United State Environmental Protection Agency

Office of Emergency Management
National Decontamination Team
Erlanger, Kentucky 41018

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Spokane Tribe of Indians
Airborne Radiological Surveys
Spokane, WA

National Decontamination Team

John Cardarelli II PhD CHP CIH PE
Mark Thomas, PhD
Paul Kudarauskas, MS
Timothy Curry MS

Dynamac Contract Support:

Robert Kroutil PhD
Jeff Stapleton MS
Kelly Smith

Arrae, Inc. Contract Support:

Paul Fletcher
Beorn Leger
Rich Rousseau
Michael Scarborough

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Executive Summary

From September 17 through September 22, 2011, the EPA Aerial Spectrophotometric Environmental Collection Technology (ASPECT) program conducted aerial surveys of nearly 40 square miles of land near Spokane, Washington. This area of Washington was mined for Uranium ore from the 1950s until the 1980s. The aerial survey was conducted to determine if residual contamination was present. The survey included both radiological and photographic surveys of areas that were formerly uranium mines and areas adjacent to the former mines. Several radiological analyses were conducted and nearly 800 aerial photographs of the area were taken.

Roughly 25,000 one-second spectra were collected and analyzed for exposure rate, equivalent uranium (eU) concentration and statistical analysis (sigma plot). Radiological analysis results indicate the following:

- Three distinct areas had exposure levels that exceeded 25 μR/h. These were the Midnite Mine, Sherwood Mine and Dawn Mill areas.
- Of the nearly 25,000 data points taken 733 indicated eU in excess of 2 standard deviations from the normal background (mean), while 84 were greater than 4 standard deviations and 42 were greater than 6 standard deviations from the mean value.
- All of the data above 6 standard deviations from the mean were located at the Midnite Mine or at Dawn Mill.
- Of the 42 data points between four and six sigma, 35 were located at Midnight Mine or Dawn Mill. There were also points found in the McCoy Lake area, East Sherwood, Martha Boardman East (2), and the New House area.
- Two of the seven points of potential interest are likely due to the extremely challenging terrain in the area and are not associated with elevated eU concentrations. One of these is located on “The Farm”, the other in South Martha Boardman 2.

Approximately 600 downward looking aerial and 200 oblique aerial photographs were taken over the entire survey area. These photos are meant to record the actual conditions of the site at the time of the survey and may indicate differences from the standard Google Earth images. All imagery, including radiological data and digital photos are available for viewing in the Google Earth application.

Access to the electronic data is available by contacting Ellie Hale, Region 9.

Acronyms and Abbreviations

AGL	above ground level
ASPECT	Airborne Spectral Photometric Environmental Collection Technology
Bi	bismuth
Ci	Curie
cps	counts per second
EPA	Environmental Protection Agency
eU	Equivalent Uranium based on ^{214}Bi region of interest
FOV	Field of view
ft	feet
FT-IR	Fourier Transform Infrared detector
FWHM	full width at half maximum
g	gram
GEM	Gamma Emergency Mapper
GPS	Global Positioning System
IR	Infrared
K	potassium
MeV	Mega electron volts
NaI(Tl)	sodium iodide thallium drifted detector
NORM	Naturally Occurring Radioactive Material
pCi	picocurie (10^{-12} Curies)
R	Roentgen
Ra	radium
Rn	radon
TENORM	technologically enhanced naturally occurring radioactive material
Th	thorium
Tl	thallium
U	uranium
μR/hr	microRoentgen per hour (10^{-6} R/hr)

1.0 Introduction

The purpose of the radiological survey was to identify areas of elevated surface uranium contamination. While subsurface concentrations of gamma-emitting isotopes can be detected by the instrumentation, self- shielding of the ground limits its effective detection to a depth of about 30 centimeters.[1]

2.0 Background and Survey Area Descriptions

In 2007, EPA Region 9 began a project in coordination with the Spokane Tribal Nations to conduct radiation surveys on the Spokane Indian Reservation which is located approximately 30 miles northwest of Spokane, Washington. The survey area comprised approximately 40 square miles and includes the former Midnite Mine, the Dawn Mill, and the Sherwood Mine.

The Midnite Mine is located in the Selkirk Mountains, about eight miles from Wellpinit, Washington. The Sherwood mine is located a few miles south of the Midnite Mine while the Dawn Mill is located 25 miles to the east.

The Midnite Mine deposit was discovered in 1954 on the Spokane Indian Reservation. The uranium was contained in autunite, uraninite, and coffinite, with gangue minerals pyrite and marcasite deposits.

The mine was operated from 1955 until 1981 by Dawn Mining Company (DMC). DMC is a subsidiary corporation owned by Midnite Mines, Inc., and Newmont Gold, Inc. The property is leased by DMC from the Spokane Tribe and individual tribal members. The leases are administered by the United States Bureau of Indian Affairs (BIA).

Uranium ore was transported from Midnite Mine to Dawn's Mill, some 25 miles east of the mine, just outside the reservation boundary. Mining operations produced approximately 2.9 million tons of ore averaging 0.2 percent uranium oxide over the life of the mining operations.

The Midnite Mine is currently inactive and contains two open pits and backfilled pits. It was listed as a Superfund site on May 11, 2000. Approximately 2.4 million tons of stockpiled ore (containing approximately 2 million pounds of uranium oxide) and 33 million tons of waste rock also remain creating elevated levels of radioactivity.

