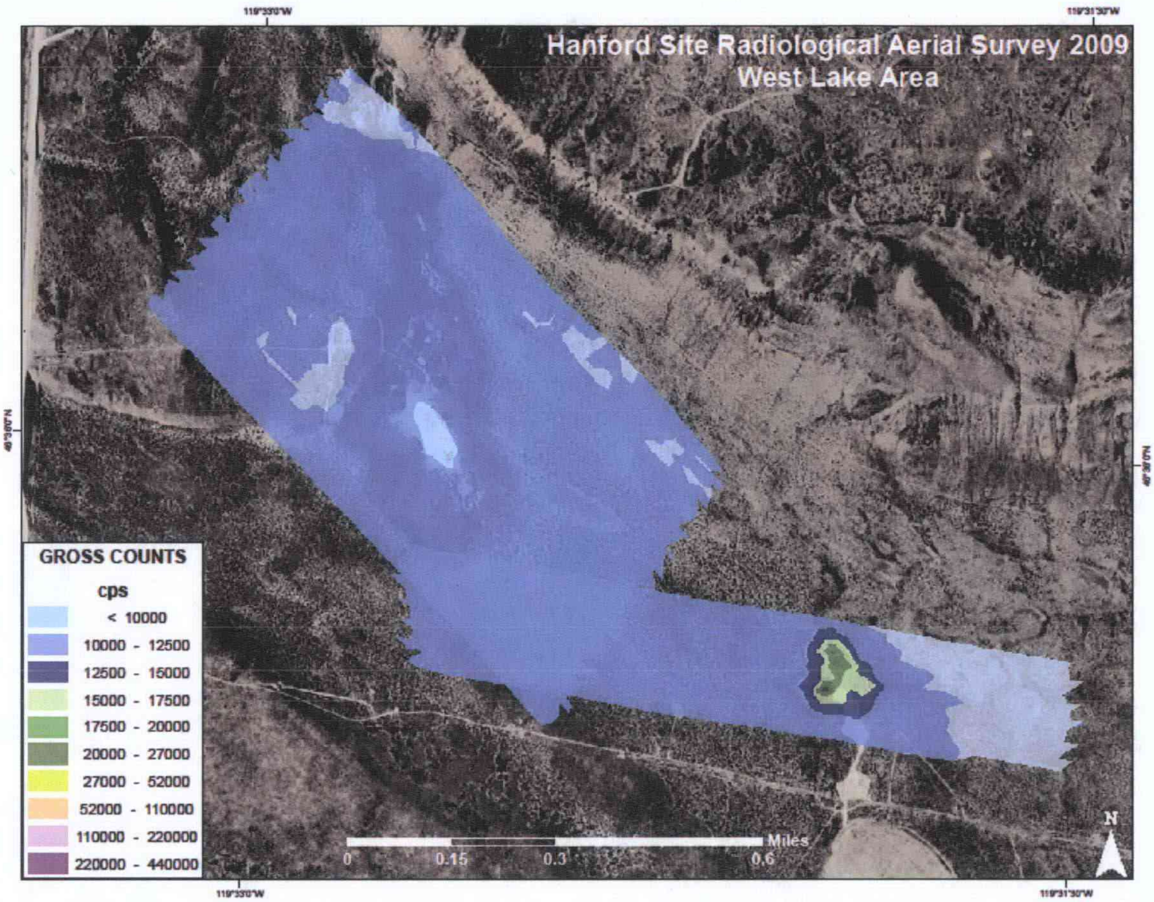


Figure 10. West Lake and Gable Mountain Pond Total Energy Spectra Gross Count Contour Data

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]

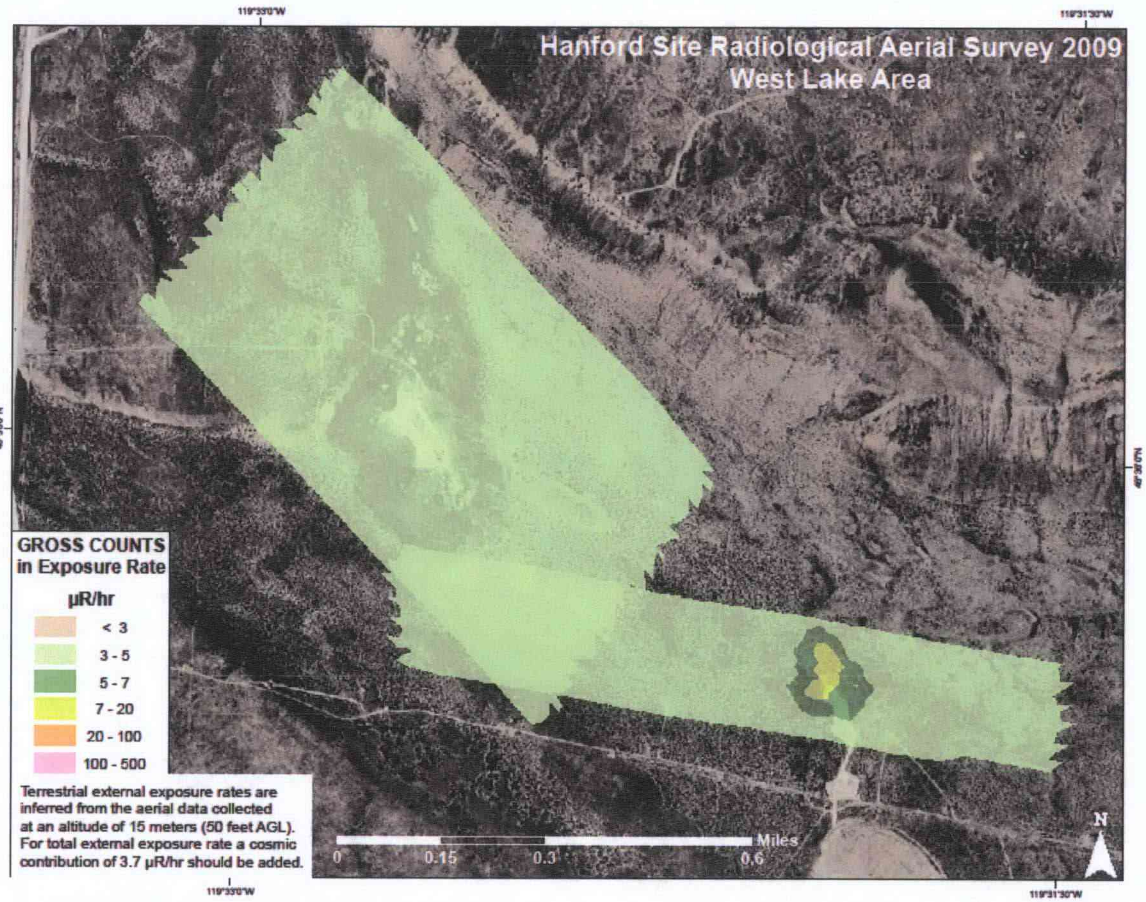


Figure 11. West Lake and Gable Mountain Pond Inferred Gamma Exposure Rates

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.

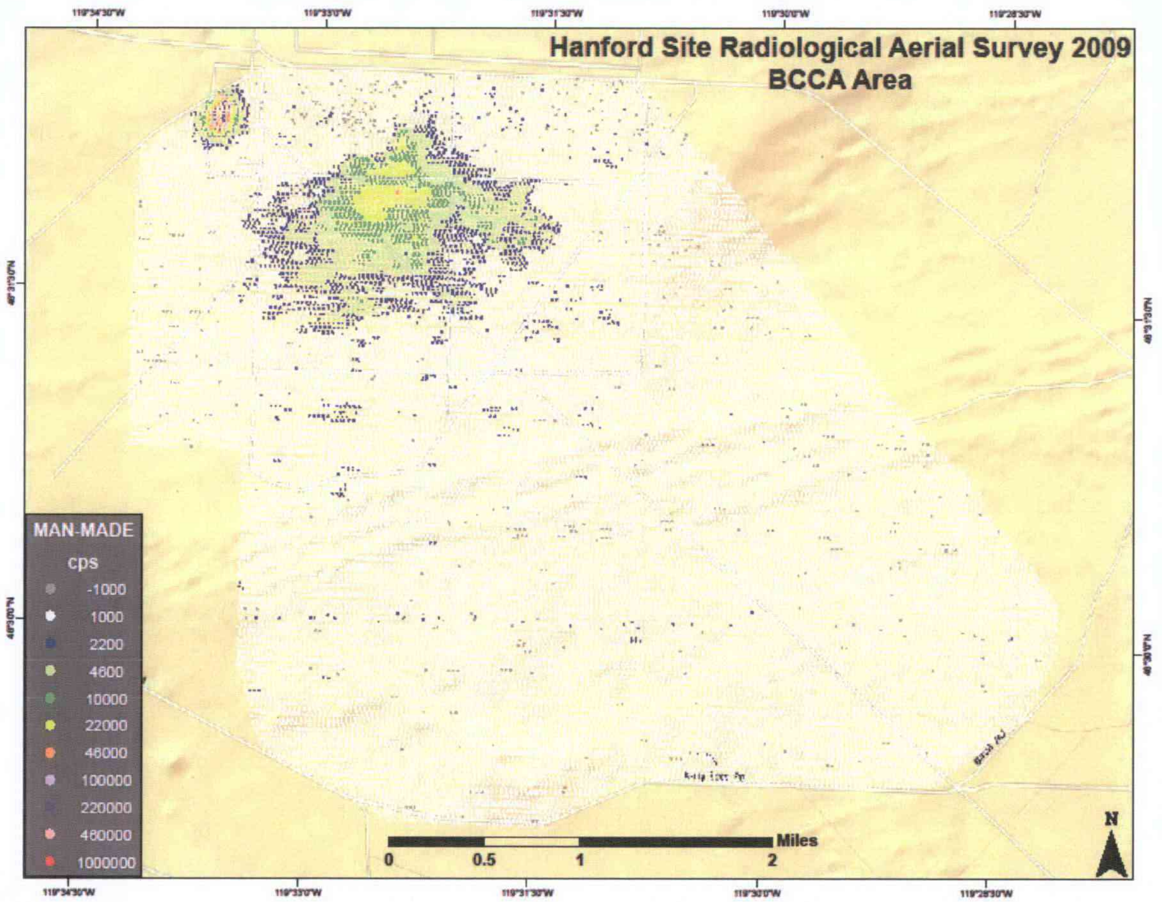


Figure 12. BCCA Man-Made Gross Count Point Data

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

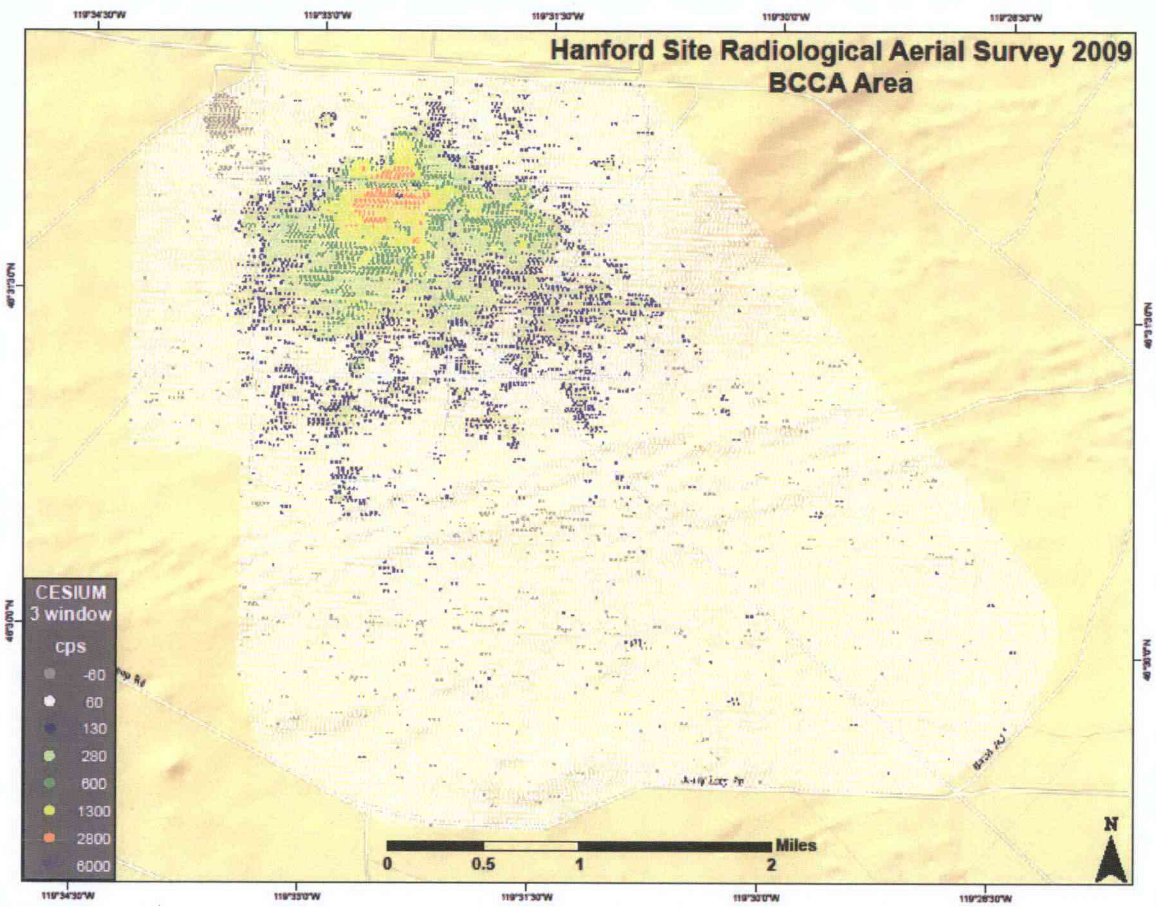


Figure 13. BCCA Cesium-137 Net Counts Point Data Results

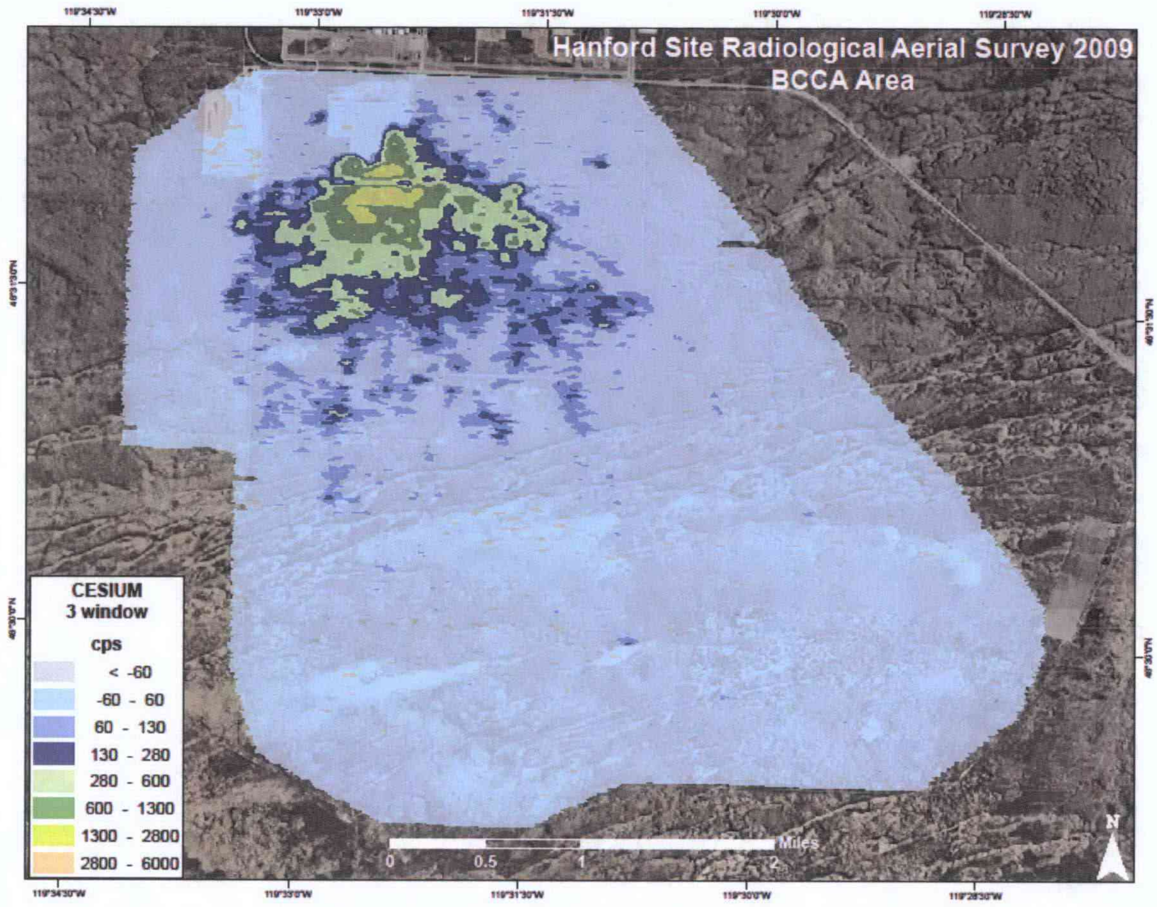


Figure 14. BCCA Cesium-137 Net Counts Contoured Data Results

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

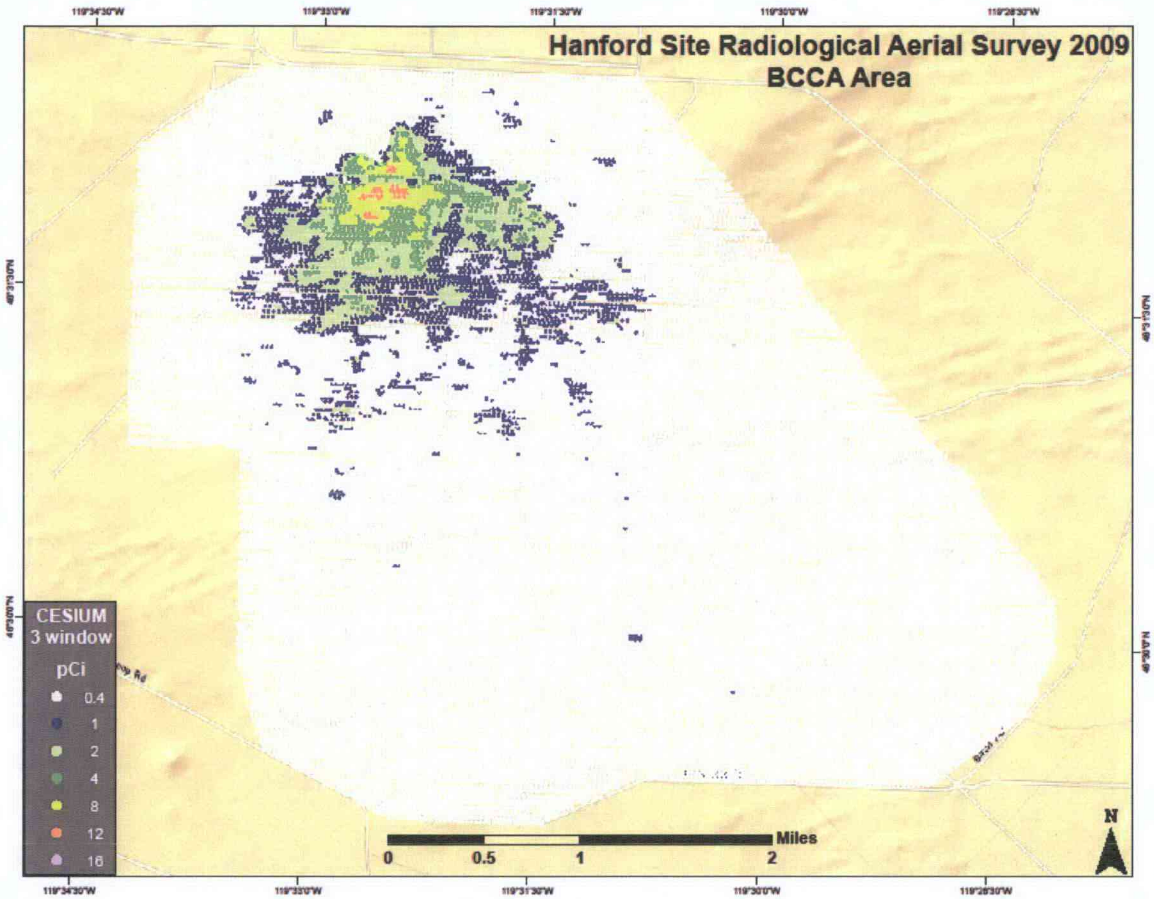


Figure 15. BCCA Cesium-137 Volumetric Activity (pCi/g) Point Data Results

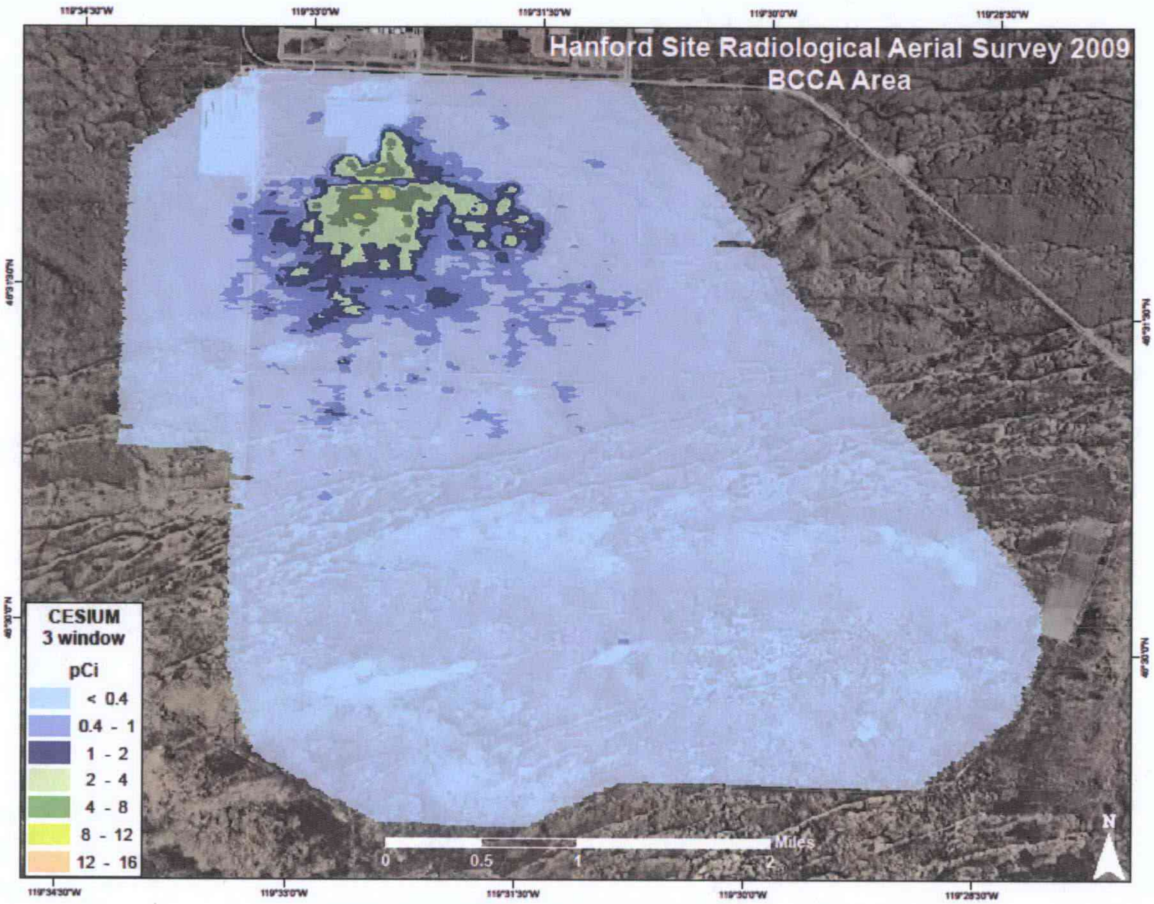


Figure 16. BCCA Cesium-137 Volumetric Activity (pCi/g) Contoured Data Results

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.

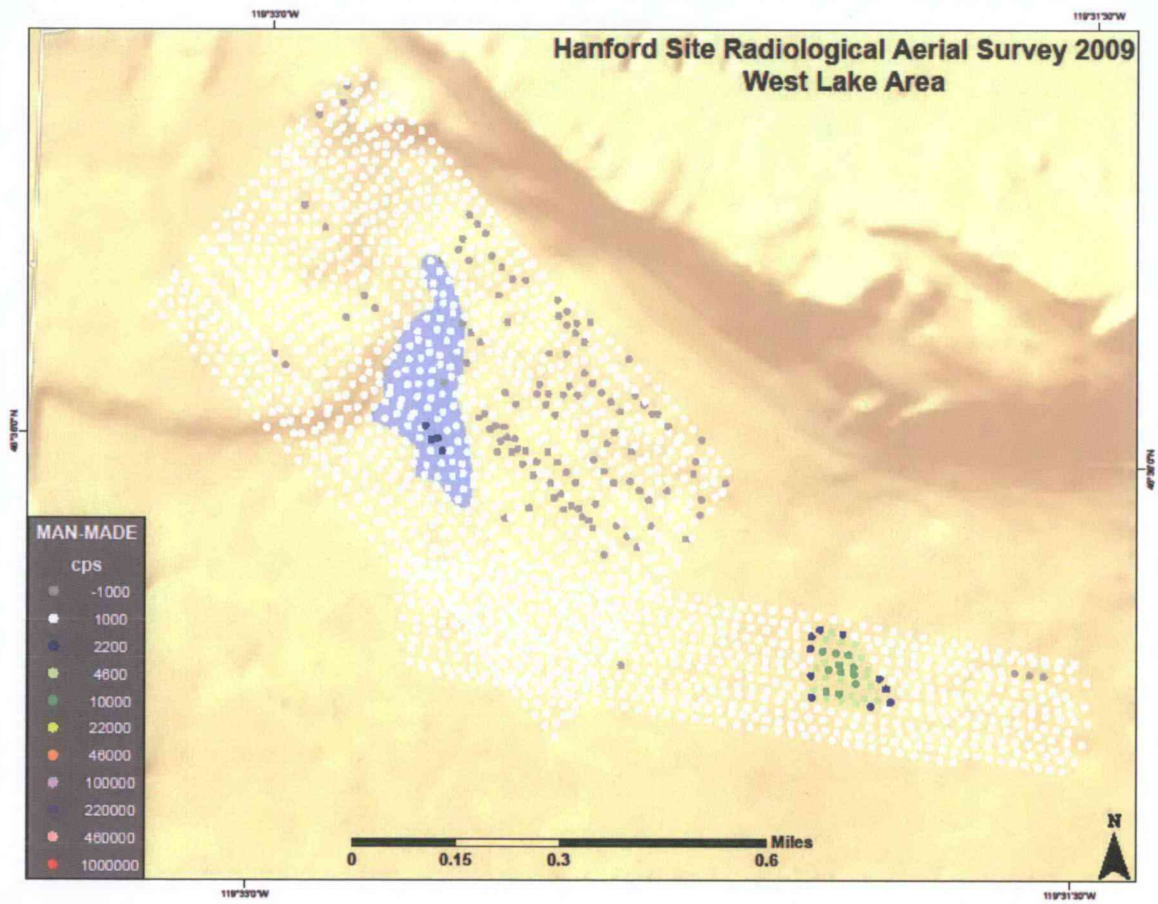


Figure 17. West Lake Man-Made Gross Count Map

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

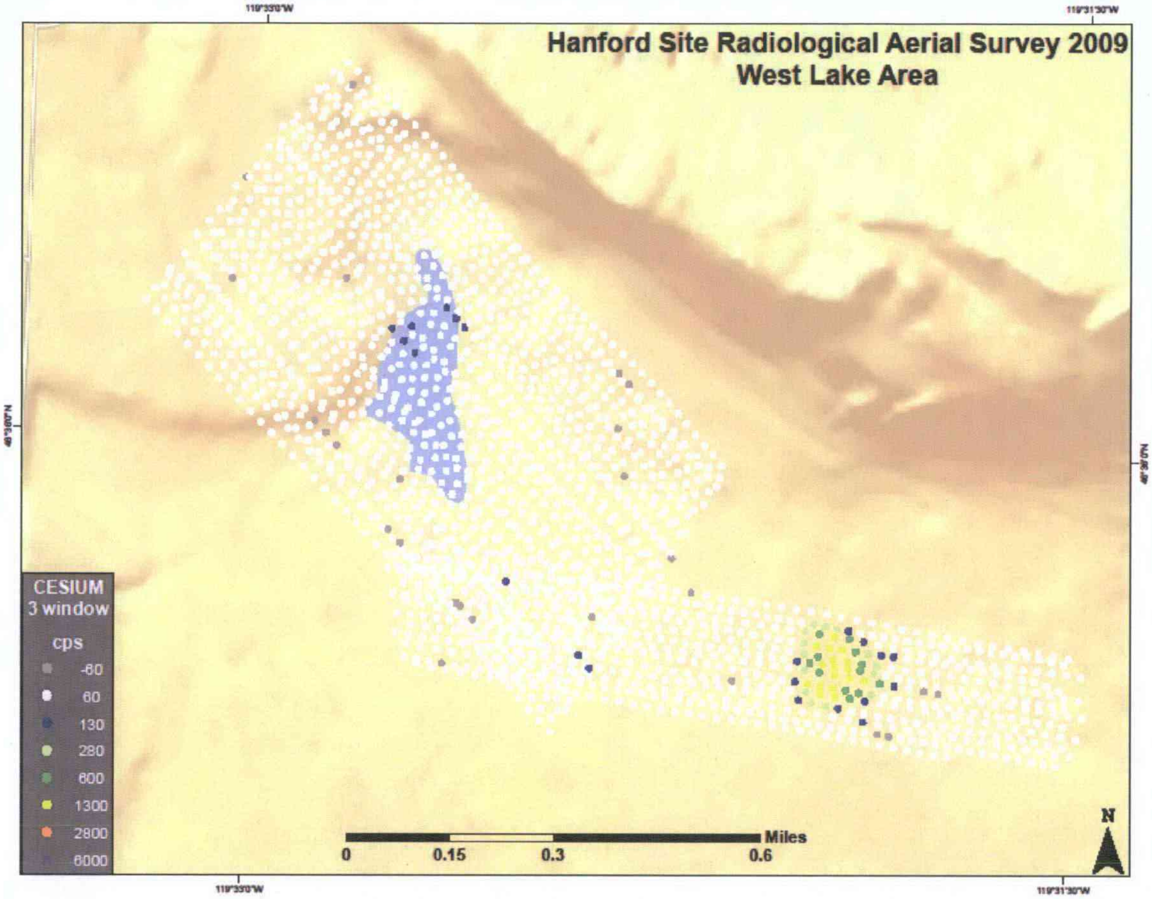


Figure 18. West Lake Cesium-137 Net Counts Point Data Results

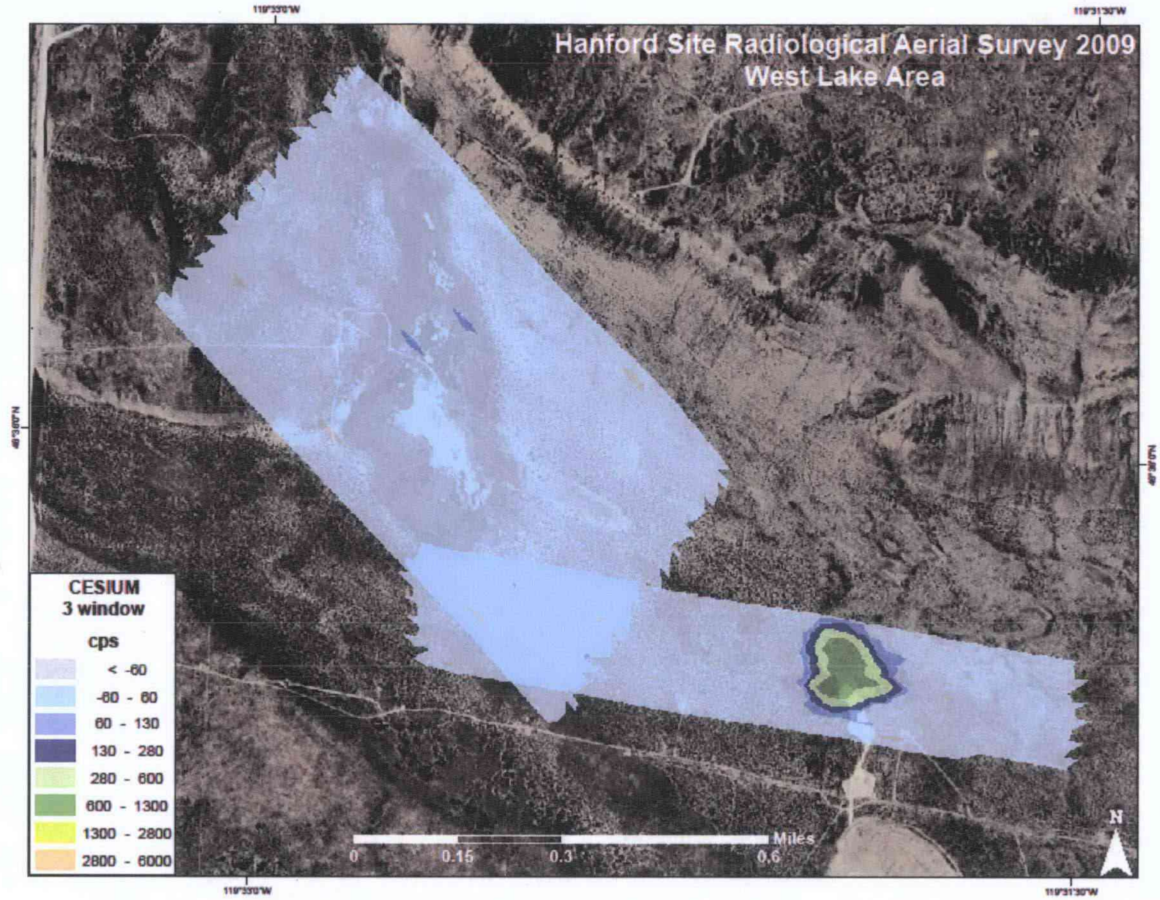


Figure 19. West Lake Cesium-137 Net Counts Contoured Data Results

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

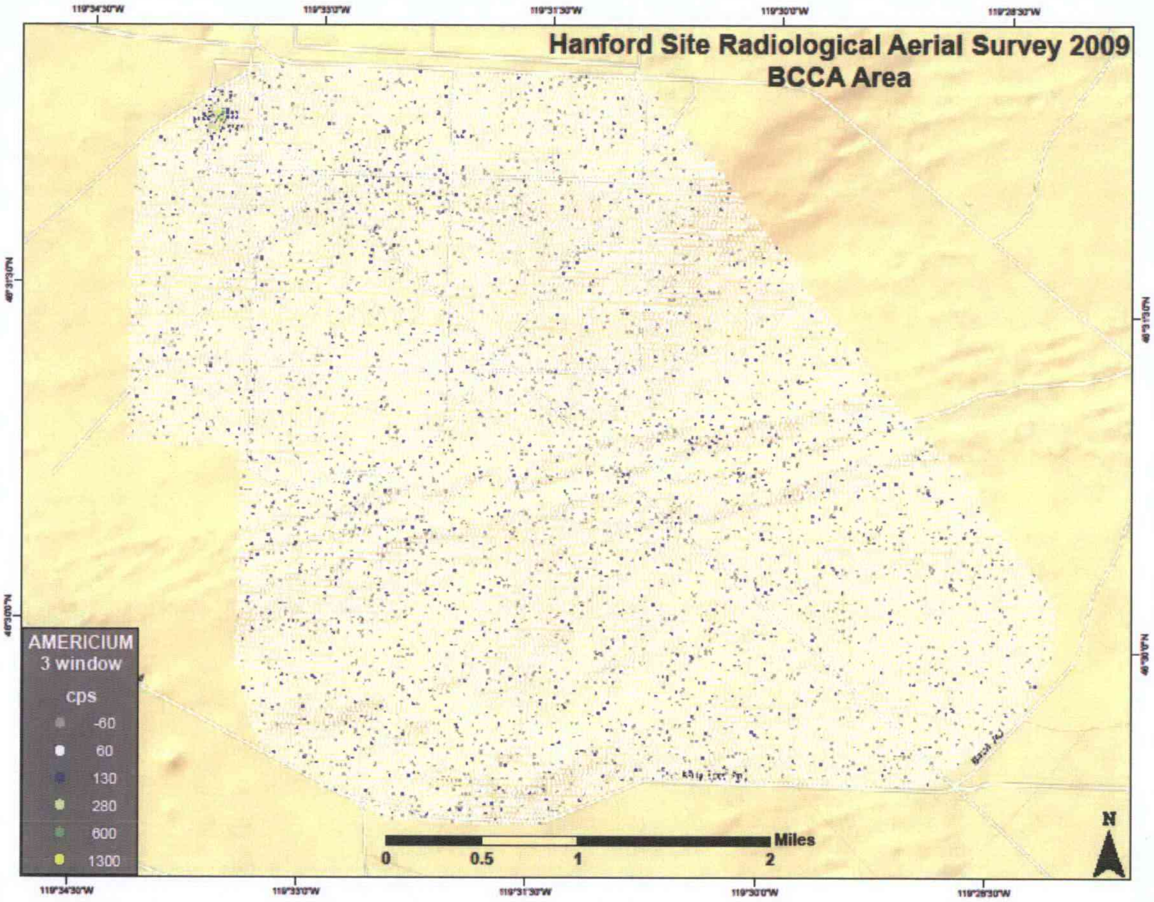


Figure 20. BCCA Am-241 Isotope Extraction Point Data Results

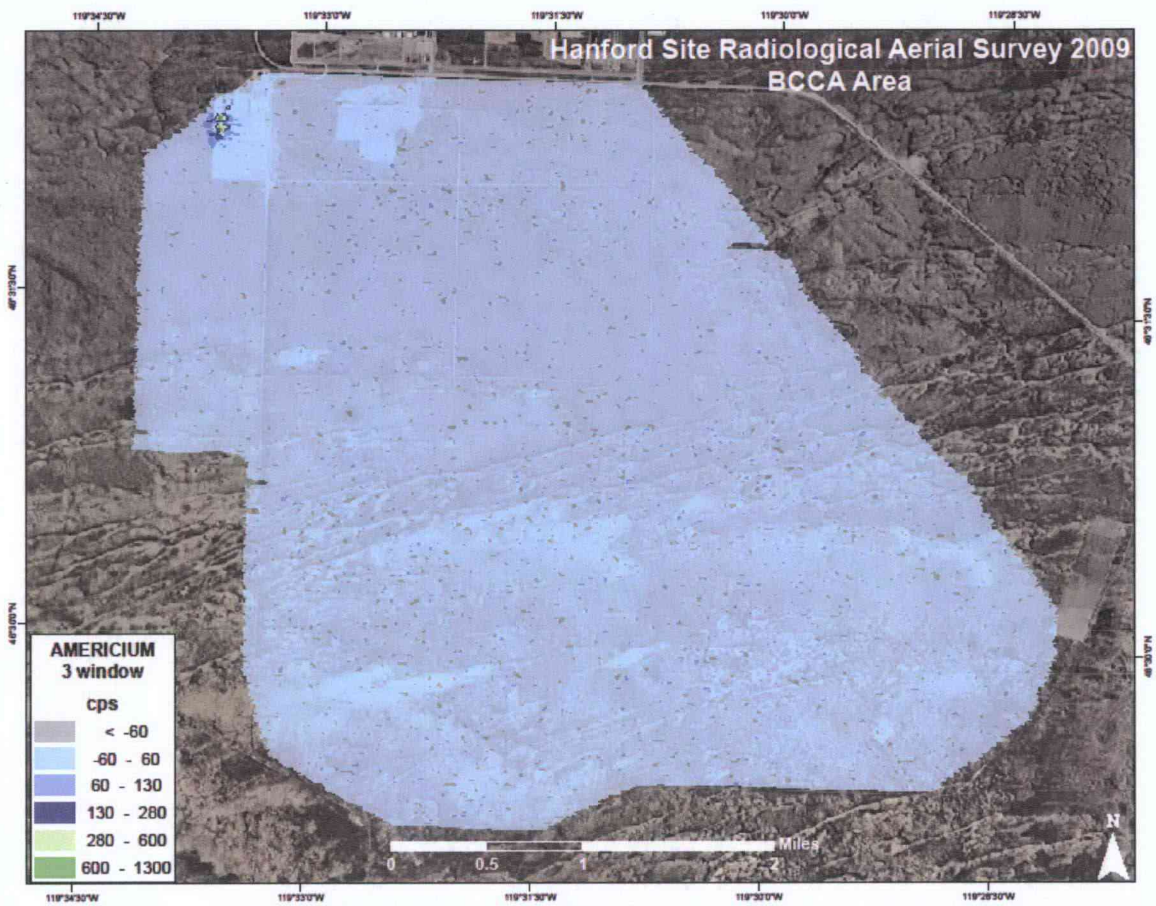


Figure 21. BCCA Am-241 Isotope Extraction Contoured Data Results

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

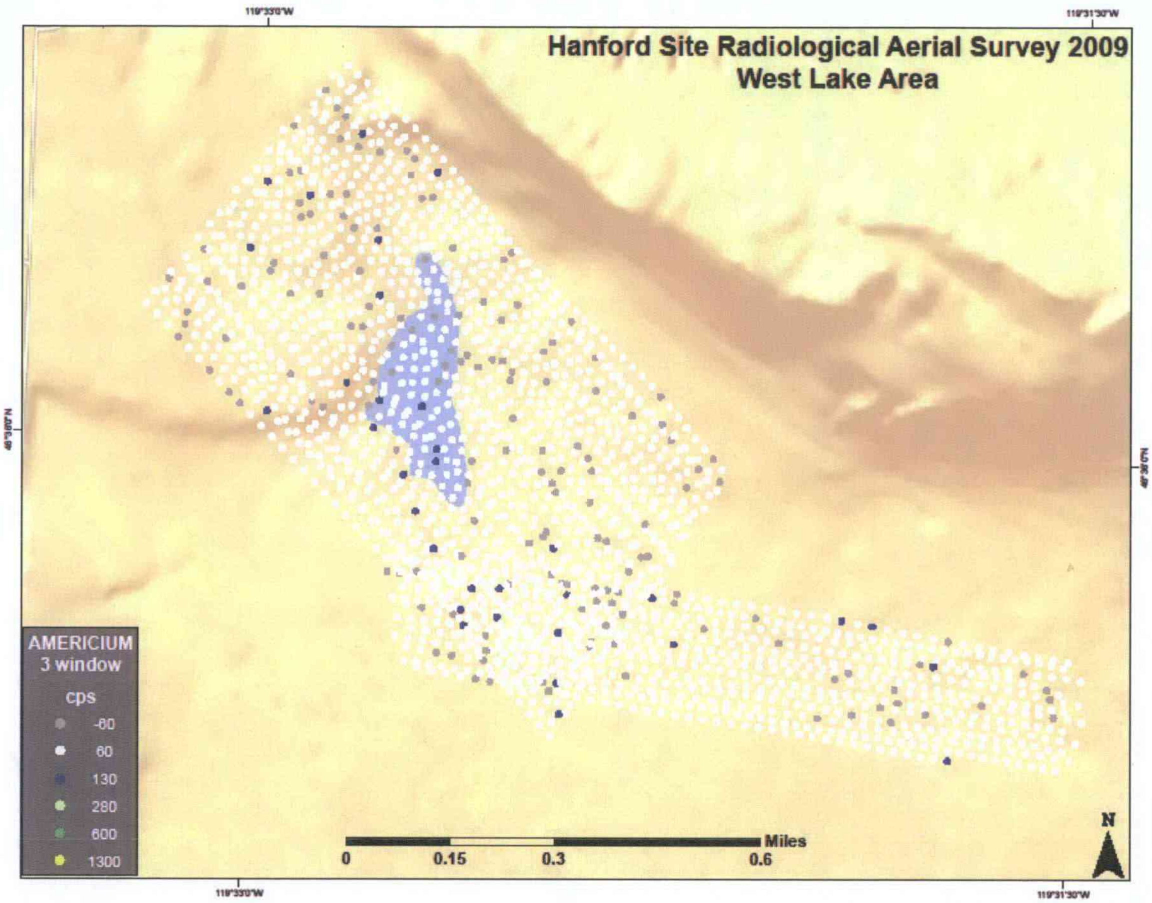


Figure 22. West Lake and Gable Mountain Pond Am-241 Isotope Extraction Point Data Results