The final cleanup plan for the site was issued September 29, 2006 and called for a cap over the area of pits filled with waste during mining, consolidation and engineered containment of remaining waste in the two open pits, removal of water entering the pits, and operation of a treatment system to treat contaminated water from the pits and seeps.

Image 1 below depicts the area of the aerial survey conducted for this report.

Image 1: Survey flight lines for the Spokane Reservation radiological survey

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3.0 Flight Parameters

Image 2: The ASPECT aircraft

The ASPECT aircraft used the following flight procedures for data collection on September 17th through September 22nd, 2011:

Altitude above the ground level (AGL):

- 500 feet for radiological survey
- 5,000 feet for photography

Target Speed: 120 knots (115 mph)

Line Spacing:

- 500 feet for radiological survey
- 3,000 feet for photographic survey

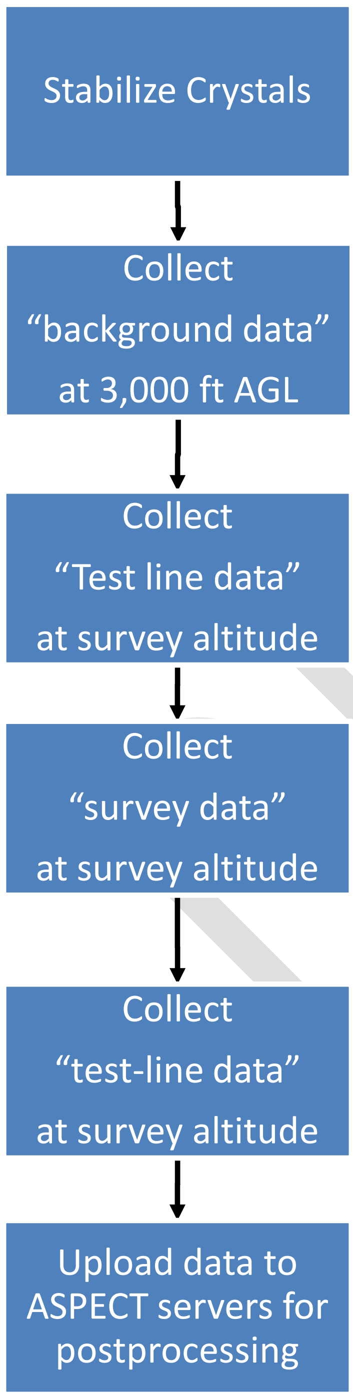
Data collection frequency:

1 per second for radiological survey

The survey areas contained 330 flight lines spaced 500 feet apart as depicted in image 1.

4.0 Data Analysis

Aerial gamma spectroscopy analysis has several distinctive considerations that must be addressed in order to obtain an accurate and meaningful product. Due to the unique interactions of gamma rays with matter, special techniques are used to process the data. This is especially true when surveying for naturally occurring radioactive materials (NORM) such as the uranium which is the focus of this survey. For a uranium survey, care must be taken to account for the background levels of uranium and this process is described in Appendix I. Also, due to the relatively weak gamma emissions from uranium (and some other radionuclides), it is generally preferable to look at the more intense emissions from daughter radionuclides further down the decay chain. Appendix II depicts the decay chain series for uranium. As an example, ASPECT typically analyzes for Bi-214 (a daughter) instead of uranium. However, care must be taken to ensure that the daughter radionuclides remain in equilibrium. Appendix III details the equilibrium considerations in aerial spectroscopy.



Several environmental factors, such as moisture, may significantly affect the detector response. Specifically, precipitation disturbs the equilibrium of the uranium decay chain and soil moisture actually shields some of the gamma rays and prevents them from reaching the detectors. There are several similar considerations that are discussed in Appendix III. Additional information is also available on the ASPECT detector types and capabilities in Appendix IV.

A unique feature of the ASPECT chemical and radiological technologies includes the ability to process spectral data automatically in the aircraft with a full reach back link to the program QA/QC program. As data is generated in the aircraft using the pattern recognition software, a support data package is extracted by the reach back team and independently reviewed as a confirmation to data generated on the aircraft.

Radiological spectral data are collected every second along with GPS coordinates and other data reference information. These data are subject to quality checks within the Radiation Solutions internal processing algorithms (e.g. gain stabilization) to ensure a good signal. If any errors are encountered with a specific crystal during the collection process, an error message is generated and the data associated with that crystal are removed from further analyses.

Prior to the survey, the RSX-4 units go through a series of internal checks. If no problems are detected, a green indicator light notifies the user that all systems are good. A yellow light indicates a gain stabilization issue with a particular crystal. This can be fixed by waiting for another automatic gain stabilization process to occur or the user can disable the particular crystal via the RadAssist Software application. A red light indicates another problem and would delay the survey until it can be resolved. The data collection process used for this survey is described below.

When powered up, the crystals go through an automated gain stabilization process. The process uses naturally occurring radioelements of potassium, uranium, and thorium to ensure proper spectral data collection.

The "background data" include radiation contributions from radon, cosmic, and aircraft sources. It does not include terrestrial radiation. Ideally, these data are collected over water at the survey altitude but when a large body of water does not exist, research has shown that an acceptable alternative is to collect data 3,000 ft above the ground (AGL).1 At this altitude atmospheric attenuation reduces the terrestrial radiation to a negligible level but is still low enough that cosmic radiation is not significant.