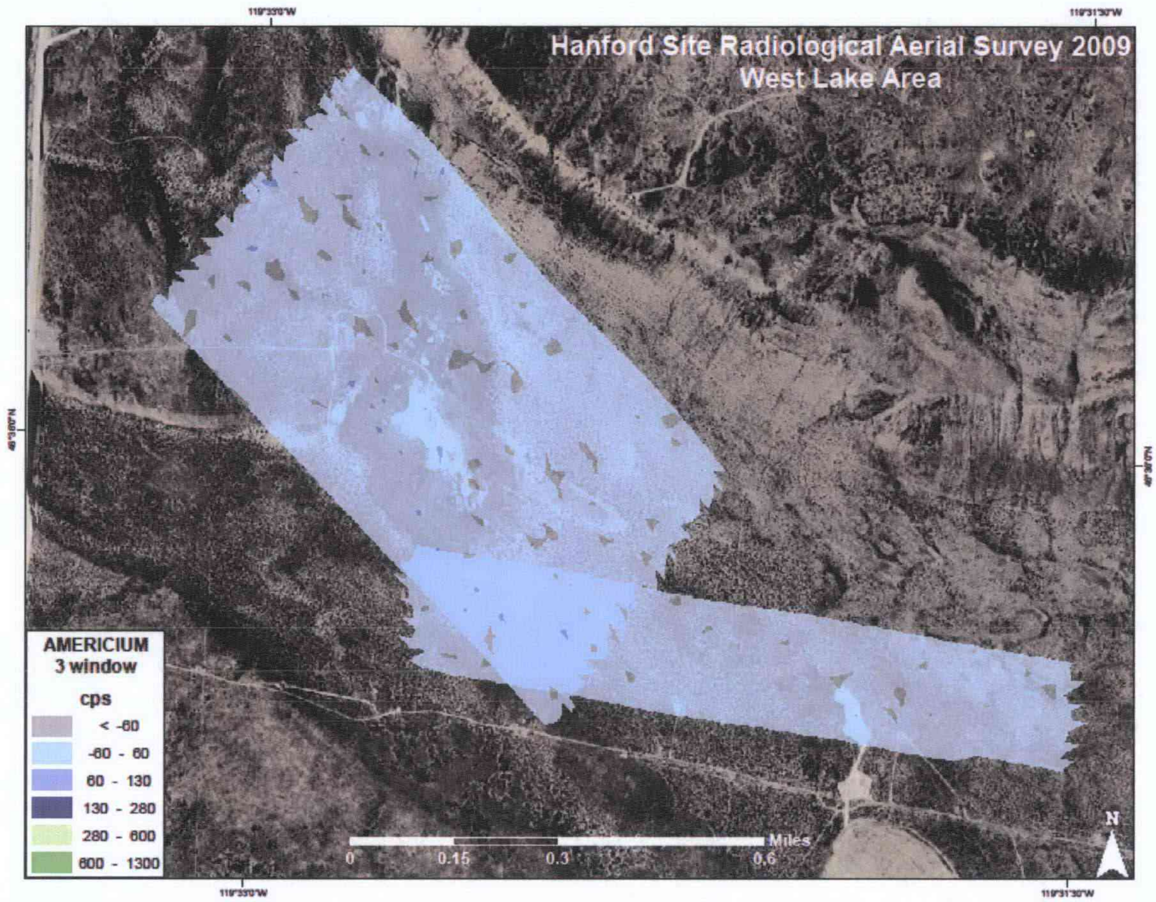


Figure 23. West Lake and Gable Mountain Pond Am-241 Isotope Extraction Contoured Data Results

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.

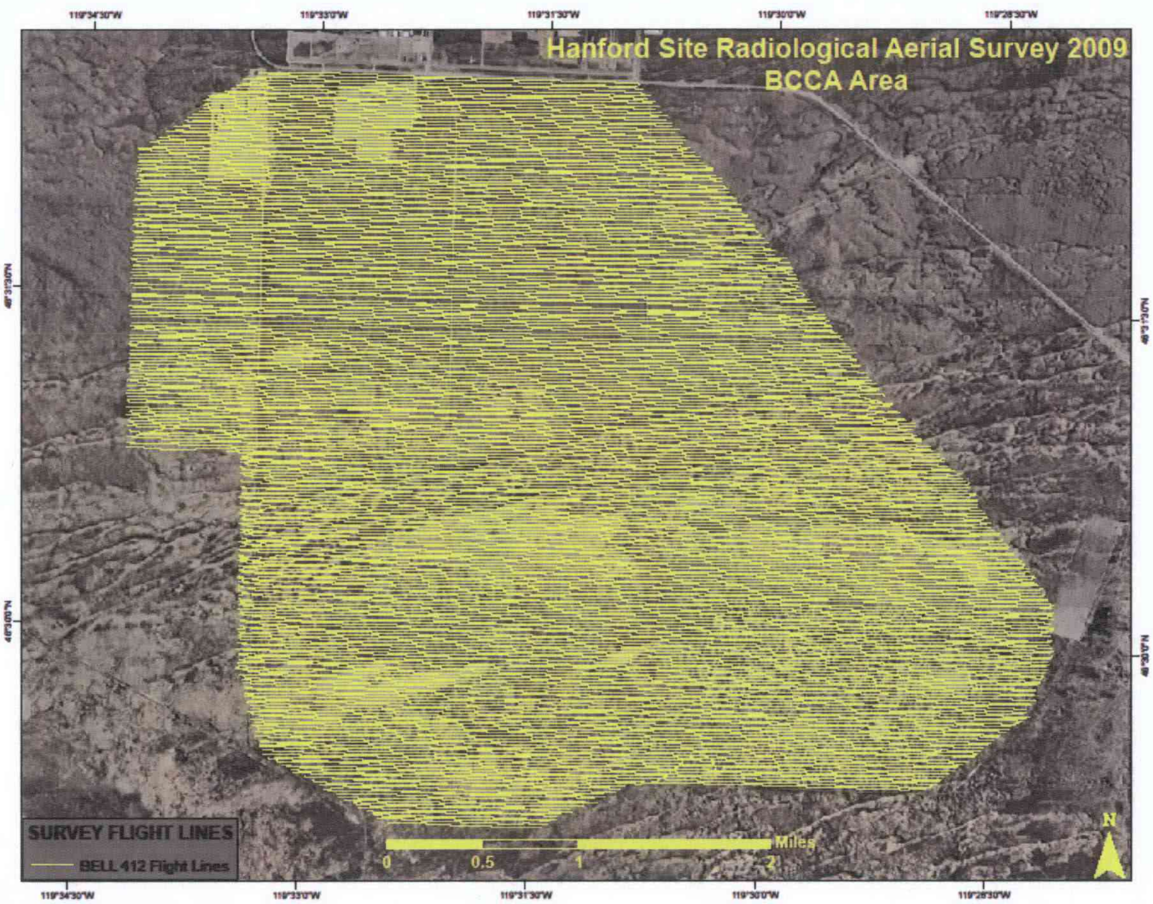


Figure 24. BCCA Flight Line Results

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

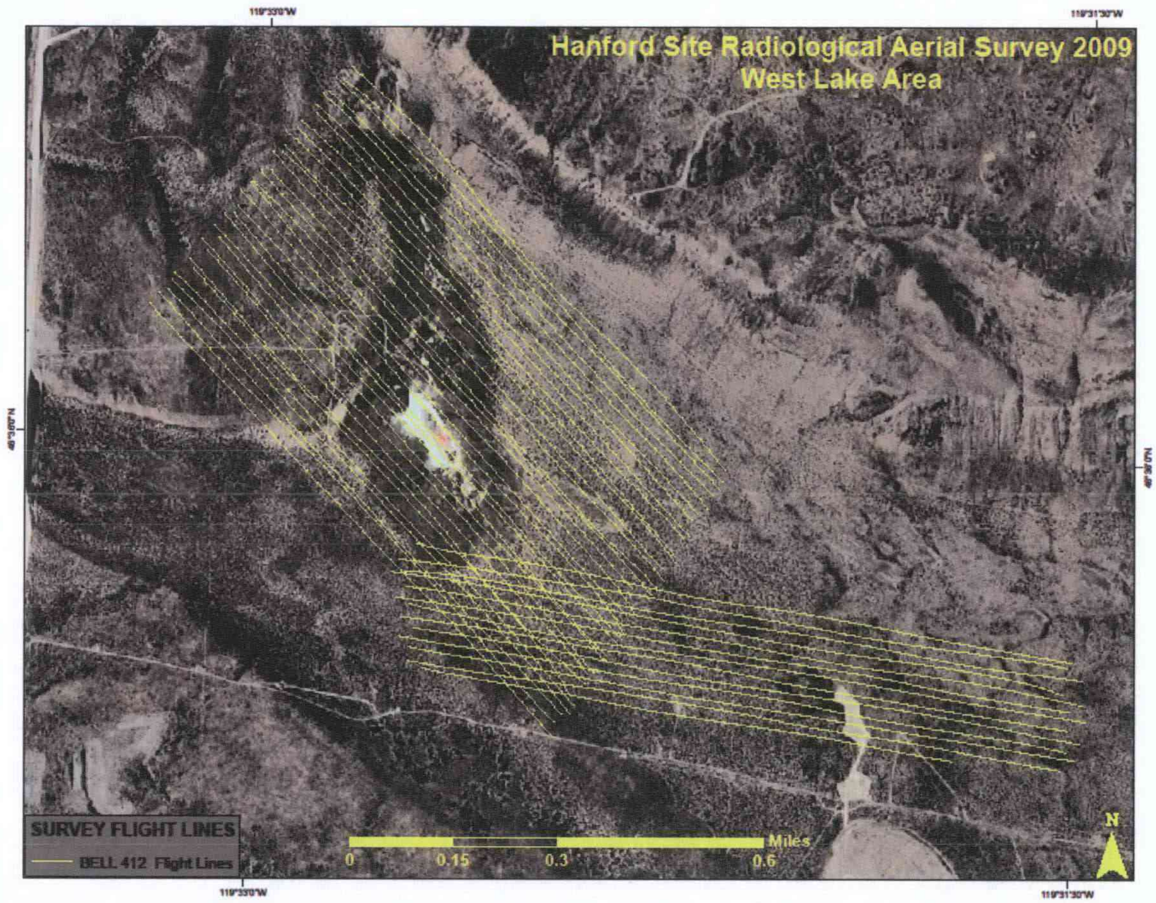


Figure 25. Example of Flight Line Precision over the West Lake and Gable Mountain Survey Areas

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

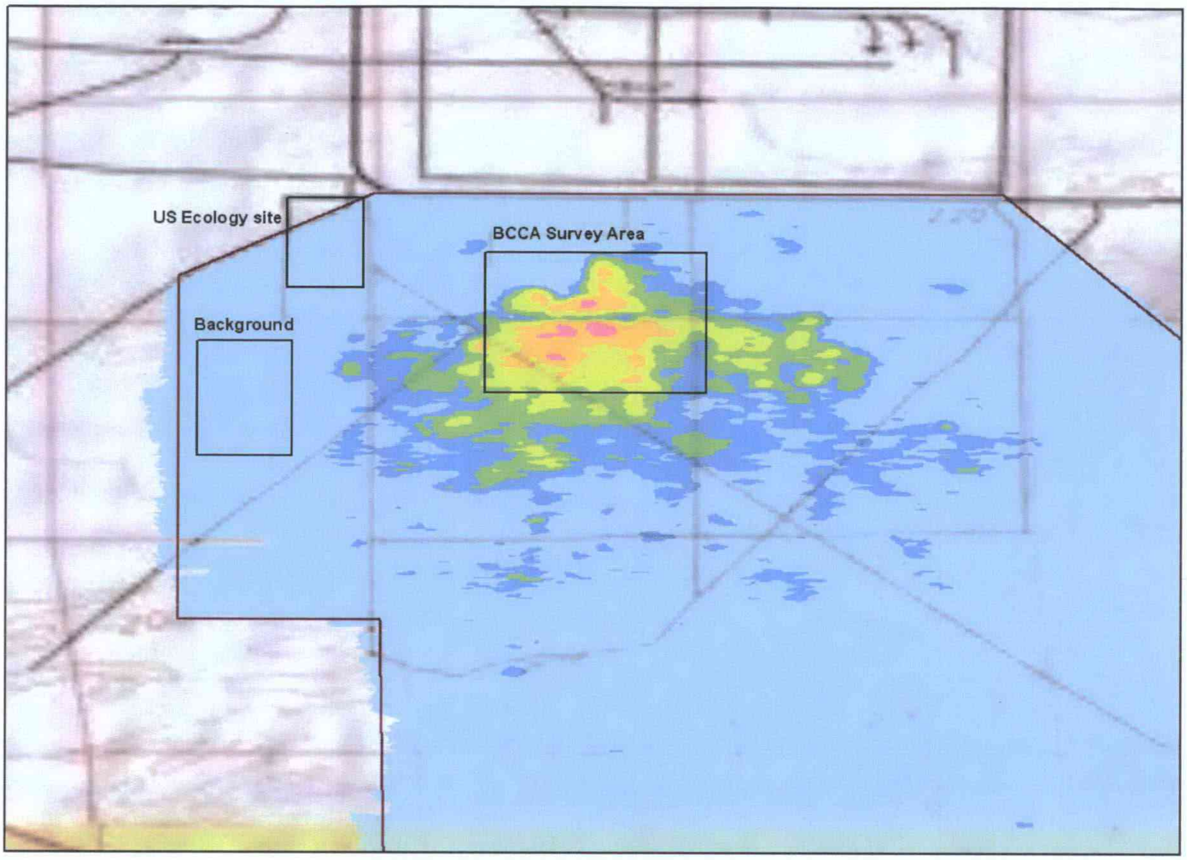


Figure 26. Gamma Spectra Analysis Locations

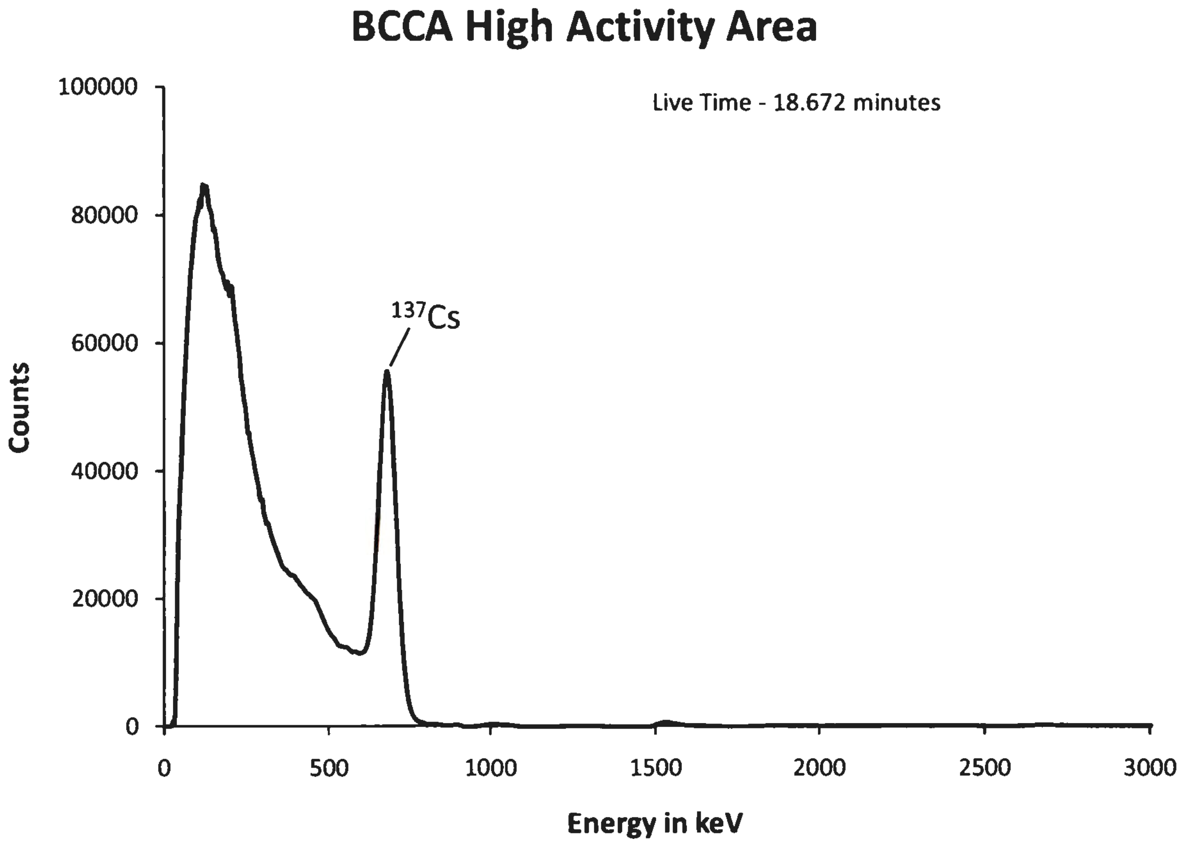


Figure 27. BCCA High Activity Area Net Spectrum

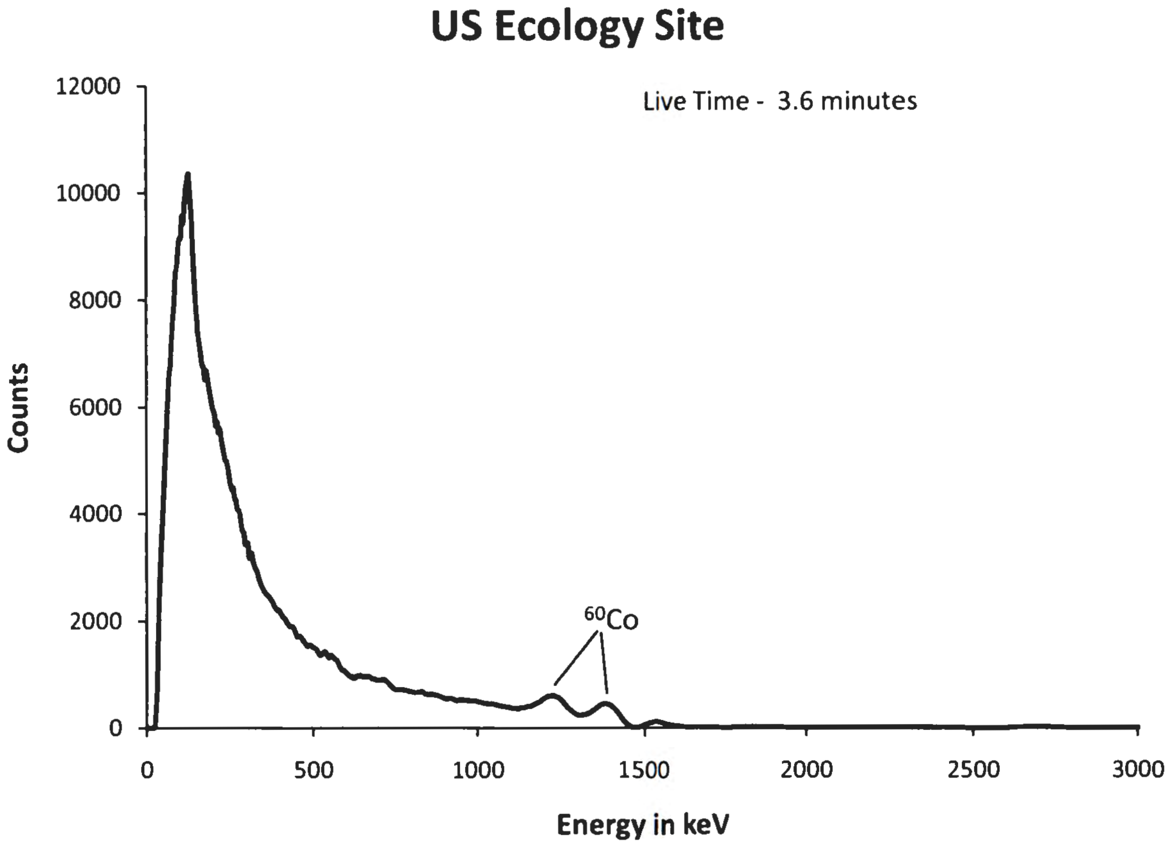


Figure 28. U.S. Ecology Site Net Spectrum

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.

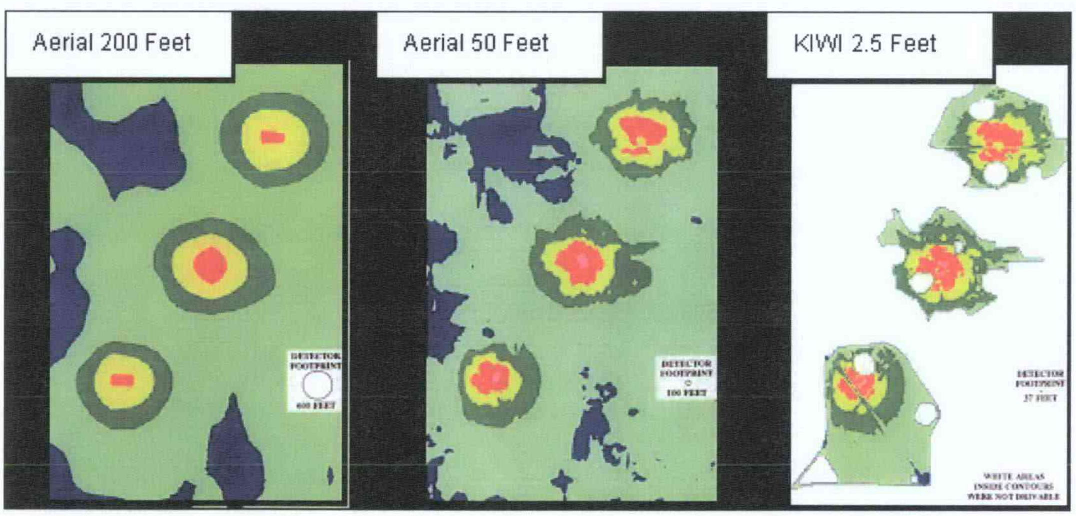


Figure 29. Example of Aerial Data Results From the NTS Due to Altitude

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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REFERENCES

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2. Colton, D. P., *An Aerial Radiological Survey of the Hanford Reservation,* Date of Survey February 29 to March 21, 1996, National Security Technologies, LLC, Las Vegas, Nevada

3. Hendricks, T., Riedhauser, S., *An Aerial Radiological Survey of the Nevada Test Site*, Date of Survey: August to September 1994, DOE/NV/11718-324, December 1999, Bechtel Nevada, Las Vegas, Nevada.

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(T*l*) 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(T*l*) 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.

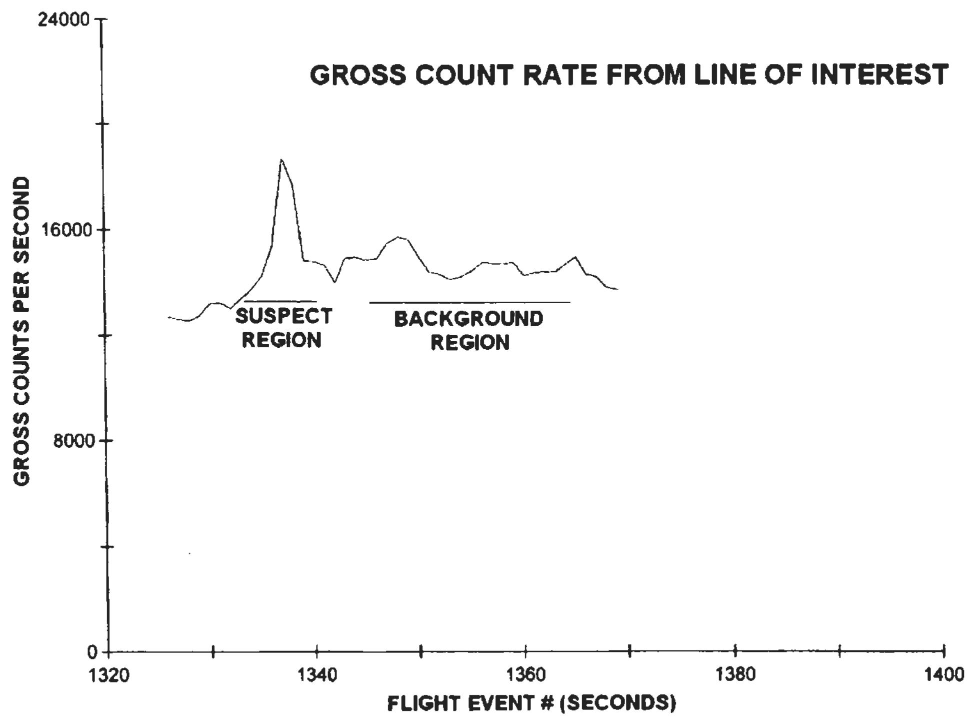

Figure B-1. Observed Total Gross Count Rate From Line of Interest

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.

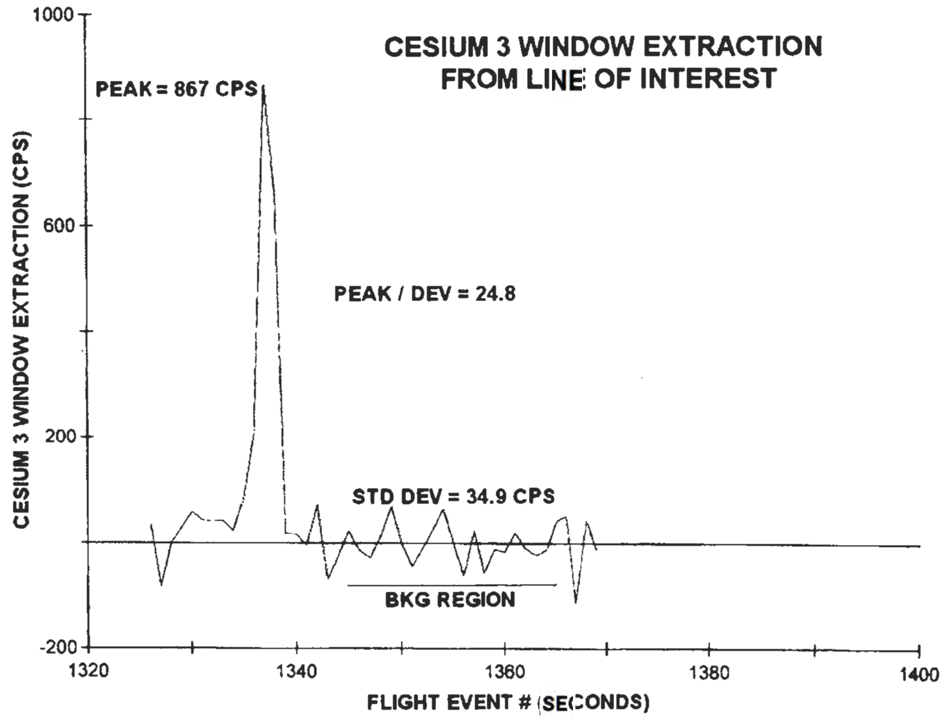

Figure B-2. Processed Cesium-137 Data Extraction

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.

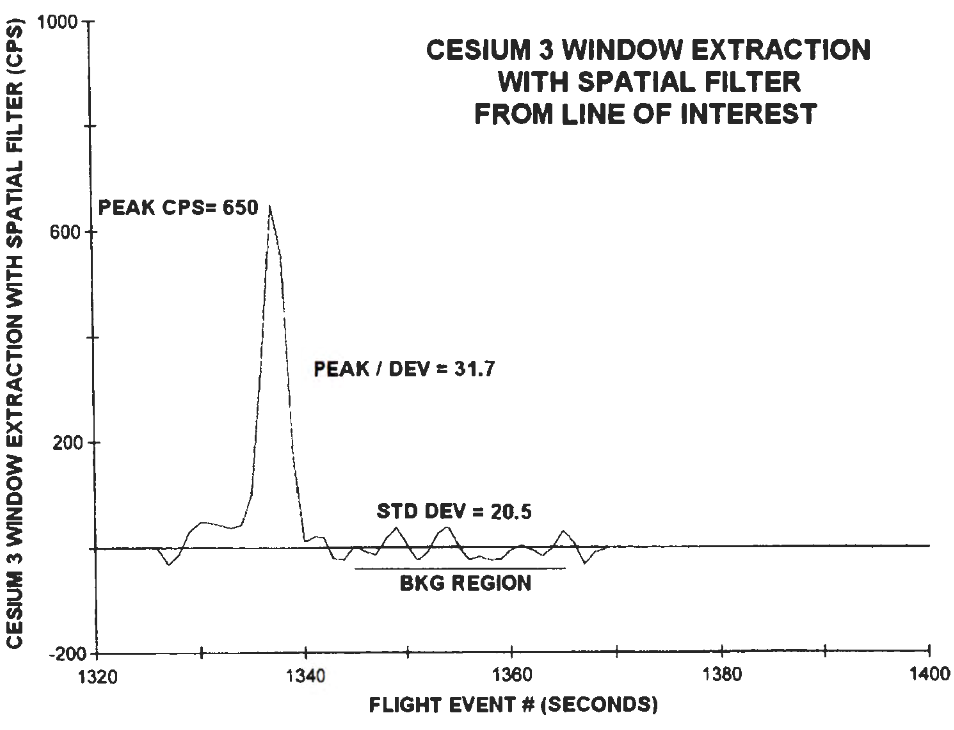

Figure B-3. Additional Improvement of Detectability by Spatial Filtering

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.

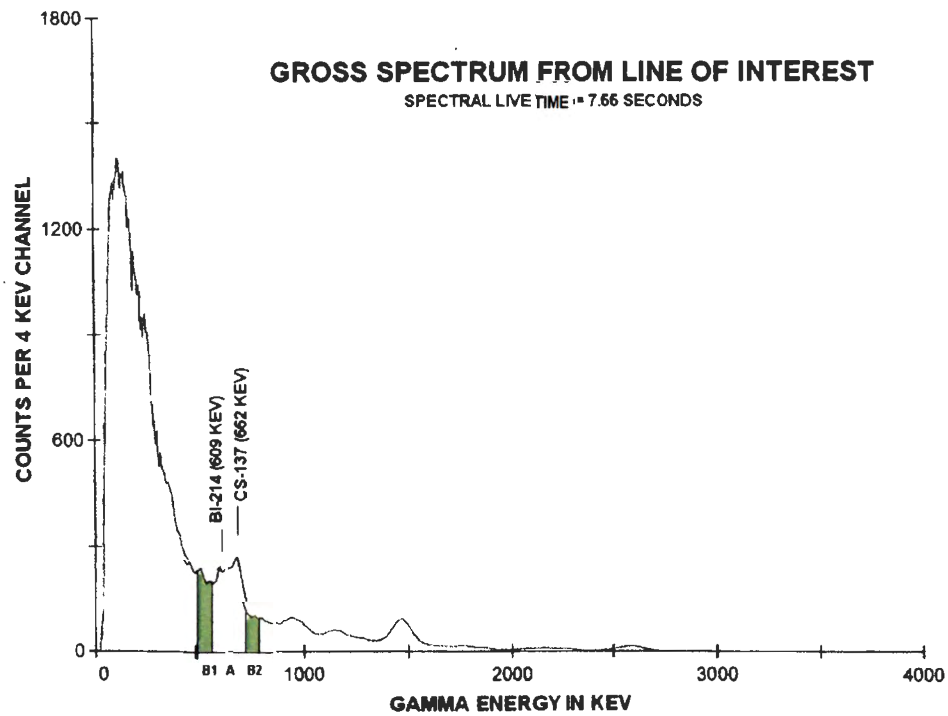

Figure B-4. Gross Spectrum from Suspect Area of LOI

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.

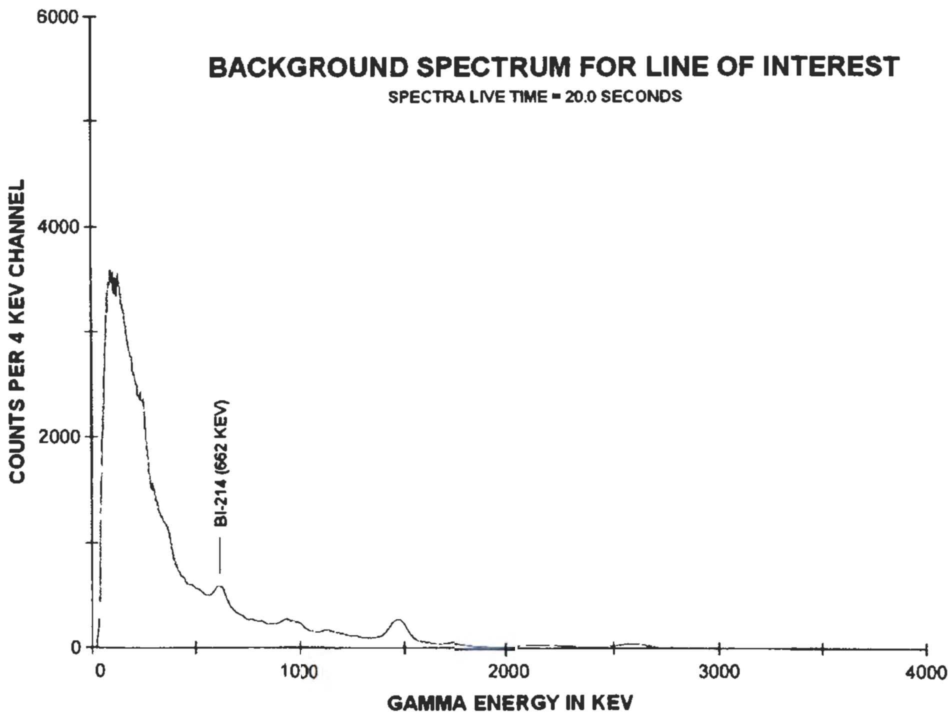

Figure B-5. Background Spectrum from LOI

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.

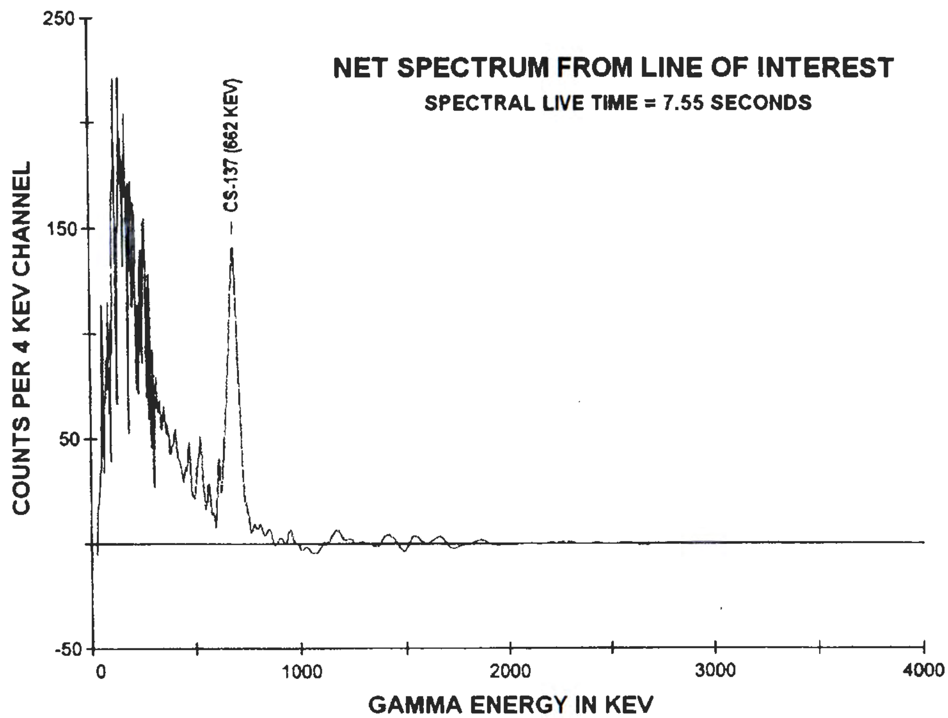

Figure B-6. Net Spectrum from Suspect Area

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 (μCi/m²/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.

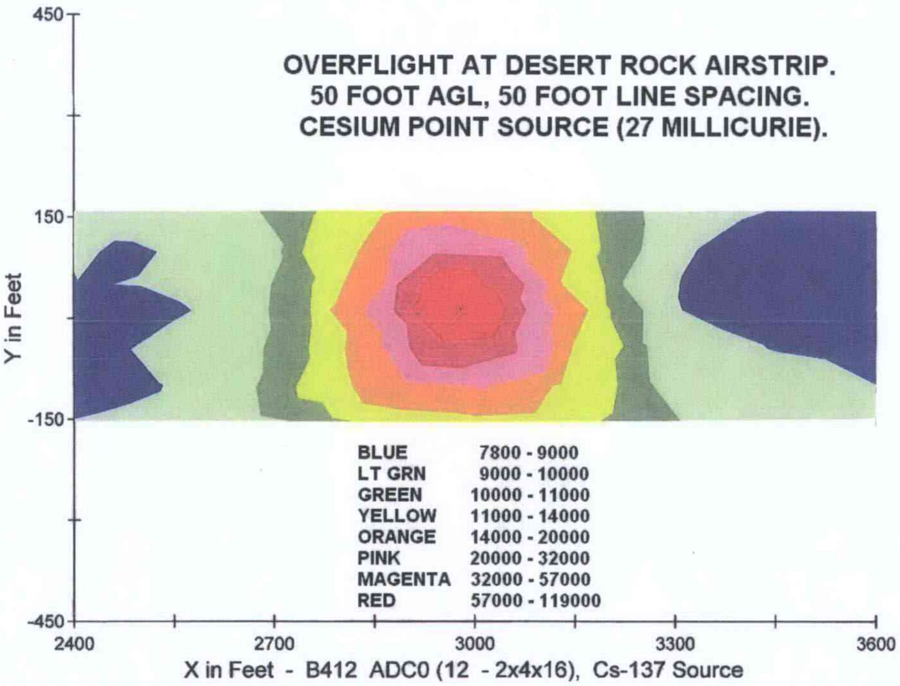

Figure B-7. Contour Map of Cesium Point Source Overflight

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 appcars that thc initial dcposition 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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Appendix B

Reprint of SGW-50393, *Kubota and Kiwi Ground Surveys of the BC Controlled Area Hanford Nuclear Reservation*, Rev. 0, published August 2011

SGW-50393
Revision 0

Kubota and Kiwi Ground Surveys of the BC Controlled Area Hanford Nuclear Reservation

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

U.S. DEPARTMENT OF ENERGY Richland Operations Office

P.O. Box 550
Richland, Washington 99352

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Kubota and Kiwi Ground Surveys of the BC Controlled Area Hanford Nuclear Reservation

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Survey Dates: October 25 – November 4, 2010

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Reviewed by:

Angela Anderson

Derivative Classifier

June 2, 2011

Abstract

The scope of work for this project consisted of two phases. The first phase was to implement a test and evaluation plan for the Berkeley Nucleonics Corporation (BNC) Surveillance and Measurement (SAM) unit 940 mounted on a Kubota® all-terrain vehicle. This candidate system was developed at the request of CH2M Hill in support of the BCCA soil clean-up project. The pickup-mounted Kiwi radiation detection system from the Remote Sensing Lab (RSL) in Las Vegas, Nevada, was used as a baseline reference system. Data recording rates, sequence of measurement, detector and system quality control measurements, global positioning system (GPS) accuracy and recording, and verification of both systems' sensitivities were evaluated during the T&E plan. Conversion coefficients from detector counts to surface activity or volumetric activity were developed and confirmed between the Kubota and RSL Kiwi systems. The results of the testing and evaluation are summarized in the report "Kubota/Kiwi Test and Evaluation Plan for a Ground Survey of the BC Controlled Area (BCCA)". Because the SAM 940 system connected to a 4"x4"x16" NaI detector is a prototype, the RSL personnel had no operational history with the unit or the data. The operations plan assumed that the RSL Kiwi would be the primary standard system for comparison to a candidate system. As such, the Kiwi conducted the same measurements as the candidate system during this process.

The second phase of the project consisted of executing surveys over a recently excavated area (Zone A) and a non-excavated area (Zone B) using both vehicles and their systems. The non–excavated area in Zone B was surveyed as a possible soil contamination reference area. The distribution of "hot spot" contamination in that area disqualified it for that function. The Kiwi completed a survey of the Zone A excavated area, estimated at ~63 acres (using GIS software and the survey perimeter shape file). During the deployment to the Hanford site a total of 67 acres was actually surveyed. The Kubota completed the survey of the excavated 63 acres approximately two weeks after the Kiwi had returned to RSL-Nellis. The data has been processed from gross counts to a man-made gross count product and eventually to a Cs-137 pCi/g map product. Recommendations for changes to Kubota/SAM 940 operating conditions that would achieve optimal data collection have been provided.

In addition to the vehicle-based surveys, RSL also deployed a mechanically-cooled high purity germanium (HPGe) in-situ system to conduct static measurements in the excavated area. The detector counts were converted to pCi/g levels. The in-situ results were displayed over the vehicle results and are generally in the same activity ranges.

The target clean-up level was 2.9 pCi/g for Cs-137. There was no "hot spot" criteria adopted for area averaging. The project adopted a conservative strategy of remediating any survey result that exceeded the clean-up level regardless of size. The results of all surveys are being submitted to the Hanford site customer in the form of the image files contained in this report. However, the results are also produced as Geographic Information system (GIS)-

® Kubota is a trademark of the 2011 Kubota Tractor Corporation, Torrance, California compatible shapefiles for use by the customer. The shape files allow the customer to retrieve specific data point information for comparison and "hot spot" clean-up as necessary.

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Acronyms and Abbreviations

AGL	above ground level
Am-241	Americium-241
AMS	Aerial Measuring System
AOI	Area of Interest
ATV	All-Terrain Vehicle
BCCA	BC Controlled Area
BNC	Berkeley Nucleonics Corporation
cm	centimeter
cps	counts per second
Cs-137	Cesium-137
DGPS	Differential Global Positioning System
DOE	U.S. Department of Energy
GIS	Geographic Information Systems
HNR	Hanford Nuclear Reservation
HPGe	High Purity Germanium
keV	kiloelectron volt
K-40	Potassium-40
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDA	Minimum Detectable Activity
MMGC	man-made gross count
NaI(T*l*)	thallium-activated sodium-iodine
NNSA	National Nuclear Security Administration
NSO	Nevada Site Office
pCi/g	Picocurie per gram
PM	photomultiplier
RadCon	Radiological Control
REDAR-V	Radiation and Environmental Data Acquisition and Recorder, Version V
ROI	region of interest
RSL–N	Remote Sensing Laboratory–Nellis
SAM	Surveillance and Measurement
Sr-90	Strontium-90
μR	microRoentgen

1.0 Introduction

1.1 Kiwi System

Aerial Measurement System (AMS) scientists at the U.S. Department of Energy/National Nuclear Security Agency's Remote Sensing Laboratory (RSL) in Las Vegas, Nevada, determined that the helicopter radiation detection system equipment, survey techniques, and data analysis protocols used for aerial surveys, could be used for a survey vehicle. As such, the aerial detection system was installed in an appropriate vehicle and nicknamed the "Kiwi" (flightless bird) (Figure 1). The development and use of the RSL Kiwi coincided with the approval and implementation of the guidance provided by the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM).

The Kiwi system uses detectors and a data collection system developed for the RSL-Nellis (RSL-N) radiological mapping helicopter mission, but mounted on a Ford F-250 crew-cab pickup truck. Eight 4" × 4" × 16" sodium iodide (NaI) detector logs are housed in four pods mounted on an angle-iron frame attached to the rear of the vehicle. The detector frame is adjustable to allow the bottom of the detector pods to be placed from 8 to 36 inches above the ground. Signals from the detectors feed into a *Radiation and Environmental Data Acquisition Recorder, Version V* (REDAR V) data-recording system mounted inside the rear of the truck cab. The eight detector logs are routed to four Analog-to-Digital Converters (ADCs). In addition to the REDAR V system, a second electronics rack cabinet houses power supplies and other support electronic equipment.