A "test line" is flown at survey altitude (usually 300 or 500 feet AGL) near the survey area. The line is not expected to contain any elevated concentrations of naturally occurring radioactive material (NORM) or man-made radionuclides. A second line is flown at the conclusion of the survey. If the difference between these lines exceeds 10 percent, then the survey data are corrected using a time-dependent linear interpolation correction factor.

Two software packages were used to generate products for this survey. The first was RadAssist Version 3.18.2.0 (Radiation Solutions, Inc., 386 Watline Avenue, Mississauga, Ontario, Canada) which produced contour plots of:

(1) **total count rate** (counts per second),
(2) **exposure rate** (microRoentgen per hour),
(3) **concentration contours for eU (equivalent uranium)** (pCi/g).

The second software package was ENVI® Version 4.8; ASPECT Version 8.6.8.0, Build 1107221901 (ITT Visual Information Solutions, Boulder, CO) which produced:

(4) **excess uranium** sigma point plots showing locations where ^{214}Bi was out of balance with the surrounding environment.

RAD Assist Method

↓

Live time correction

↓

Subtract cosmic and aircraft background contribution (coefficients)

↓

Radon contribution correction was not performed using RadAssist

↓

Perform stripping correction (ASPECT specific calibration coefficients were determined after these surveys)

↓

Perform height correction (μ=0.0050 m^{-1})

↓

Perform exposure rate conversion (determined after these surveys)

↓

Create contour plots
Exposure Rate (µR/h)
Uranium Concentration (pCi/g)

ENVI ASPECT Method

↓

Live time correction

↓

Subtract cosmic and aircraft background contribution (3,000 ft AGL)

↓

"Test Line" (determines "normal")
Height correction (μ=0.0017 m^{-1})
Calculate ^{214}Bi ROI K-value (median)

↓

Subtract radon contribution (Test Lines)

↓

Determine net count rate for ^{214}Bi and standard deviation (sigma value; σ)

↓

Determine Sigma Values
(<-6σ, -6 to -4; -4 to -2; -2 to 2; 2 to 4, 4 to 6, >6σ)

↓

Create excess Uranium point plots

Total count rate products illustrate gamma activity from all terrestrial sources after subtracting the "background data" contributions from radon, cosmic and aircraft sources. They can be used to assess the wide range of radioactivity present in the environment. The calibration coefficients were determined based on methodology published by the International Atomic Energy Agency.[3] Radon was accounted for by using data collected over water and then adjusting the land-based data by the levels measured over water. The flight over water also was used to develop a site-specific calibration correction factor for potassium, equivalent uranium/radium, and equivalent thorium concentrations.

Excess uranium sigma points were determined using an algorithm published by the DOE and incorporated into the ENVI EPA ASPECT software program. This algorithm is based on the assumption that natural background radioisotope contributions are stable over large geographical areas. This will result in a spectral shape that remains essentially constant over large count rate variations (Figure 1).

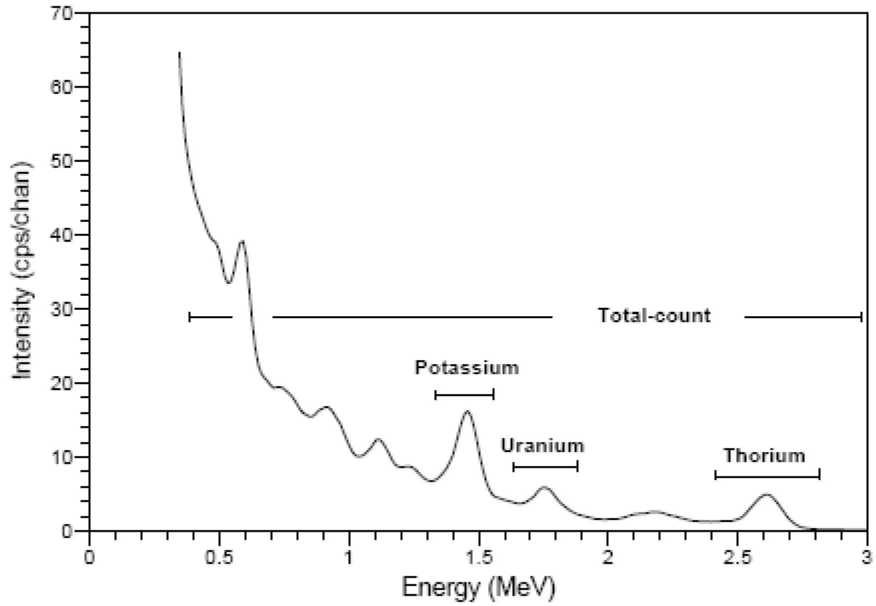


Figure 1: Typical airborne gamma ray spectrum showing positions of the conventional energy windows. *Adapted from IAEA-TECDOC-1363.*

To determine excess uranium count rate, the region-of-interest around ^{214}Bi (labeled uranium above, 1659 keV to 1860 keV) is compared to the region-of-interest (ROI) represented by nearly the entire spectrum, called the Total Count ROI (36 keV to 3,027 keV). The count rate ratio between these windows (e.g., Uranium ROI / Total Count Rate ROI) is relatively constant and is referred to as the "K" value. The actual windows (ROIs) are listed in Appendix V. A K-value was determined from the "test line" data collected before and after each survey. The median K-value (e.g., most common K-value) was used in the algorithm to determine excess thorium.