In addition to seating two people, the front-half of the cab houses the Global Positioning System (GPS) steering indicator used by the vehicle driver to maintain proper survey line spacing, and the keyboard and display system used by the electronics technician to operate and monitor the REDAR system. An AgNav™ positioning/steering system was recently installed in the Kiwi. This system allows the driver and technician to create survey plans in real time. This can be invaluable for surveys with daily changes in planned survey areas inside or outside the original site boundaries.

The Kiwi detectors produce voltage pulses which are proportional to the energy of the incident gamma-rays. These resulting voltage pulses are processed by the REDAR system, Version V. Four complete gamma-ray energy spectra are recorded during each second of a survey operation. The spectral energy range spans from 0 to 4,000 kiloelectronvolt (keV). Each full gamma spectrum permits the identification of other gamma-emitting radioisotopes present in the environment, in addition to the target contaminants. This allows a more accurate determination of the amounts of anthropogenic radioisotopes present compared with background levels, even if background levels change spatially over the survey area.

Figure 1. *RSL Kiwi System. The four detector pods are seen on the rear of the truck. A GPS antenna is mounted above the pods, and a generator for powering the system is mounted on the bed of the truck.*

1.2 Kubota/SAM 940 System

The candidate vehicle-based radiation detection was developed at the request of CH2M Hill in support of the BCCA soil clean-up project. The Kubota vehicle (Figure 2) is a diesel-powered all terrain vehicle (ATV) with an enclosed cab. The project installed a hydraulic lift system for adjusting the height of the detector box as needed. The GPS antenna is installed on the top beam of the hydraulic system above the detector box. The Berkeley Nucleonics Corporation (BNC) Surveillance and Measurement unit 940 (SAM 940) is installed in the cab of the vehicle. The detector box contains one 4" × 4" × 16" NaI detector.

Figure 2. *Kubota with SAM 940 System. The detector box is seen mounted on the hydraulic lift mounted on the rear of the vehicle. A GPS antenna is mounted on top of the lift frame.*

1.3 High Purity Germanium In-situ System

Measurements were performed with a high-purity germanium (HPGe) detector in support of the Hanford surveys. The measurements were collected with the HPGe in the *in situ* configuration: detector pointed toward the ground, with the detector end-cap one meter above the ground (Figure 3). The detector used for these measurements was an ORTEC® Detective-EX100: a mechanically cooled, p-type, co-axial detector with a crystal length of 50mm, diameter of 65mm, and a nominal efficiency of 40% relative to a 3" × 3" NaI detector.

The efficiency of the HPGe detector had been previously determined by use of radioactive button sources. Spectra were collected with the sources at a distance of one meter from the end of the detector, and at several angles relative to the axis of the detector. The spectra were analyzed, and the count rates in the peaks corresponding to the gamma-rays emitted by the sources were compared to the gamma-rays emitted by the source:

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$$\varepsilon = \frac{N}{TAp} \tag{1}$$

where N is the measured net counts in the gamma-ray peak, T is the spectrum duration, A is the source activity in Bequerels, and p is the probability per decay of emitting the gamma-ray.

Figure 3. *The Ortec Detective HPGe detector used for in-situ measurements with the Kiwi and Kubota survey vehicles in the background.*

2.0 KIWI and Kubota Survey Results

2.1 Survey Site Description

The Hanford Nuclear Reservation (HNR) 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, Washington, located at the site's southeastern boundary. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries. The Saddle Mountains form the northern boundary. The nearest population center is the Tri-Cities area (Richland, Pasco and Kennewick, Washington), 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. All nine of the reactors have been shutdown. Located in the center of the reservation are 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 in underground tank farms and burial sites located within and around the 200-Areas.

The BC Controlled Area (BCCA) is the focus of a contaminated soil clean-up project. The BC complex consists of six cribs—engineered soil waste disposal sites—and 20 trenches that were used in the 1950's 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, eaten the cesium and strontium salts, and then spread radioactivity to surrounding areas through their droppings. 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 surveys. The northern part of the BCCA 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 designated as "Zone A", which has the highest levels of contamination from cesium-137 and strontium-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". See Figure 4.

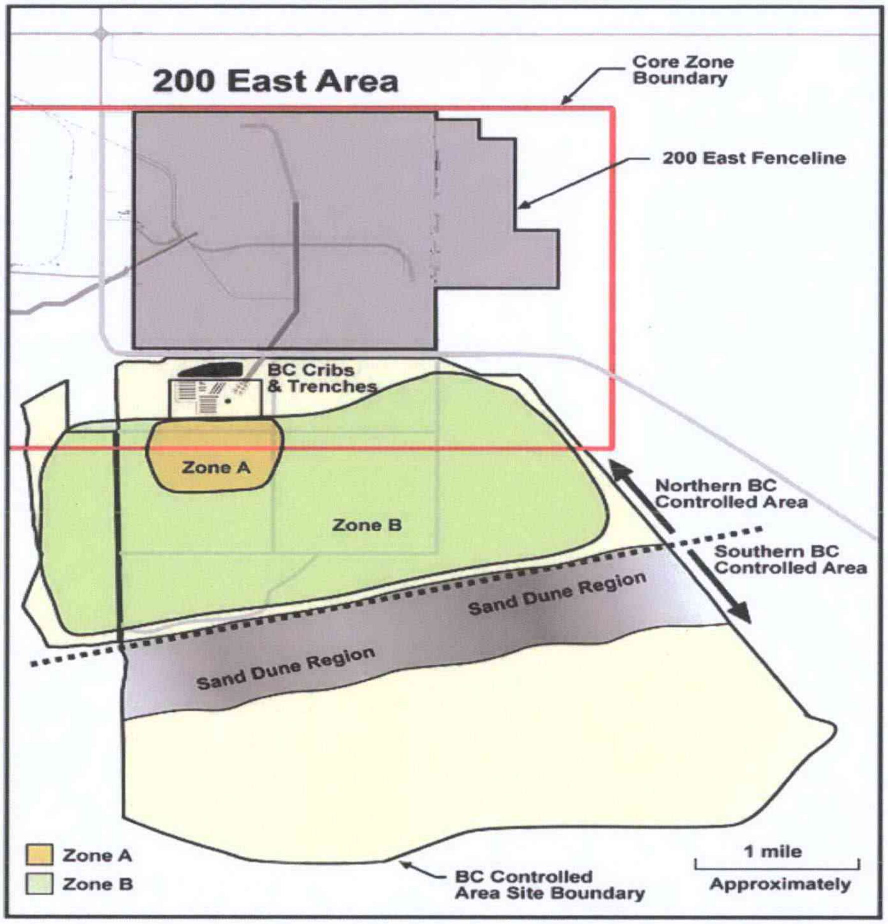


Figure 4. *The BC Controlled Area on the Hanford Nuclear Reservation*

RSL-N performed a helicopter survey of the BCCA in September 2009. The purpose of that survey was to update the previous radiological surveys of the BCCA. The aerial survey parameters: an altitude of 15 meters (50 feet) above ground level (AGL) and parallel line spacing of 23 meters (75 feet) were chosen to maximize the man-made radiation sensitivity and reduce the effective footprint of the helicopter radiation acquisition system. The BCCA deposition footprint was more complex than mapped after previous aerial surveys, primarily in 1996, due to the enhanced spatial resolution and sensitivity of the 2009 survey. The survey results confirmed that the soil contamination levels in Zone A exceeded the project's clean-up levels. See Figure 5.

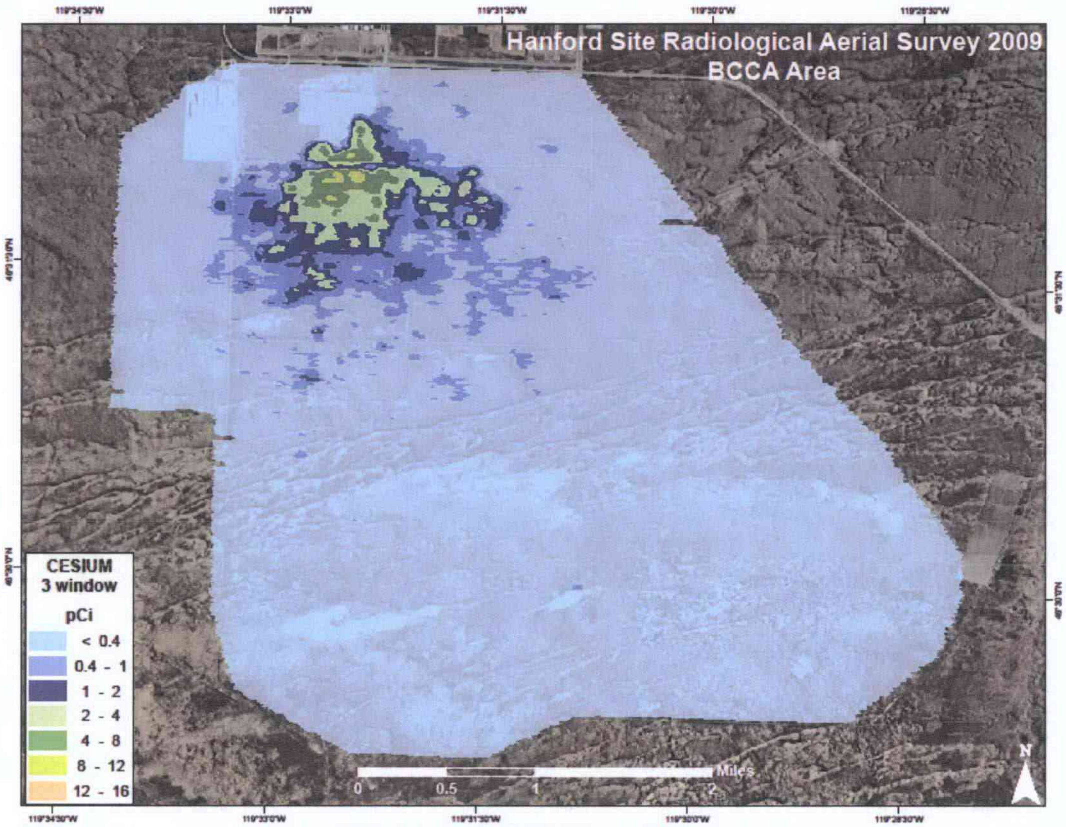


Figure 5. *2009 Aerial Survey Results*

Since September 2009, the project has excavated approximately 70 acres within the original Zone A and adjacent Zone B soil contamination areas. The project has been using hand-held NaI detection equipment to field screen the areas to determine compliance with the clean-up level of 2.9 pCi/g for Cs-137. The Kiwi and Kubota vehicles were tasked to perform an initial verification survey of the excavated areas.

2.2 Data Analysis Algorithms

2.2.1 Gross Count Method

To obtain a gross count (GC) contour, the count data that were collected by the AMS equipment were first integrated between 38 and 3,026 keV:

$$C_G = \sum_{E=38}^{3026} c(E) \tag{2}$$

where

C_G = gross count rate (counts per second [cps]),
E = photon energy (keV), and
$c(E)$ = count rate in the energy spectrum at energy E (cps).

The system records gamma rays with energies up to 4,000 keV; however, there are very few gamma rays above 3,000 keV.

Since GC contours are meant only to depict net terrestrial radiation levels, counts from cosmic radiation and airborne radon will be subtracted. Furthermore, the terrestrial count rate will be converted to an exposure rate E_G by applying a conversion factor S_f.

$$E_G = \frac{C_G}{S_f} \tag{3}$$

Measured count rates were leveled by comparing with count rates from an established test area and were normalized to detector live time[1].

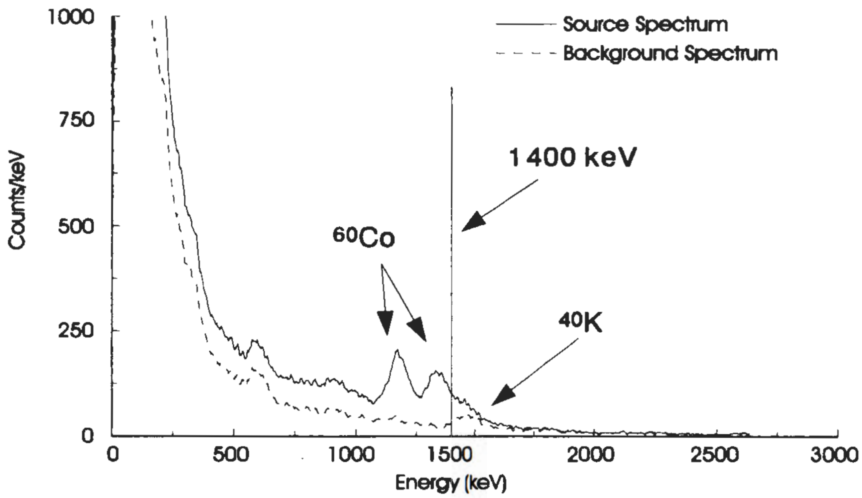


Figure 6. *NaI Gamma Ray Spectrum Illustrating MMGC Energy Regions*

The conversion from gross count to an exposure rate is based on the assumption that the source is spread uniformly over the width of the detector footprint, or field of view. Because of this assumption, the exposure rate is underestimated over sources that are small with respect to the size of the footprint. For example, an intense point source of radiation can produce measured count rates at the detector equivalent to those from a much less intense large-area source. These issues and calculations are further discussed in Section 3.

[1] "Live time" is the amount of time over which the detector integrates readings.

GC data include contributions from natural sources of radiation. Consequently, these data include variations in terrestrial background radiation levels. Contours resulting from these variations in natural radiation often match specific surface features, such as tree lines, boundaries of cultivated land, and bodies of water, because of the different attenuation characteristics of the different materials. Exposure rate contours offer a sensitive means of identifying anomalous, potentially anthropogenic changes in the radiation environment, in addition to detailing variations in the natural background radiation emissions.

2.2.2 Man-Made Gross Count Method

The man-made gross count (MMGC) method is used to differentiate between anthropogenic radiation and naturally occurring radiation in a survey. The MMGC method also referred to here as the MMGC filter, relies on the fact that most gamma-ray emissions from long-lived, anthropogenic sources of radioactivity occur in the energy region below about 1,400 keV. In areas where only natural sources of gamma radiation are present, the ratio of the counts appearing below 1,400 keV to those appearing above 1,400 keV remains relatively constant. This relationship is true even if natural background radiation levels vary by a factor of 10 across the survey area. If this ratio changes spatially, it is most likely because of a contribution from anthropogenic gamma radiation.

The MMGC algorithm is a means of identifying regions in the survey area where the shape of the energy spectrum deviates significantly from the shape of the background, or reference spectrum. The MMGC algorithm is very sensitive to small changes in the abundance of anthropogenic isotopes, while being very insensitive to large changes in the abundance of natural isotopes.

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.

Figure 6 shows two typical NaI gamma-ray spectra. Superimposed on a background spectrum is a spectrum obtained with Co-60 present. Counts from an anthropogenic radioisotope, such as Co-60, fall almost entirely in the low-energy region below 1,400 keV. This condition is true for most anthropogenic radioisotopes of concern, which causes the ratio of counts in the low-energy range to counts in the high-energy range to change.

The normal ratio of counts in the low-energy region to counts in the high-energy region for a survey area is calculated from data obtained in an area that contains only natural sources of radioactivity. These counts are integrated over each energy region. To match the energy limits of the discrete channels of the acquired spectra, the low-energy region extends from 38 to 1,394 keV. The high-energy limits are then 1,394 to 3,026 keV. This ratio can be computed with Equation 4:

$$K_{MM} = \frac{\sum_{E=38}^{1394} c_{ref}(E) - B_{MML}}{\sum_{E=1394}^{3026} c_{ref}(E) - B_{MMH}} \qquad (4)$$

where

B_{MML} = average background counts in the MMGC low-energy window (cps),

and

B_{MMH} = Average background counts in the MMGC high-energy window (cps).

The background count rates are derived from drive data. These two background count rates remove the effect of non-terrestrial background from the MMGC extraction in a manner similar to the background removal in the GC algorithm. The subscript "*ref*" denotes that the counts in each channel, *c(E)*, are obtained from a reference area of natural background radiation. This ratio is applied to each second of data from the survey area:

$$C_{MM} = \left[\sum_{E=38}^{1394} c(E) - B_{MML}\right] - K_{MM}\left[\sum_{E=1394}^{3026} c(E) - B_{MMH}\right] \qquad (5)$$

where

C_{MM} = Anthropogenic (man-made) count rate (cps).

The MMGC algorithm allows the data to be analyzed such that variations in the count rate due to changes in natural background levels are filtered out. In regions with only natural background radiation, the MMGC algorithm will yield count rates that fluctuate statistically around zero. Variations in count rate due to anthropogenic or industrially enhanced radioisotopes then appear as isolated contours.

The increase in sensitivity obtained with the MMGC analysis over that of the GC method is significant. However, the MMGC filter is also sensitive to changes in the relative composition of natural background radiation. For example, areas exhibiting excess concentrations of natural potassium, uranium, and/or thorium, the ratio of the low-energy to high-energy gamma rays may be different, even though the gamma rays are emitted by naturally occurring radioisotopes. In such cases, the MMGC algorithm may generate a set of "false positive" anomalies on the MMGC contour map. A background-subtracted gamma energy spectrum in this case will only show natural radioisotopes or a smoothly varying background with no discernable peaks.

2.2.2.1 Gamma Spectral Analysis

The MMGC algorithm is very general and is sensitive to any change in the low-energy portion of the spectrum. It does not exactly identify the causes of the change—whether (1) a true anthropogenic isotope is present in this region, (2) the increased low-energy gamma rays are caused by naturally occurring isotopes whose gamma rays underwent more inelastic scatterings before reaching the detectors (for example, a change from a grassy meadow to a dense wooded area), or (3) the isotopic composition of the spectrum in this region of the survey is significantly different from where K_{MM} was determined (for example, granite versus limestone). Once a region appears in the anthropogenic contours, the energy spectrum is searched for individual isotopes. An analysis of the gamma-ray spectrum is used to identify the isotopes that are present in the spectrum and caused the MMGC deviation.

Generally, the large background field (from the naturally occurring isotopes) is not of interest—only the portion of the spectrum attributable to the anthropogenic isotopes is. Unfortunately, the number of counts at any given energy in a single one-second measurement is so small as to make the identification of a particular isotope very difficult. To increase the number of counts in the spectrum being analyzed (and thus produce better statistics), the spectra from neighboring measurements are combined to produce a single spectrum showing the radiation measured over some larger area.

To determine net spectra at an identified anomaly, each area of interest is divided into "peak" and "background" regions. The contour levels used to define these regions are usually MMGC levels. The peak and background boundaries may be defined by other means (e.g., GC contour levels). The peak region of the spectrum consists of the spectra contained in the area bounded by the chosen contour level. The background region consists of the spectra contained outside the chosen contour level. This partitioning generally guarantees that the background spectrum is representative of the geology near the anomaly, but there will be some contribution of anthropogenic radioactivity in the background region.

This technique produces a net spectrum that has very little contribution from the naturally occurring radioisotopes in the region and makes the identification of the remaining isotopes fairly easy. The technique has one major drawback, in that it does not necessarily produce a true indication of the strength of the isotopes seen in the net spectrum. That is, comparing the intensity of an isotope in one net spectrum with the intensity of that same isotope in another spectrum may not be meaningful.

Numerous techniques can be used to scale the background spectra when creating the net gamma-ray spectra. One technique that will be used involves computing the ratio of the live times of the peak and background regions and using the results to normalize the data. This technique therefore creates a net spectrum by subtracting the background spectrum, normalized by the ratio of the peak live time to the background live time, from the peak spectrum:

$$c_{Net}(E) = c_{Peak}(E) - \frac{T_{Peak}}{T_{Bkg}} c_{Bkg}(E) \tag{6}$$

Where:

$c_{Net}(E)$ = counts in the net energy spectrum at the energy E (cps)

$c_{Peak}(E)$ = counts in the peak energy spectrum at the energy E (cps)

T_{Peak} = total spectrum live time composed of all peak-region spectra (s)

T_{Bkg} = total spectrum live time from all background-region spectra (s)

$c_{Bkg}(E)$ = counts in the background energy spectrum at energy E (cps).

This method of normalization is relatively straightforward to implement. If there is an excess of naturally occurring radioisotopes, the net spectrum will preserve the high-energy photopeaks of these isotopes.

2.2.2.2 Spectral Distortions

If the survey contains areas of very high activity, the count rate in the detectors may become high enough to distort the spectra. This distortion results from having insufficient time between the electrical pulses generated by the amplifiers on the photomultiplier tubes. When these pulses reach the data collector, one pulse is superimposed on the tail of another pulse, and the data collector determines a voltage for this combined pulse that is no longer characteristic of the individual pulses. At moderate count rates, this distortion may appear as a broadening of the photopeak widths and possibly as a shift in a photopeak's apparent energy. At very high count rates, these effects become more severe, and it may be nearly impossible to recognize any pattern to the photopeaks present in the spectrum. If the count rate in the 8-detector array is high and produces distorted spectra, then the analysis continues using the spectra collected by the single detector.

2.2.3 Isotope Extraction Algorithms

The algorithms employed in the search for particular isotopes are very similar to the MMGC algorithm. The major difference is that instead of using the full gamma-ray energy spectrum, they use only a few small portions of it. Two such algorithms are the 2-window algorithm and the 3-window algorithm.

2.2.3.1 The 2-Window Algorithm

The 2-window algorithm is the simplest of several window algorithms in use. It employs a narrow window centered on the energy of the specific photopeak of the isotope of concern. The algorithm assumes that the background counts in the photopeak window are proportional to the counts recorded in a background window located at higher energies. The background window may abut the photopeak window or may be separated from it in the energy spectrum. Note that the form of the equation for C_2 is identical in form to the equation for MMGC previously defined:

$$C_2 = \left[\sum_{E=E_1}^{E_2} c(E) - B_{2L} \right] - K_2 \left[\sum_{E=E_3}^{E_4} c(E) - B_{2H} \right] \quad (7)$$

with

$$K_2 = \frac{\sum_{E=E_1}^{E_2} c_{ref}(E) - B_{2L}}{\sum_{E=E_3}^{E_4} c_{ref}(E) - B_{2H}} \quad (8)$$

where

C_2 = count rate from the 2-window algorithm (cps),

$c(E)$ = count rate in the gamma-ray energy spectrum at the energy E (cps),

E_n = limiting energies of the windows ($E_1 < E_2 \leq E_3 < E_4$) (keV),

K_2 = ratio of the counts in the photopeak window to the counts in the background window in the reference region of the survey area,

$c_{ref}(E)$ = count rate in the reference gamma-ray energy spectrum at energy E (cps),

B_{2L} = average background counts in the 2-window low-energy window (cps), and

B_{2H} = average background counts in the 2-window high-energy window (cps).

The proportionality factor, K_2, is determined in a region of the survey that does not contain any of the specific isotopes of concern so that the photopeak window contains only background counts and, therefore, can be simply related to the number of counts in the background window. If the principal source of background gamma rays in the photopeak window is from scattered gamma rays from photopeaks at higher energies, this is a good assumption. If there are other isotopes with photopeaks in or near the photopeak and background windows, this algorithm fails.

2.2.3.2 The 3-Window Algorithm

If a reference region free of the specific isotope cannot be found, or if the compositions of the other isotopes change drastically between the reference region and the rest of the survey area, then a simple multiplicative factor will not relate the counts in the photopeak window to the counts in the background window. To solve this problem, the 3-window algorithm employs a background window on each side of the photopeak window. (The two background windows generally abut the photopeak window in energy.) This algorithm assumes that for any spectrum, the number of background counts in the photopeak window is linearly related to the counts in the two background windows.

$$C_3 = \left[\sum_{E=E_2}^{E_3} c(E) - B_{3P} \right] - K_3 \left[\left(\sum_{E=E_1}^{E_2} c(E) - B_{3L} \right) + \left(\sum_{E=E_3}^{E_4} c(E) - B_{3H} \right) \right] \quad (9)$$

with

$$K_3 = \frac{\sum_{E=E_2}^{E_3} c_{ref}(E) - B_{3P}}{\sum_{E=E_1}^{E_2} c_{ref}(E) - B_{3L} + \sum_{E=E_3}^{E_4} c_{ref}(E) - B_{3H}} \quad (10)$$

where

C_3 = count rate from the 3-window algorithm,
E_n = limiting energies of the windows ($E_1 < E_2 < E_3 < E_4$),
B_{3P} = average background counts in the 3-window photopeak window (cps),
B_{3L} = average background counts in the 3-window low-energy window (cps),
B_{3H} = average background counts in the 3-window high-energy window (cps), and
K_3 = ratio of the counts in the primary window to the counts in the two background windows in a reference region of the survey area.

The 3-window algorithm is also very useful in extracting low-energy photopeak counts where the shape of the Compton-scattering contributions from other isotopes is changing significantly.

2.2.3.3 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.

2.2.4 Methods to Estimate Soil Concentrations

The instruments used in this survey measure gamma-ray emissions, which directly correspond to exposure levels. However, many radiation-protection regulations are written in terms of soil activity levels rather than exposure levels, because soil activity levels are more commonly measured. Soil activity levels of concern are generally determined on the basis of human or ecological health risks, which, in turn, are directly related to exposures. These exposure estimates are computed from the soil activity level data on the basis of a number of assumptions.

The exposure data gathered during the pilot study aerial survey was used to estimate what soil activity levels would result in these measured exposures through a similar, inverted process. By making assumptions about the distribution of the radioisotopes in the soil, soil activity levels that would provide equivalent measured exposures can be computed.

The conversion from a measured count rate to soil activity depends on several factors, including the distance from the source to the detector, the types and thicknesses of the materials between the source and detector, the size of the detector, and the distribution of the isotopes in the soil. For this survey, all of these factors are known with the exception of the source distribution in the soil. Figure 7 gives typical conversion factors and minimum detectable activities (MDAs) for six possible distributions. All of the distributions vary only as a function of the depth in the soil. The graph uses RSL derived curves from data collected during the testing and evaluation of the Kiwi and Kubota systems. The soil sample depth is in centimeters. The curves represent different exponential distributions of cesium activity. For example, "0.15 exp" represents exponential activity which decreases by a factor of "e" (2.71828) for every 0.15 cm of soil depth.

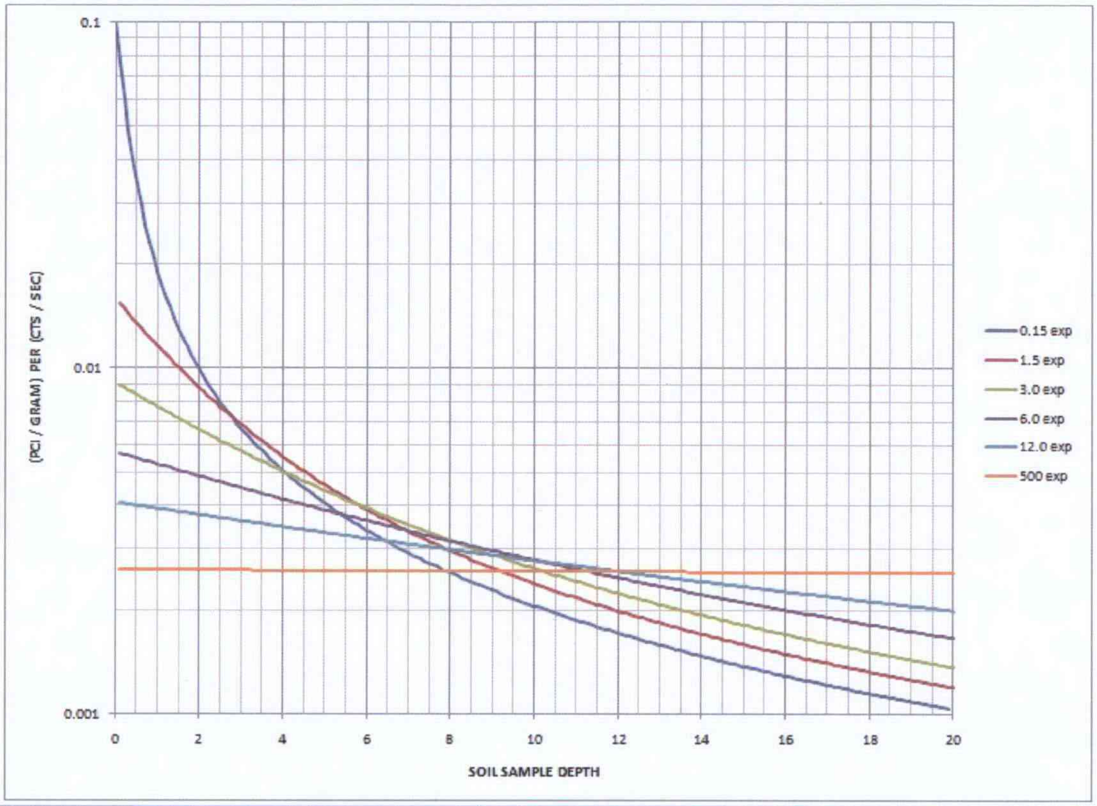


Figure 7. *Soil Depth Conversion Chart for 8-detector Kiwi System*

2.2.4.1 Cesium-Specific Volumetric Activity Conversion Algorithm

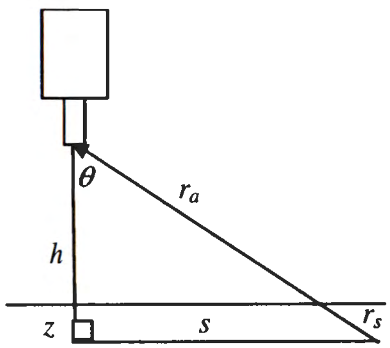
Conversion of count rate information to soil volumetric activity involves a number of parameters. These include detector type, number, and configuration; vehicle speed; isotope of interest; specific extraction algorithm; specific distribution of isotope in soil; soil density and moisture.

For estimation purposes, AMS utilizes a computer code written by an RSL scientist to derive the system sensitivity. The code uses a simulation of the detection system response function and typical natural background spectrum. 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.

For the Kiwi survey, the value of 0.0025 pCi/gram per 1 net photopeak count of Cs-137 was utilized to create the initial Cs-137 3-window extraction pCi/g map products. The value of 0.01875 pCi/g per 1-cps Cs-137 net photopeak was used for the Kubota data due to a factor of 7.5 relative sensitivity between the 8 detector Kiwi array and 1 detector Kubota system. The assumed soil sample depth was 15 cm as per the BCCA project technical staff. (See Figure 7).

2.2.4.2 HPGe-Specific Volumetric Activity Conversion Equations

Exponentially distributed in the soil



$$N = TA\beta \int_0^\infty \int_0^\infty \frac{\varepsilon(\theta)e^{-\lambda z}}{4\pi(r_a + r_s)^2} e^{-\mu_a r_a} e^{-\mu_s r_s} 2\pi s\, ds\, dz$$

where

N = net counts in photopeak
T = count time
A = source activity (Bq/cm^3)
β = gamma-ray yield (per decay)
μ_a = gamma-ray attenuation coefficient in air
μ_s = gamma-ray attenuation coefficient in soil
$\varepsilon(\theta$ = effective area of the detector

r_a = $h/\cos\theta$
r_s = $z/\cos\theta$
s = $(h+z)\sin\theta/\cos\theta$

λ = soil depth decay constant (cm^{-1}) = 1/(15 cm) for Hanford

$$N = TA\beta \int_0^{\infty}\int_0^{\pi/2} \frac{\varepsilon(\theta)e^{-\lambda z}}{4\pi(h+z)^2/\cos^2\theta} e^{-\mu_a h/\cos\theta} e^{-\mu_s z/\cos\theta} 2\pi(h+z) \frac{\sin\theta}{\cos\theta} \frac{(h+z)}{\cos^2\theta} d\theta dz$$

$$N = TA\beta \int_0^{\infty}\int_0^{\pi/2} \frac{\varepsilon(\theta)}{2} \frac{\sin\theta}{\cos\theta} e^{-\mu_a h/\cos\theta} e^{-(\lambda+\mu_s/\cos\theta)z} d\theta dz$$

$$N = TA\beta \int_0^{\pi/2} \frac{\varepsilon(\theta)}{2} \frac{\sin\theta}{\cos\theta} e^{-\mu_a h/\cos\theta} \frac{\cos\theta}{\lambda\cos\theta + \mu_s} d\theta$$

$$N = TA\beta \int_0^{\pi/2} \frac{\varepsilon(\theta)}{2(\lambda\cos\theta + \mu_s)} \sin\theta\, e^{-\mu_a h/\cos\theta} d\theta$$

3.0 Kiwi Results

3.1 Kiwi Gross Count Point Data 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 decay 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 U-238 and 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), Tl-208 and Ac-228 (decay products in the Th-232 chain), and Pb-214 and Bi-214 (decay products 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 Decay Products. 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 decay products 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 decay products 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 decay products contributes 1–10 percent of the natural background radiation level seen in vehicle-based 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).

Figure 8 represents the gross count point data produced in the total energy spectrum of the acquisition system during the survey. The map products generated from the data collected during BCCA survey represent the gross count point data produced by summing the full-energy spectra recorded by the eight detectors carried by the Kiwi. The point data represent each 1-second result recorded by the Kiwi acquisition system.

After the previous aerial surveys conducted in 2009, the primary map product was the Cs-137 activity contoured data in cps 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 point data files have a number of attributes that improve site characterization and remediation efforts. The shape file, a standard data file format used by GIS software contains specific latitude and longitude information for each data point. Ground teams can greatly improve their performance using this information to find the location of elevated count rates. The point data map products have been included in this report as requested by the customer. The Kiwi gross counts map product in Figure 8 consists of 68,994 data points collected and processed. NOTE: The term point data is somewhat of a misnomer since each GIS data point actually represents an effective detection footprint circle of ~8 meters diameter for the Kiwi detector configuration.

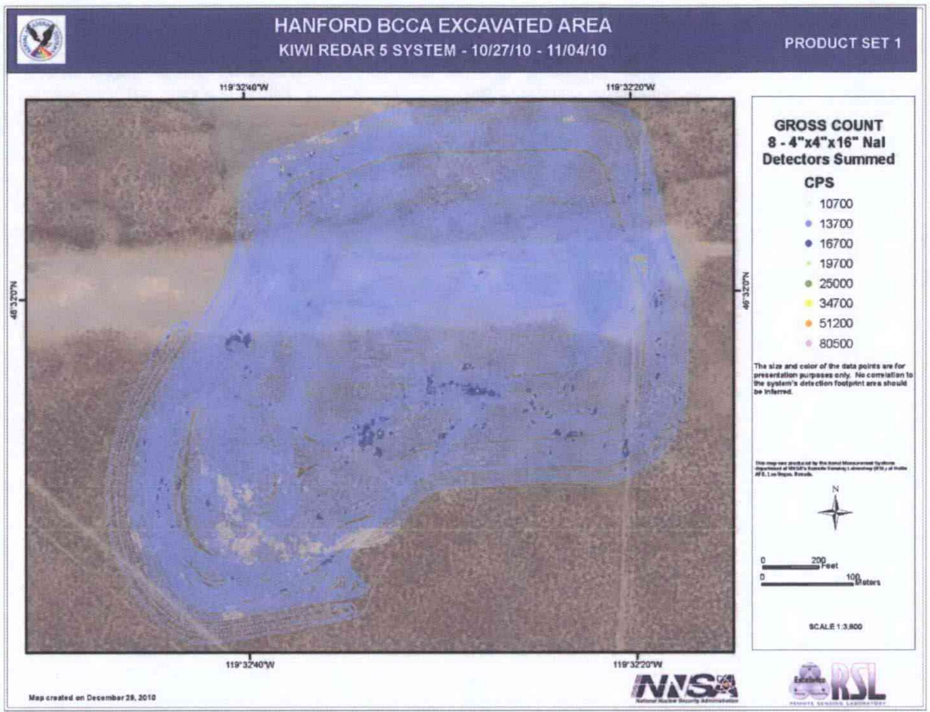


Figure 8. *Kiwi Gross Counts – All eight NaI detector logs have been summed for this map*

3.2 Kiwi Man-Made Gross Count Point Data Map (BCCA)

The MMGC algorithm (discussed in Section 2) was used to study the Kiwi data for man-made radionuclides in the survey area. The MMGC map (Figure 9) shows the activity that is attributable to gamma radiation from man-made radioisotopes with the variable natural background component removed. The results are displayed as point data in place of the normal contour data map at the customer's request.

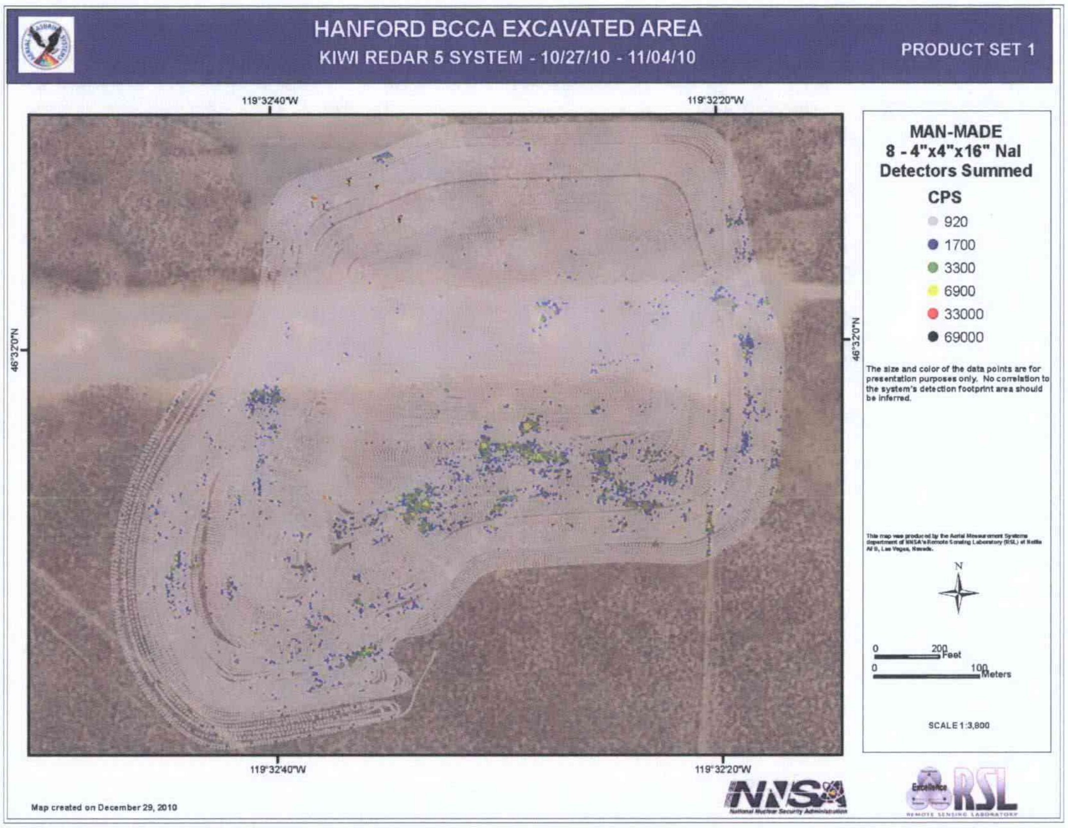


Figure 9. *Kiwi Man-made gross count results over the survey area*

3.3 Kiwi Cesium-137 Volumetric Activity (pCi/g) Point Data Maps

The results of the Cs-137 extraction for the eight summed detectors and the left, left-center, right-center and right pods (two detectors each) are presented in Figures 10-14. The conversion of extracted Cs-137 counts to pCi/g levels assumed that the remaining activity in the soil would be widely distributed relative to the Kiwi detector footprint. If that assumption is reasonable, the map products for the eight summed detectors and the two detectors per pod results should be similar on a point-by-point comparison. The five maps are very similar with less than 1% of the total data points showing a different activity level between the summed detectors and individual pod maps. There are no individual "hot spots" above the clean-up level that were not detected by at least two of the individual detector pods on the Kiwi.

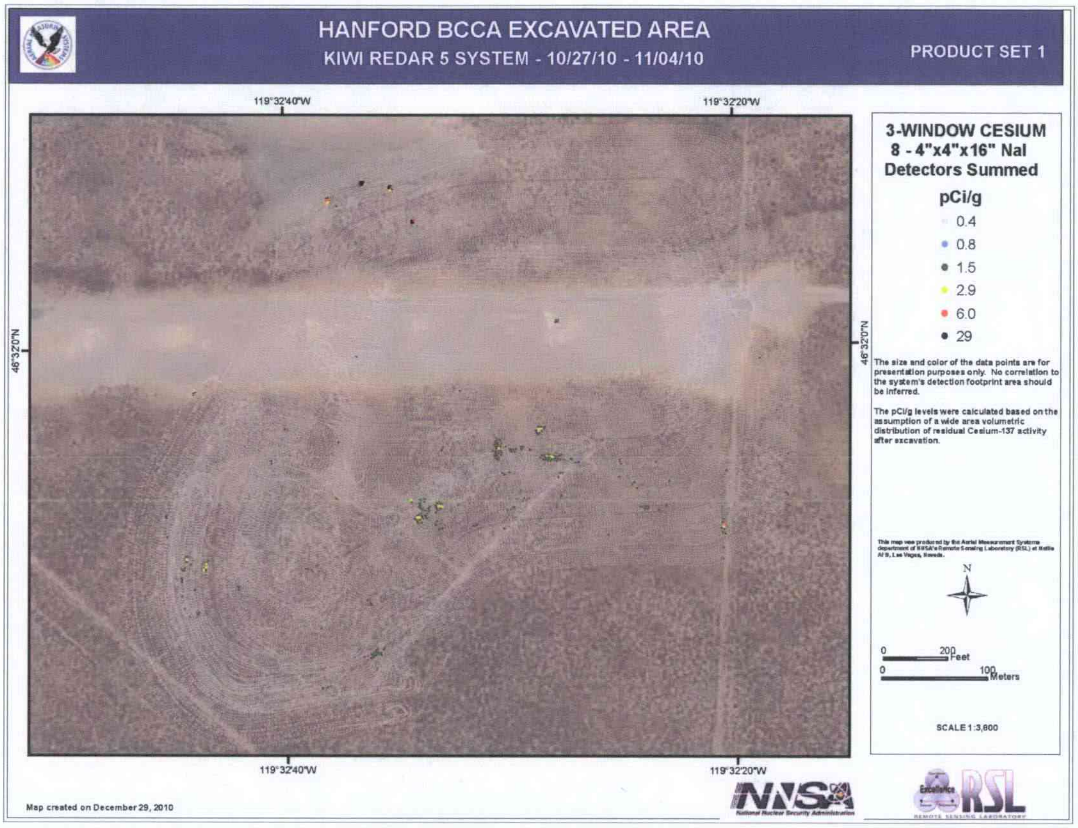


Figure 10. *Calculated Cs-137 volumetric activity using data from all eight detector logs*