K-value = $\dfrac{\text{Count rate in } \textbf{\textit{target}} \text{ region-of-interest}}{\text{Count rate in "Total Count" region-of-interest}}$

Excess activity can be estimated using the following formula:

Excess U activity = **Measured** U activity **–** **Estimated** U activity

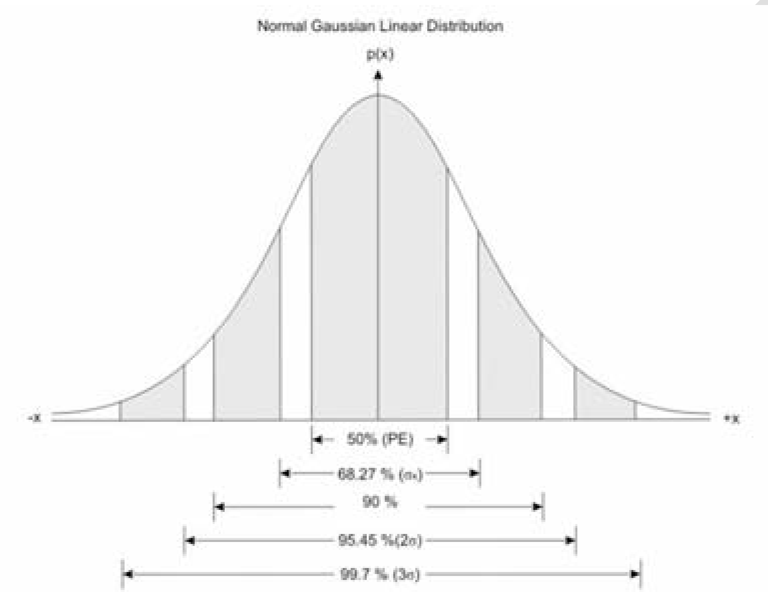
Where:

Measured U activity = the measured count rate within the **U** ROI during the survey

Estimated U activity = **K-value** * measured count rate in Total Count ROI during the survey
The equation for excess activity becomes:

EXCESS U = Measured U ROI – (K * Measured Total Counts ROI)

The most likely value of net "excess uranium" should be zero, and since radiological disintegrations are randomly occurring events, the second-by-second "excess U" results are statistically distributed about the mean in a normal Gaussian distribution (Figure 2).



Standard deviation (σ, sigma) represents the spread of the data about the mean. In this survey, the mean value (net "excess Th") was zero.

1 σ = 68.27% of the data
2 σ = 95.45% of the data
3 σ = 99.73% of the data
4 σ = 99.99366% of the data
5 σ = 99.99994% of the data
6 σ = 99.999999% of the data

Figure 2: Normal Gaussian Distribution and associated confidence intervals.

Every measurement was scored according to its "sigma" value and color coded according to the ranges in Figure 3. The color code and range were arbitrarily selected to limit the risk of false positives to 1 in about 15,800,000 samples (greater than or less than 6 sigma).

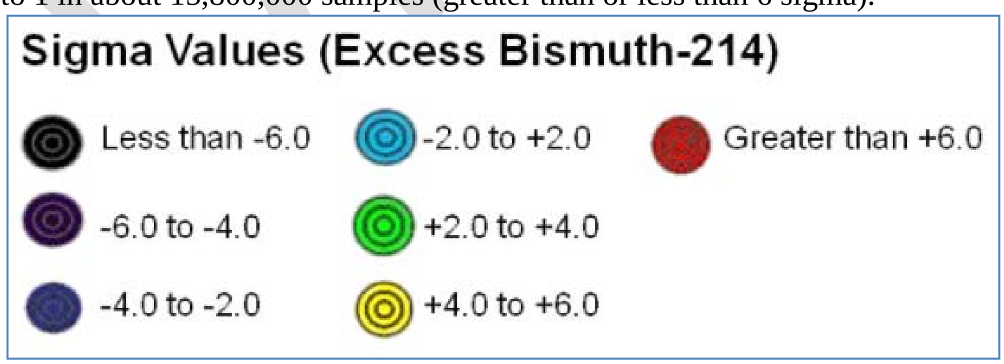


Figure 3: Standard Deviation Legend for Excess Uranium

5.0 Results

5.1 Radiological Results

ASPECT collected radiological and photographic information over the Spokane Reservation area from September 17-22, 2011. This survey covered nearly 40 square miles of land and consisted of about 25,000 data points. Radiological products included contour plots for exposure rate, and uranium concentration (Images 3 to 5) and excess uranium sigma plots, which represent the number of standard deviations from background (Image 6).

Since uranium is a naturally occurring radionuclide and is ubiquitous in nature, special analysis is required in order to determine whether the uranium that is detected is greater than the naturally occurring uranium concentrations. The analysis used is referred to as a sigma plot as discussed in section 4. Areas on a sigma plot with values greater than 4 are very likely to contain uranium or its decay products in concentrations greater than background, while values greater than 6 sigma almost certainly indicate above background levels for uranium and its decay products. Of the nearly 25,000 data points collected in this survey, 42 were greater than 4 sigma (standard deviations) from the mean value and an additional 42 points were greater than 6 sigma from the mean.

The following table summarizes the sigma plot results for excess uranium for the entire survey area. Fully 97 percent of the area surveyed was below the 2 sigma threshold. There was 2.6 percent of the surveyed area that fell between 2 and 4 sigma, while the areas between 4 and 6 sigma and those above 6 sigma were both 0.42 percent of the total. This translates to approximately 110 acres of area between the 4 and 6 sigma threshold and an additional 110 acres above the 6 sigma threshold. Approximately 665 acres fall between 2 and 4 sigma. Nearly 25,000 acres are below the 2 sigma values. Data above the 6 sigma threshold were located either near the Midnite Mine or the Dawn Mill. More than 80 percent of the data between 4 and 6 sigma were also associated with either Midnight Mine or Dawn Mill.

The table on the following page also indicates those elevated results that are likely the result of the local topography (canyons and valleys tend to cause the system to overestimate concentrations). Likely instances of this occurred both at “The Farm” and in “South Martha Boardman 2”.

Theimages on the pages that follow are summarized below:

Image Numbers	Image Description
3 - 11	Flight lines for radiological surveys
12 - 30	Exposure Rate contour maps
31 - 53	Equivalent Uranium (eU) contour maps
54 - 78	Sigma Plot maps

Comments	Flt. Block	Area	# Data	< 2 Sigma	> 2 Sigma	>4 Sigma	>6 Sigma
	1	Two Rivers	1836	1804	32	0	0
Area of potential interest.	2	Big Meadow	3210	3173	37	0	0
	3	McCoy Lake	3486	3438	47	1	0
All elevated readings associated with the mine.	4	Midnite Mine	1050	882	113	26	29
	5	Sherwood	1500	1497	3	0	0
	6	West Sherwood	715	715	0	0	0
	7	Cayuse	476	454	22	0	0
	8	Buffalo Pasture	35	35	0	0	0
	9	Wyncoop	406	381	25	0	0
Area of potential interest.	10	East Sherwood	869	828	40	1	0
	11	Wellpinit	1473	1451	22	0	0
	12	SW Wellpinit	710	702	8	0	0
	13	Longhouse	630	623	7	0	0
	14	S Martha Boardman	891	875	16	0	0
NE corner shows apparent topographic anomaly for eU contour. SW corner is an area of potential interest	15, 28	Farm + South Farm	895	867	27	1	0
	16	N Wellpinit	312	307	5	0	0
	17	Turtle Lake	84	81	3	0	0
	18	Cottonwood	103	103	0	0	0
	19	Little Chamokane Crossing	264	264	0	0	0
Area of potential interest.	20	Martha Boardman East	1890	1747	141	2	0
All elevated readings associated with the mill.	21	Dawn Mill	510	463	25	9	13
	22	Ford	330	330	0	0	0
	23	Moyer Pit	1190	1189	1	0	0
	24	Northeast Moyer Pit	448	432	16	0	0
Area of potential interest.	25	New House	480	466	13	1	0
	26	North Reservation Road	105	102	3	0	0
	27	Northeast Corner	322	320	2	0	0
Single point above 4 sigma likely due to topography.	30	S Martha Boardman 2	504	462	41	1	0
		Totals	24724	23991	649	42	42
				97.0%	2.6%	0.2%	0.2%

Notes: Flight block 28 data was combined with block 15 data for The Farm.
Flight block 29 was not required as data from adjacent flight blocks was used to characterize this area.

Image 3: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for Two Rivers, Big Meadow and McCoy Lake
Blocks 1 - 3
September 17-22, 2011

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Image 4: Spokane Tribe of Indians Airborne Radiological Survey
Flight lines for Midnite Mine, Sherwood Mine, Sherwood West and Cayuse Mountain
Blocks 4 – 7 September 17-22, 2011

(b)(4) copyright

Image 5: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for Buffalo Pasture, Wyncoop and East Sherwood
Blocks 8 - 10
September 17-22, 2011

(b)(4) copyright

Image 6: Spokane Tribe of Indians Airborne Radiological Survey
Flight lines for Wellpinit, Longhouse, S. Martha Boardman and The Farm,
Blocks 11 – 15, 28
September 17-22, 2011

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Image 7: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for N. Wellpinit, Turtle Lake and Cottonwood Road
Blocks 16 - 18
September 17-22, 2011

(b)(4) copyright

Image 8: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for Chamokane Crossing and Martha Boardman
Blocks 19 and 20
September 17-22, 2011

(b)(4) copyright

Image 9: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for Dawn Mill, Ford, Moyer Pit
Flight Blocks 21-24
September 17-22, 2011

(b)(4) copyright

Image 10: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for New House and Reservation Road
Flight Blocks 25-27
September 17-22, 2011

(b)(4) copyright

Image 11: Spokane Tribe of Indians Airborne Radiological Survey
Flight Lines for Flight Block 30
September 17-22, 2011

(b)(4) copyright

Image 12: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Two Rivers and Big Meadow
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (μr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern. See image 32 for isolated areas of excess uranium that may warrant additional investigation.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 13: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
McCoy Lake
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

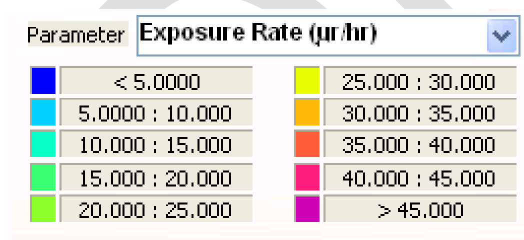
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 14: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Midnite Mine, Sherwood Mine and Sherwood West
September 17-22, 2011