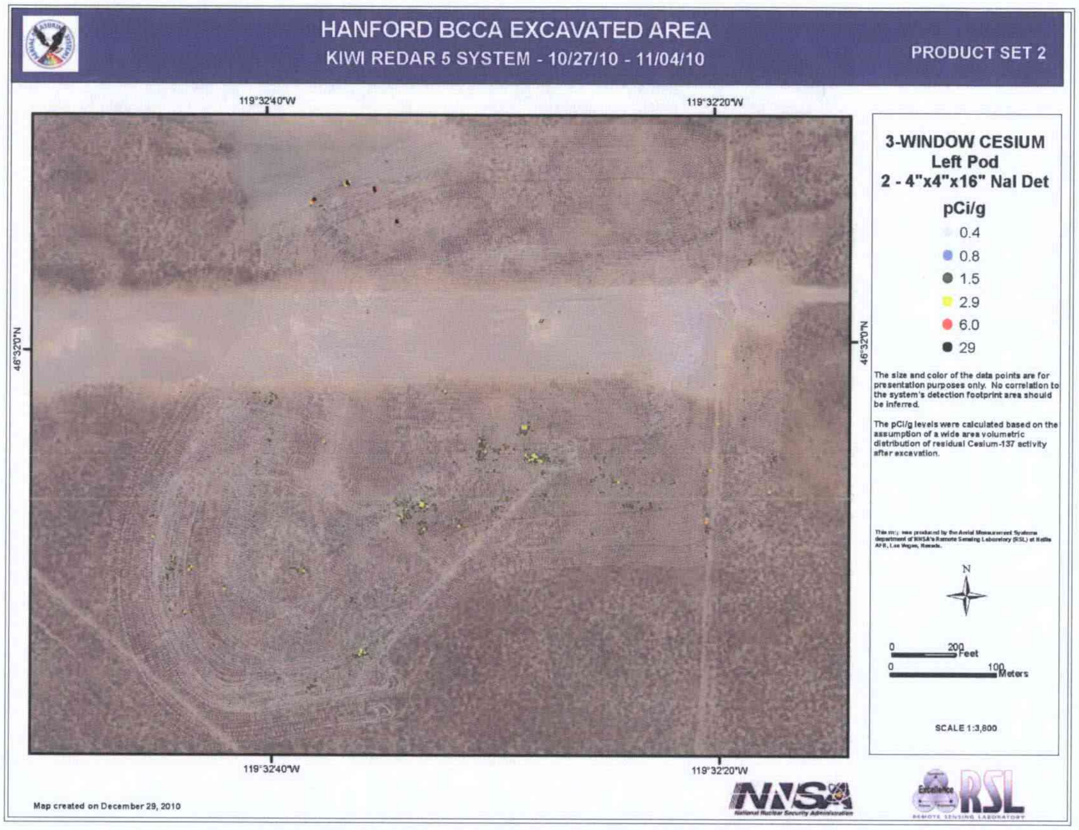


Figure 11. *Calculated Cs-137 volumetric activity using data from the left Kiwi pod (two detector logs)*

Figure 12. *Calculated Cs-137 volumetric activity using data from the left center Kiwi pod (two detector logs)*

Figure 13. *Calculated Cs-137 volumetric activity using data from the right center Kiwi pod (two detector logs)*

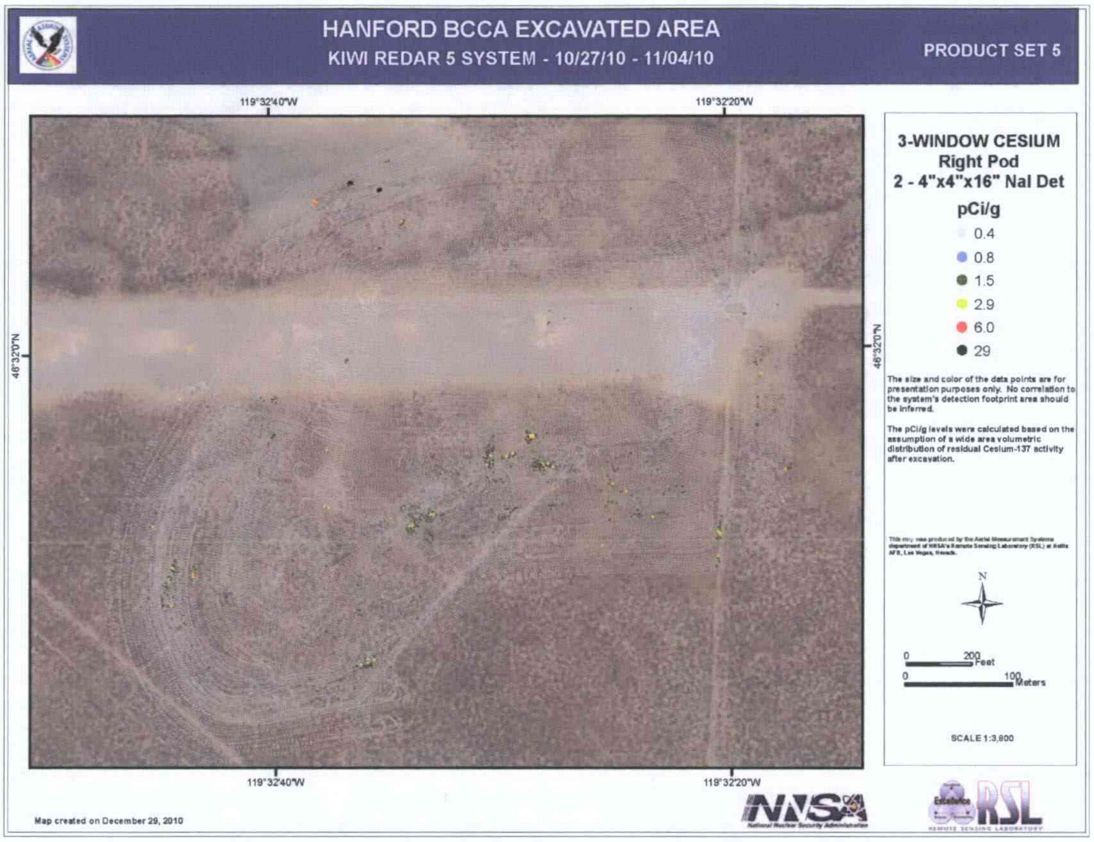


Figure 14. *Calculated Cs-137 volumetric activity using data from the right Kiwi pod (two detector logs)*

4.0 Kubota Results

4.1 Kubota 3-Window Cesium Counts Zone B

The work scope included surveys by both vehicles over a non-excavated area within the BCCA project to create a soil contamination reference area. The criteria for a reference area included:

- One or more areas of uniform soil contamination activity with a minimum size of 1,000 ft^2 to allow for multiple vehicle measurements. This would verify the detector counts to pCi/g conversions on the vehicle systems, especially after repairs, detector replacements or modifications to hardware or software.
- The uniform contamination areas would be measured by the in-situ HPGe system to derive the pCi/g activity levels.

- Soil samples could be taken to confirm the activity levels in pCi/g for Cs-137, document the contamination depth thru the soil column and provide additional Cs-137/Sr-90 ratios.

Project personnel designated an area in Zone B as a candidate reference area. The Kiwi and Kubota conducted surveys over sections of this site. The site had not been excavated and was approximately 0.5 miles (0.8 kilometers) from the Zone A excavated area. The site had numerous old-growth clusters of sagebrush and rabbit-brush that prevented a full survey to be conducted. The Kubota survey results are presented in Figure 15 as an example of the Cs-137 activity levels in the site. Any areas of elevated activity were much smaller than required with distinctive "hot spot" variability. The Kiwi results were the same.

Based on the initial survey results from this site, the Zone B candidate reference area was abandoned for further study. Subsequent discussions between the RSL scientists and BCCA project technicians and scientists confirmed that the soil contamination patterns discovered in Zone B were prevalent throughout the BCCA site and the reference area effort would not be successful.

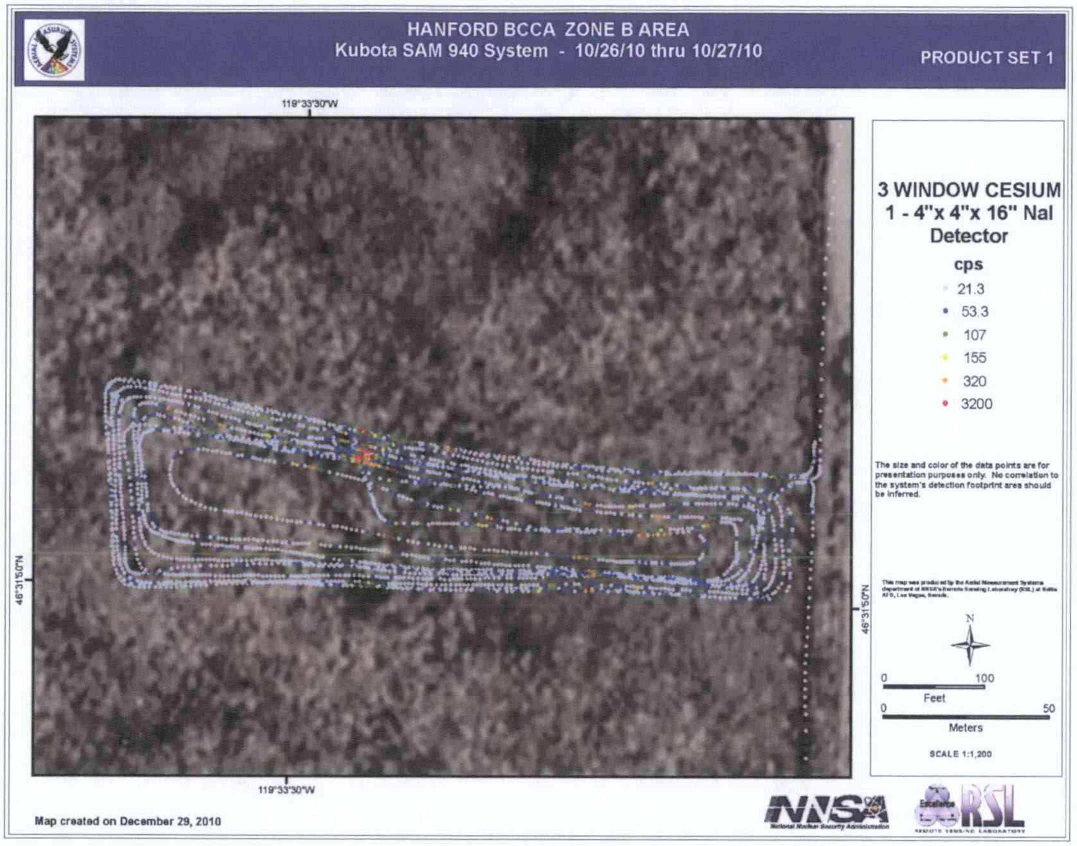


Figure 15. *Kubota results for candidate reference area in Zone B. Cs-137 hot spots are clearly visible*

4.2 Kubota Gross Count Point Data Maps (BCCA)

The Kubota system used one NaI detector versus the Kiwi 8-detector system. However, as discussed in Section 3.1, the Kubota system would be equally affected by the naturally occurring terrestrial radionuclides, radon and its decay products and the cosmic radiation contributions since the detector material and volumes are identical. The raw gross count results were not always consistent between survey drives due to hardware and software features of the SAM 940 system. Two data sets were normalized to adjacent drive results to produce the map product in Figure 16. The quality assurance technique of driving the test line at the start and end of each survey allows for the adjustments made to the data sets.

The Kubota gross counts map product in Figure 16 consists of 123,365 data points collected and processed. NOTE: The term point data is somewhat of a misnomer since each GIS data point actually represents an effective detection footprint circle of ~7 meters diameter for the Kubota detector configuration.

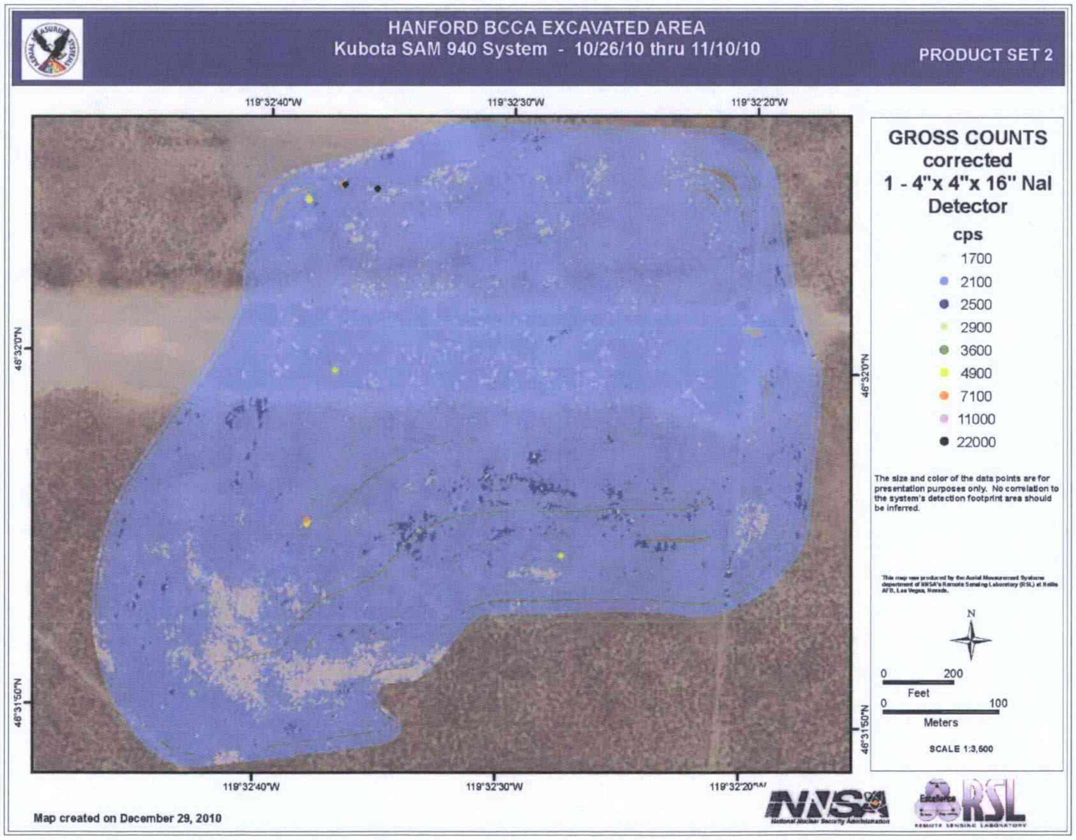


Figure 16. *Kubota gross count results for the survey area*

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

The MMGC algorithm (discussed in Section 2) was used to study the Kubota 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 results are displayed as point data in place of the normal contour data map at the customer's request.

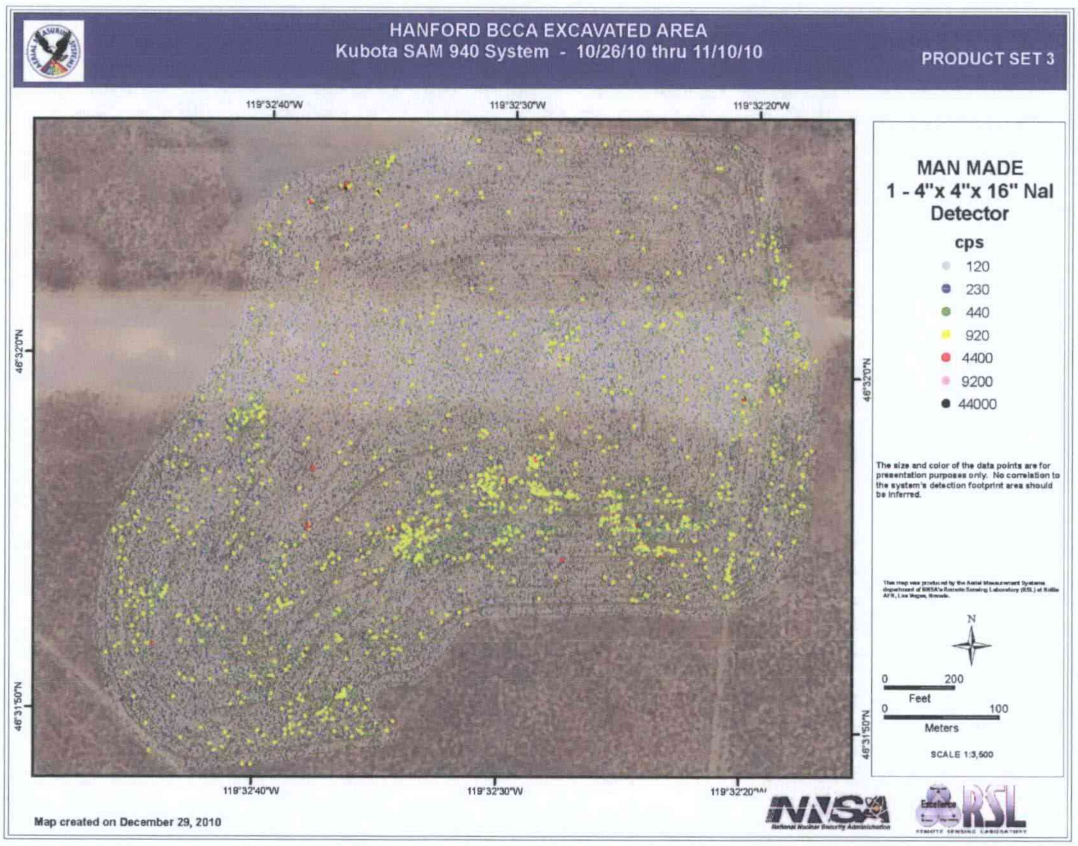


Figure 17. Kubota man-made gross count results for the survey area

4.4 Kubota Gamma Spectral Analysis Results

The MMGC algorithm is very general and is sensitive to changes in the low-energy portion of the spectrum, but 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.

In a typical radiation background area, the numbers 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 spatially adjacent 1-second spectra are combined to produce a single spectrum for a larger area. This process is useful during scoping surveys to identify or confirm the presence of specific radionuclides in the survey area. During a verification survey, this process is used to confirm that all man-made anomalies are due only to previously identified radionuclides. An example of the process is shown in the following Figures 18 - 21.

4.4.1 Examples of Net Spectra Gamma Analysis

Figure 18 illustrates the process of combining 1-second data points into background and area-of-interest (AOI) spectra for analysis. The figure contains two background areas and three AOIs as an example of the net spectra analysis.

Figure 19 contains the two background and three AOI spectra results from the areas selected in Figure 18. The five spectra have a similar pattern thru the entire energy range from approximately 40 keV to 3,000 keV. The AOI spectra generally have fewer counts per energy channel due to the smaller size area used for the compilation of the 1-second data points.

The results in Figure 20 and 21 show the power of the net spectra analysis to remove the background contributions from the AOI spectra to aid in the identification of the man-made radionuclide. The expanded view in Figure 20 shows that the energy peaks for the three AOIs reside at approximately 660 keV which is consistent with Cs-137. This process confirms that all the elevated man-made gross count areas are the result of Cs-137 activity, which is the primary gamma-emitting man-made radionuclide in the BCCA site.

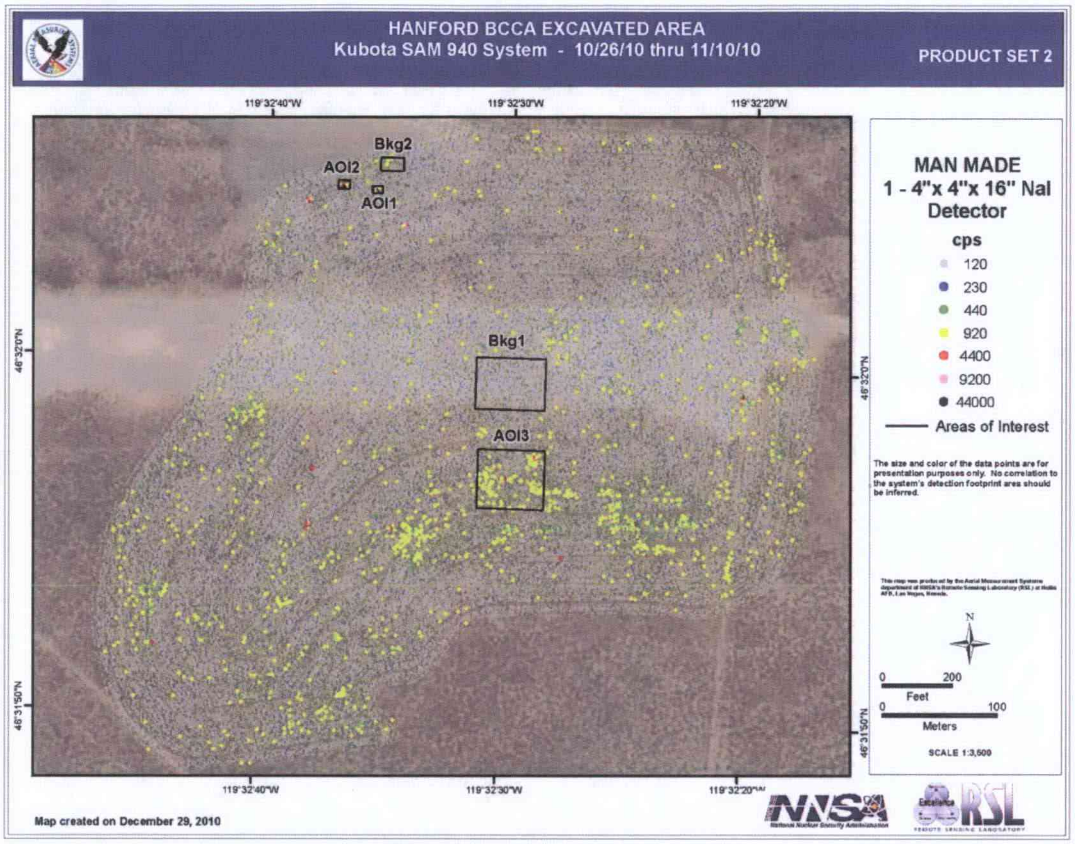


Figure 18. *Net Spectra Analysis Areas. Two background areas and three areas of interest have been selected.*