(b)(4) copyright



Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Areas around the Midnite Mine in the northeast and Sherwood Mine in the south indicate elevated exposure rates. Images 41-43 can be consulted to better understand the uranium concentrations in these areas.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 15: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Cayuse Mountain, Buffalo Pasture, Wyncoop Landing and East Sherwood
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (μr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 16: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Wellpinit
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 17: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Southwest Wellpinit
September 17-22, 2011

(b)(4) copyright

Parameter Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 18: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Longhouse
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (μr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 19: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
South Martha Boardman
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (μr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 20: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
The Farm
September 17-22, 2011

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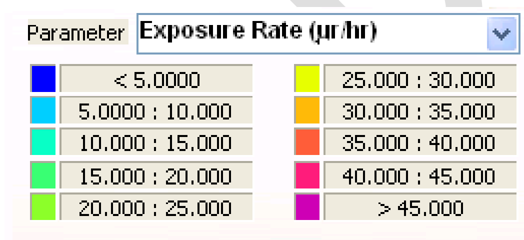


ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The area in the northeast corner of this survey is likely an anomaly due to rapid changes in topography.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 21: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
North Wellpinit
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 22: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Turtle Lake
September 17-22, 2011

(b)(4) copyright

Parameter Exposure Rate (μr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

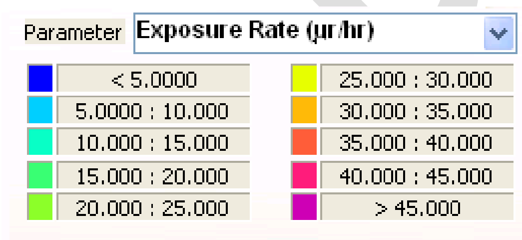
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 23: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Cottonwood
September 17-22, 2011

(b)(4) copyright



Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 24: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Chamokane Creek
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 25: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Martha Boardman
September 17-22, 2011

(b)(4) copyright

Parameter Exposure Rate (μr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

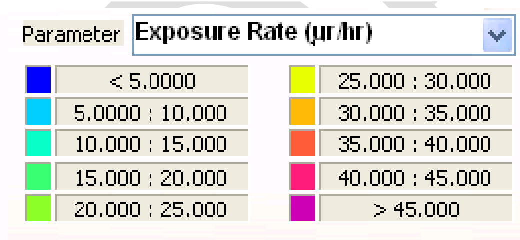
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 26: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Dawn Mill
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Slightly elevated exposure rates were noted in the Dawn Mill area.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 27: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Ford
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 28: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Moyer Pit
September 17-22, 2011

(b)(4) copyright

Parameter Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 29: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
Northeast Moyer Pit, New House, Reservation Road
September 17-22, 2011

(b)(4) copyright

Parameter: Exposure Rate (µr/hr)

< 5.0000	25.000 : 30.000
5.0000 : 10.000	30.000 : 35.000
10.000 : 15.000	35.000 : 40.000
15.000 : 20.000	40.000 : 45.000
20.000 : 25.000	> 45.000

ASPECT Program

Flight Parameters

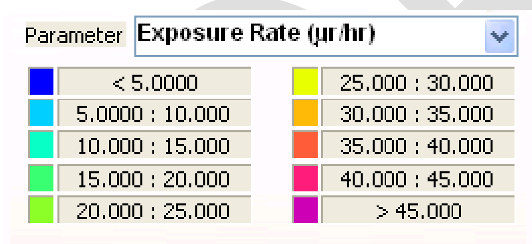
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 30: Exposure Rate Contour
Spokane Tribe of Indians Airborne Radiological Survey
South Martha Boardman 2
September 17-22, 2011

(b)(4) copyright



<u>Flight Parameters</u>

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 31: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Two Rivers and Big Meadow
September 17-22, 2011

(b)(4) copyright

The areas along the southeast edge of the Two Rivers area indicate several regions of slightly elevated uranium concentrations that may warrant further investigation

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 32: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
McCoy Lake
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

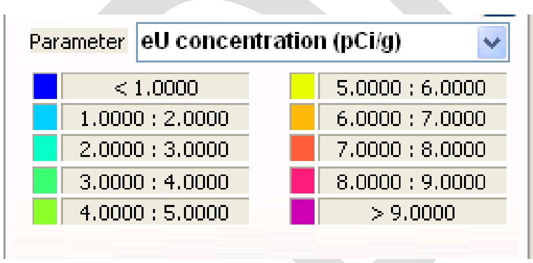
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 33: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Midnite and Sherwood Mines
September 17-22, 2011

(b)(4) copyright



Flight Parameters

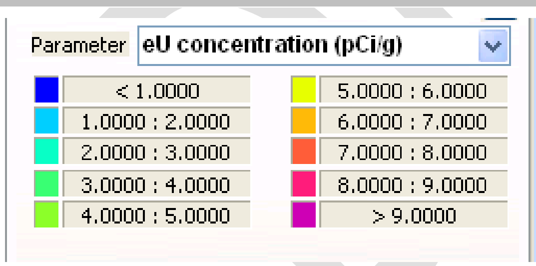
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Uranium concentrations are elevated in both the Midnite Mine and Sherwood Mine areas. Encircled areas are enlarged in the following pictures to show greater detail for these regions.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 34: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Sherwood Mine
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Enlarged view of the elevated uranium concentration contours surrounding the Sherwood Mine.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 35: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Midnite Mine
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

UNITED STATES EPA ENVIRONMENTAL PROTECTION AGENCY NATIONAL DECON TEAM EMERGENCY RESPONSE

ASPECT Program

Flight Parameters

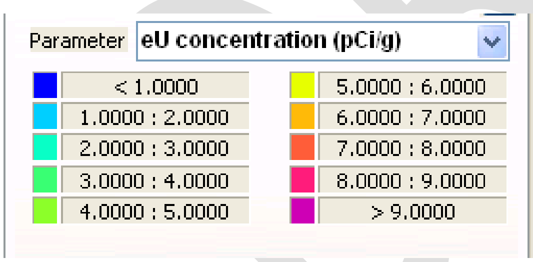
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Enlarged view of the elevated uranium concentration contours surrounding the Midnite Mine.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 36: Equivalent Uranium (eU) Contour
Cayuse Mtn., Buffalo Pasture, Wyncoop Landing
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 37: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Wellpinit
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 38: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Southwest Wellpinit
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

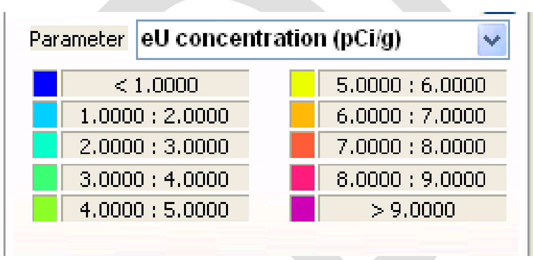
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 39: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Longhouse
September 17-22, 2011

(b)(4) copyright



Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 40: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
South Martha Boardman
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

UNITED STATES EPA ENVIRONMENTAL PROTECTION AGENCY NATIONAL DECON TEAM EMERGENCY RESPONSE

ASPECT Program

Flight Parameters

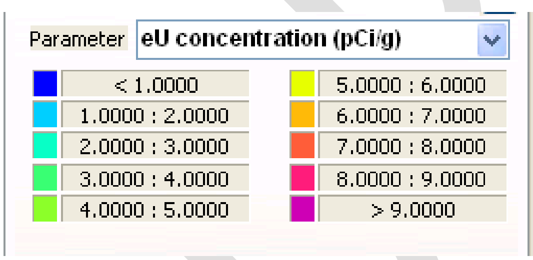
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 41: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
The Farm
September 17-22, 2011

(b)(4) copyright



Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The elevated concentration contour in the northeast corner of this parcel is due to topography issues in the survey.

The elevated concentrations in the westernmost portions of the area are not explained by topography and may warrant further investigation.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 42: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
North Wellpinit
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 43: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Turtle Lake
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

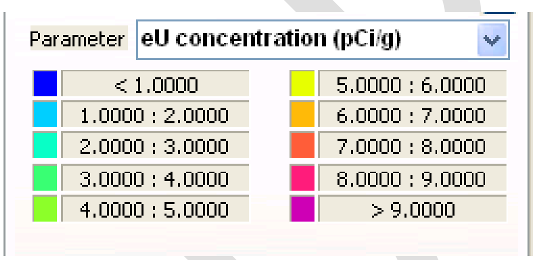
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 44: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Cottonwood Road
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

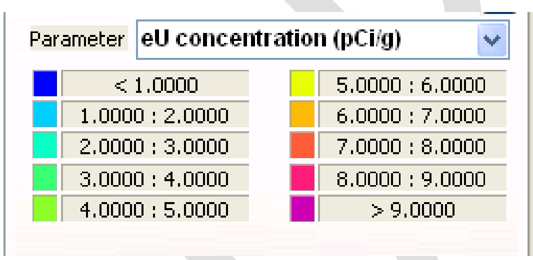
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 45: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Chamokane Crossing
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

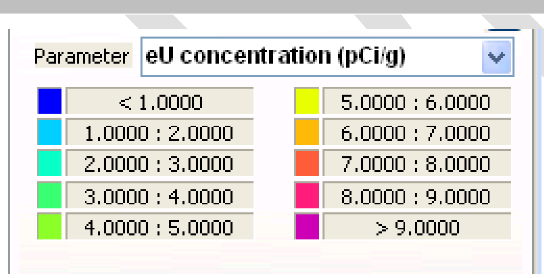
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 46: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Martha Boardman
September 17-22, 2011

(b)(4) copyright



Flight Parameters

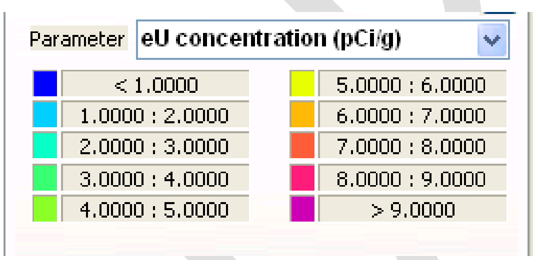
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

A few areas in the southern end of this survey block may warrant additional investigation.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 47: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Dawn Mill
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Uranium concentrations are elevated in the Dawn Mill area.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 48: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Ford
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 49: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Moyer Pit
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 50: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
New House, North Moyer Pit, North Reservation Road
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