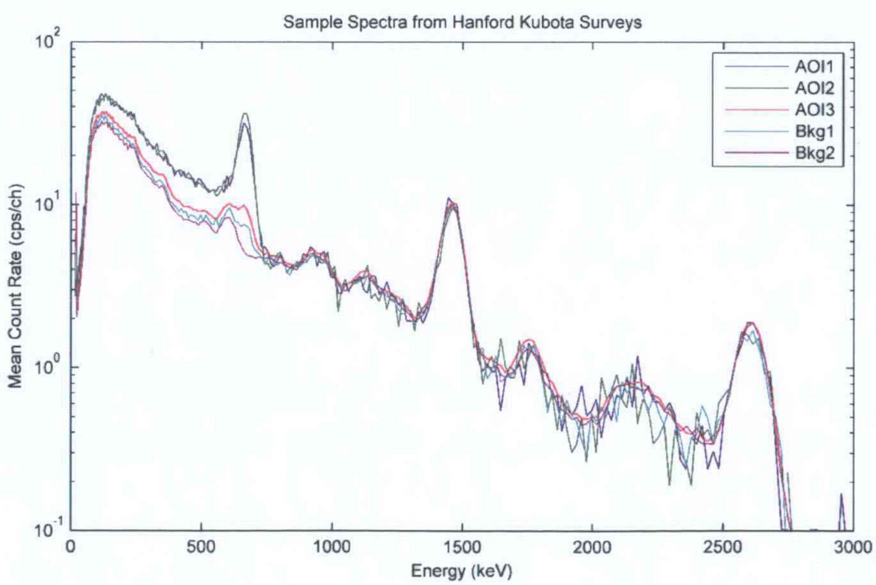


Figure 19. *Gross Spectra (Backgrounds and AOIs)*

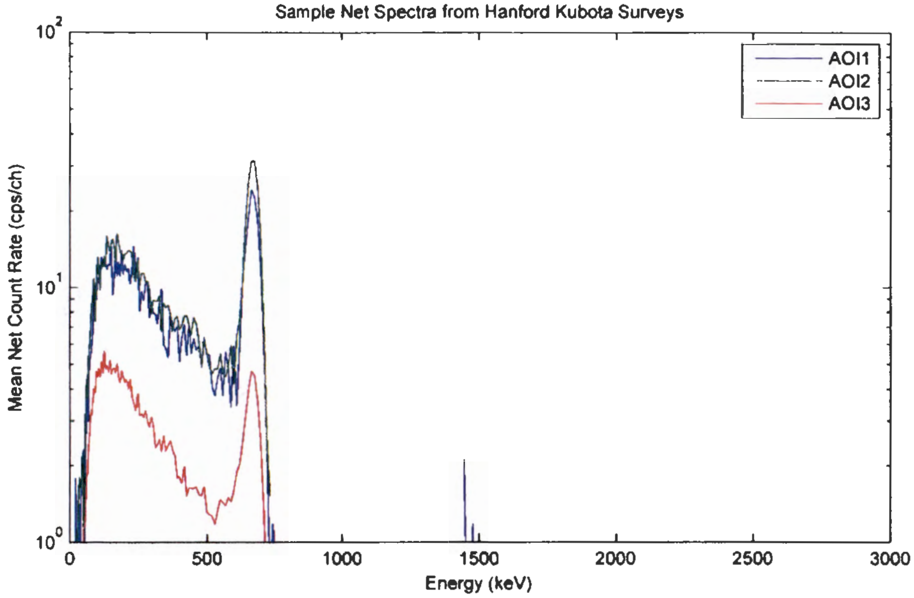


Figure 20. *Net spectra of areas of interest from Figure 19*

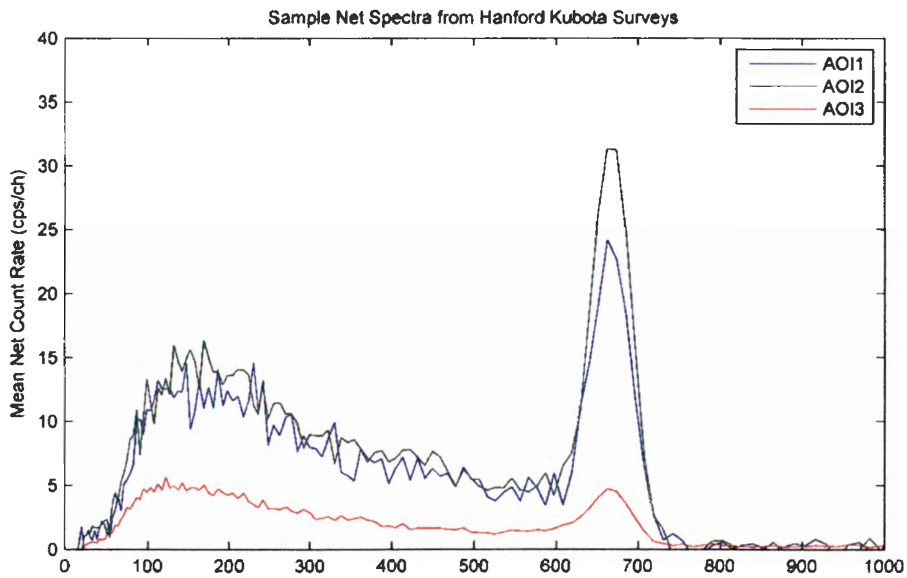


Figure 21. *Expanded view of net spectra of AOIs from Figure 20*

4.4.2 Kubota Cesium-137 Volumetric Activity (pCi/g) Point Data Maps

The analysis procedures used for the Kubota data were identical to those used for the Kiwi data. The total number of data points processed was almost double due to the slower speed and tighter line spacing used for the Kubota system. The summed data product in Figure 22 is consistent with the equivalent Kiwi map products.

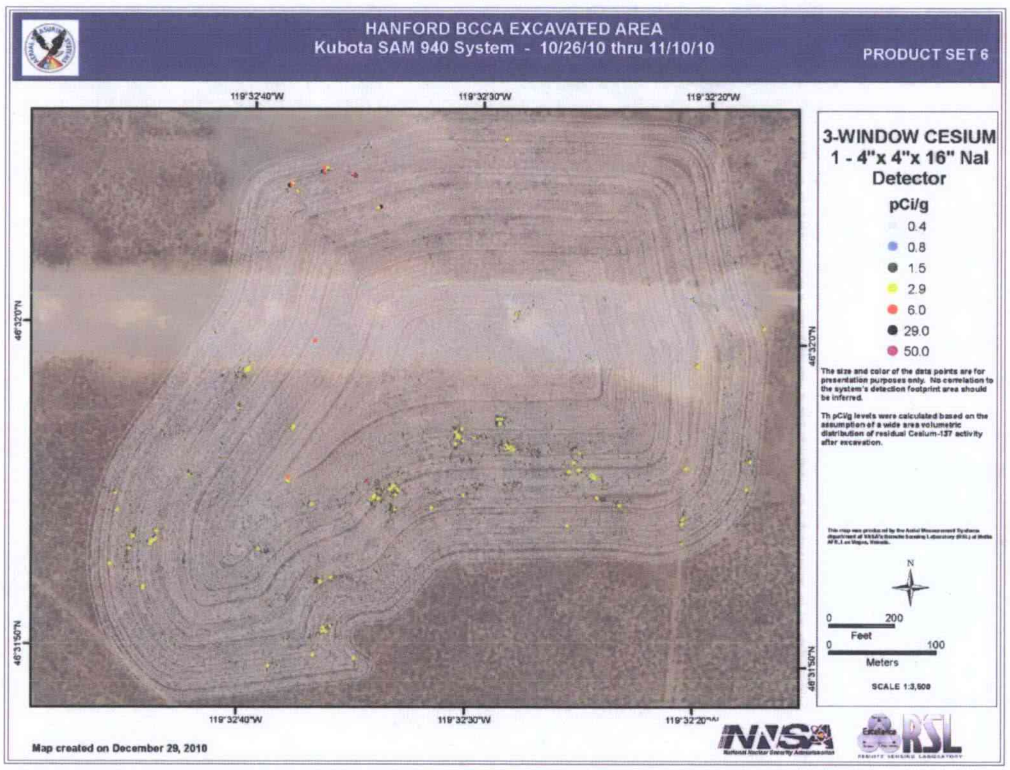


Figure 22. *Kubota Cs-137 volumetric activity results for the survey area*

5.0 High Purity Germanium In-situ Measurement Results

The HPGe In-situ measurements were 20 minutes in duration except for two of 60 minute duration. Although the calibration and volumetric activity conversions for this system were conducted under procedures unique to an in-situ system, the Cs-137 results are similar to the vehicle system results except for one location. That one location over the clean-up level was first identified by the Kiwi and Kubota systems after the man- made gross count analysis was completed. The MMGC analysis and CS-137 conversion indicated that the "hot spot" was buried contamination. The HPGe was used to evaluate the Cs-137 peak and Compton scatter to estimate the depth. The in-situ measurement indicated a location above the clean-up level as expected. The average depth of the "hot spot" activity was greater than the 15-cm criteria used for the default pCi/g calculations. The project decided to include the location for removal although it was deeper than the other "hot spot" locations at less than the 15-cm criteria (Figure 23).

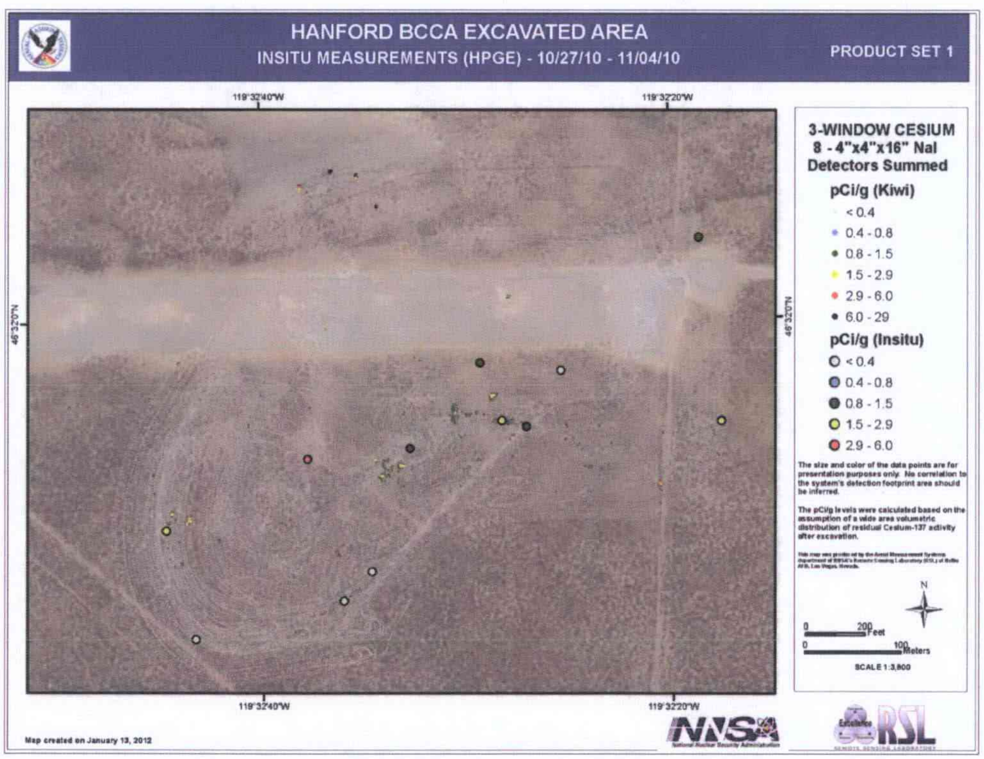


Figure 23. *HPGe Cs-137 Results*

6.0 Kubota Survey Results After Hot Spot Removal

During the week of January 10th 2011, 5 of the identified red spots (2.9 to 6.0 pCi/g) and 4 of the yellow spots (2.0 to 2.9 pCi/g) provided to the customer in a preliminary 2010 Kiwi survey data set were excavated. The size and depth of excavations varied from hotspot to hotspot, with the depths typically 12 to 18 inches (30 to 45 cm). The equipment used has a nominal depth of 12 inches (30 cm) per excavation pass through the soil column. Portable NaI detectors were used during the hotspot removal to provide an indication of when excavation was complete. On January 12th and 18th, the Hanford Kubota with the 4"×4"×16" NaI detector log re-surveyed these hotspots. Several passes were made over each hotspot hole following standard 3 to 4 mph survey protocol.

Figures 24 and 25 are the results of the removal activities. Figure 24 shows the locations of the limited surveys and the path of the Kubota between locations. Figure 25 is the revised map product with the "hot spot" removal data results replacing the previous Kubota survey results.

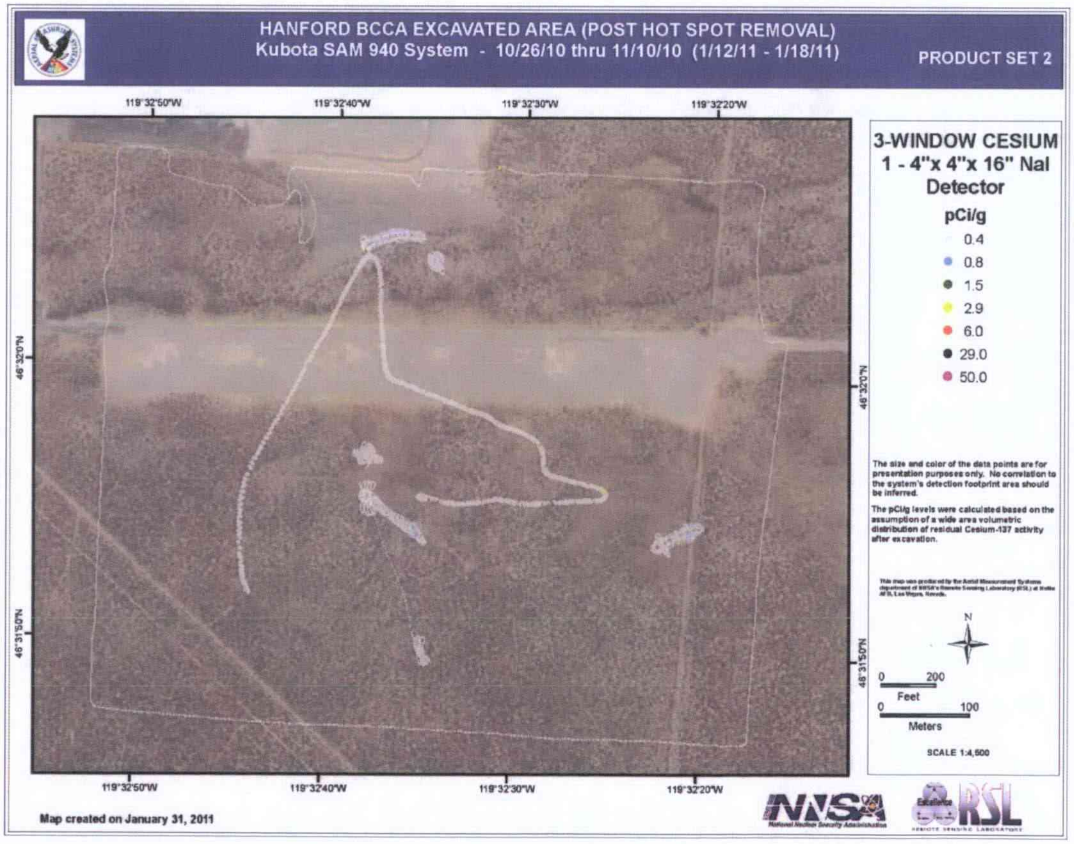


Figure 24. Kubota Cs-137 Hot Spot Removal Surveys

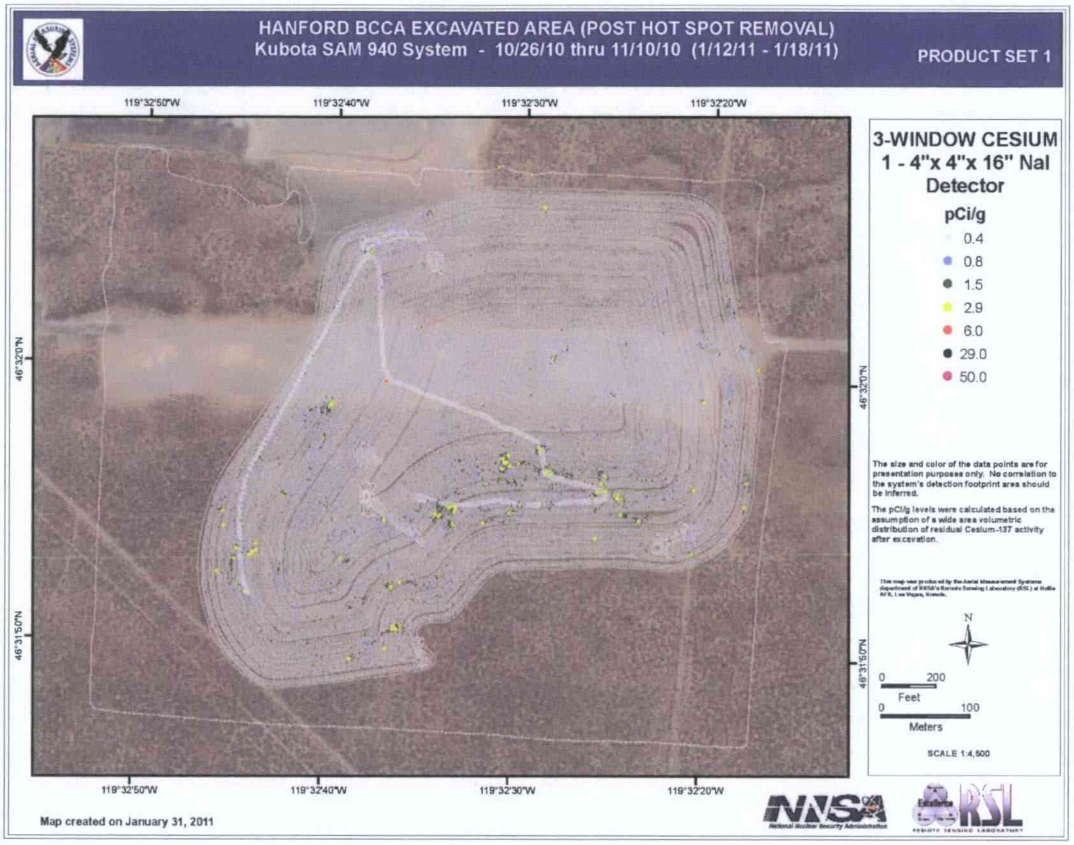


Figure 25. *Kubota Cs-137 Consolidated Results (Jan. 18, 2011)*

7.0 Data Management

The map products used for this report are just one of data presentation formats of the data produced during the various phases of this project. As discussed in Section 6 of this report, the excavation process continues at the BCCA site. To utilize the Kiwi and Kubota data effectively, the project has tasked RSL and their own HNR GIS staff to use shape files as the primary method to plan and review excavation and "hot spot" removal activities. As discussed, the image files produced for this survey report are documentation of the analysis procedures used and the consolidated results. The shape files contain the point data results and location information crucial for continuing operations. RSL will continue to produce shape files, create map products and store all survey data in support of this project.

8.0 Conclusions

1. SAM 940/Kubota Characterization – The survey system and vehicle meet the minimum requirements preset for the project's clean-up level sensitivity for residual Cs-137 in the soil. However, due to the non-synchronous data recording with the GPS clock, the system's point data accuracy will be reduced at higher vehicle speeds. In addition, the automatic calibration function does appear to occasionally produce different gross count background rates in the same area. This anomaly can be rectified during post-survey data processing.
2. Zone B (Candidate Reference Area) Survey Results – As illustrated in Section 4.1, the Zone B area chosen as a potential area for the Kiwi and Kubota reference area contained numerous Cs-137 small areas of elevated activity ("hot spots"). The majority of the highest Cs-137 counts in the spectra qualified as "hot spots" with 1-2 seconds of high activity with a substantial drop-off to low spectra counts along the drive path. As the Kubota breadcrumbs in the map product also indicate, the area has not been remediated and it is difficult to drive in a repeatable pattern with constant line spacing. Therefore, the area is not suitable as a reference area.
3. The gross count results and man-made gross count results for both systems show that the background gross count levels are very consistent throughout the survey site absent the contribution of Cs-137 activity to the data. The gross count results were very consistent day-to-day indicating no significant radon contributions during the surveys.
4. The man-made spectral analysis confirms Cs-137 as the only man-made gamma-emitting radionuclide within the survey area. There was no high count spectral distortion affecting identification of Cs-137.
5. The Cs-137 spectra count data indicated six "hot spots" that exceeded the projected clean-up level. Subsequent field investigation of the locations confirmed that the majority of the radioactivity was confined to an area less than 1 m^2 for each anomaly.
6. As of this report date, five of the hot spots and four other areas approaching the 2.9 pCi/g clean-up level have been removed and Kubota verification surveys completed.
7. The data product emphasis continues to be on the creation and updates of shapefiles for the project to use for planning.

9.0 References

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

Survey Site:	**BCCA**
Survey Coverage:	67 Acres (271,082 m^2)
Survey Date:	October 2010
Survey Altitude:	28 inches (71 cm)
Aircraft Speed:	4 knots (2 meters per second)
Line Spacing:	8 feet (2.4 meters)
Navigation System:	Trimble DGPS (WAAS corrections) differential
Line Direction:	Circular
Detector Configuration:	Eight 4″ × 4″ × 16″ NaI(T*l*) detectors ADC0= 2 NaI detectors ADC1= 2 NaI detector ADC2= 2 NaI detectors ADC3= 2 NaI detectors
Acquisition System:	REDAR-V
Conversion Factors:	0.0025 pCi/g per 1-cps Cs-137 net photopeak
Air Attenuation Coefficient:	Not Applicable
Vehicle:	Ford F-250 – "Kiwi"
Federal Team Lead	Joe Ginanni
Project Management:	Karen McCall Elaine Hawkins
Project Scientist:	Craig Lyons
In Situ Scientist	Colin Okada
Data Scientist:	Thane Hendricks
Data Analyst:	Sonia Bonilla
Electronic Technicians:	Mike Lukens Mike LeRoy

Appendix B
Kubota Survey Parameters

Survey Site:	**BCCA**
Survey Coverage:	67 Acres (271,082 m^2)
Survey Date:	October-November 2010
Survey Altitude:	14 inches (35 cm)
Aircraft Speed:	2 knots (1 meter per second)
Line Spacing:	5 feet (1.5 meters)
Navigation System:	DGPS
Line Direction:	Circular
Detector Configuration:	One 4″ × 4″ × 16″ NaI(T*l*) detector
Acquisition System:	SAM 940
Conversion Factors:	0.01875 pCi/g per 1-cps Cs-137 net photopeak
Air Attenuation Coefficient:	Not Applicable
Vehicle:	Kubota ATV – "Crawler"
Federal Team Lead	N/A
Project Management:	Randy Hermann – CH2MHill
Project Scientist:	John Stamper- CH2MHill
Data Scientist:	Thane Hendricks-RSL
Data Analyst:	Jez Stampahar-RSL
Electronic Technicians:	N/A

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