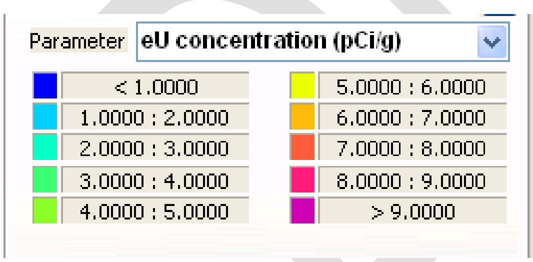
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 51: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
Northeast Corner
September 17-22, 2011

(b)(4) copyright



<u>Flight Parameters</u>

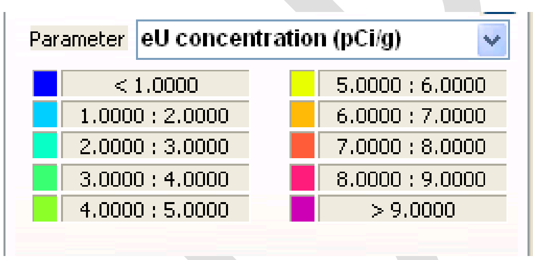
500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 52: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
South Martha Boardman 2
September 17-22, 2011

(b)(4) copyright



ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The northernmost area of South Martha Boardman 2 is a potential topographic artifact.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 53: Equivalent Uranium (eU) Contour
Spokane Tribe of Indians Airborne Radiological Survey
South Martha Boardman (2),
September 17-22, 2011

(b)(4) copyright

Parameter: eU concentration (pCi/g)

< 1.0000	5.0000 : 6.0000
1.0000 : 2.0000	6.0000 : 7.0000
2.0000 : 3.0000	7.0000 : 8.0000
3.0000 : 4.0000	8.0000 : 9.0000
4.0000 : 5.0000	> 9.0000

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The northernmost area of South Martha Boardman 2 is a potential topographic artifact.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 54: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Two Rivers
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

Less than -6.0
-6.0 to -4.0
-4.0 to -2.0
-2.0 to +2.0
+2.0 to +4.0
+4.0 to +6.0
Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern. Image 31 in the equivalent Uranium section indicates two areas bordering the river that may be of potential concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 55: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Big Meadow
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 56: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
McCoy Lake
September 17 - 22, 2011

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data indicates one area of potential concern. The encircled area is enlarged in the subsequent image to show additional detail.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 57: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
McCoy Lake
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The southwest corner of the McCoy Lake flight block contains a single point above 4 sigma. This area may warrant additional investigation.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 58 - Excess Uranium Sigma Plot
Midnite Mine and Sherwood Mine
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The uranium sigma plot indicates that there are elevated levels in the Midnite Mine area. The following image is enlarged to show greater detail for these regions.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 59 - Excess Uranium Sigma Plot
Midnite Mine
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

Less than -6.0
-6.0 to -4.0
-4.0 to -2.0
-2.0 to +2.0
+2.0 to +4.0
+4.0 to +6.0
Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Elevated data points in the area around Midnight Mine.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 60 - Excess Uranium Sigma Plot
Cayuse Mountain, Buffalo Pasture, East Sherwood and Wyncoop Landing
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern

.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 61 - Excess Uranium Sigma Plot
Wellpinit
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 62: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Southwest Wellpinit
September 17 - 22, 2011

(b)(4) copyright

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 63: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Longhouse
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 64: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
South Martha Boardman
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 65: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
The Farm (+South)
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data indicate an area of potential concern in the western edge of the farm flight block. This area is enlarged for great detail in the next image.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 66: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
The Farm
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

A single data point in the Southwest corner of the Farm has excess uranium above the four sigma level and may warrant additional investigation.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 67: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
North Wellpinit
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 68: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Turtle Lake
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 69: Cottonwood Road
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 70: Excess Uranium Sigma Plot
Chamokane Creek Crossing
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 71: Excess Uranium Sigma Plot
Martha Boardman
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data indicate two areas of significant concern.in the southeast corner of the survey area. The next image shows an enlarged view of the area.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 72: Excess Uranium Sigma Plot
Martha Boardman
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

Less than -6.0	-2.0 to +2.0	Greater than +6.0
-6.0 to -4.0	+2.0 to +4.0	
-4.0 to -2.0	+4.0 to +6.0	

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 73: Excess Uranium Sigma Plot
Dawn Mill, Ford, Moyer Pit
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

Less than -6.0
-6.0 to -4.0
-4.0 to -2.0
-2.0 to +2.0
+2.0 to +4.0
+4.0 to +6.0
Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The Dawn Mill area indicates an area of elevated uranium levels. The subsequent image is enlarged to show the affected area in detail.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 74: Excess Uranium Sigma Plot

Dawn Mill
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The Dawn Mill area excess uranium is detailed at higher resolution in this image.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 75: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Northeast Moyer Pit, Reservation Road, New House
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

A single point above the 4 sigma threshold is noted in the northeast area of the survey blocks. The encircled area is enlarged in the following image.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 76: Excess Uranium Sigma Plot
New House
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

Less than -6.0
-6.0 to -4.0
-4.0 to -2.0
-2.0 to +2.0
+2.0 to +4.0
+4.0 to +6.0
Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

A single point above the 4 sigma value may warrant additional investigation.

This image should not be used independently to assess potential health risks.
Additional information is necessary to make appropriate health-related decisions.

Image 77: Excess Uranium Sigma Plot
Spokane Tribe of Indians Airborne Radiological Survey
Northeast Corner
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

ASPECT Program

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

Data does not indicate any areas of significant concern.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

Image 78: Excess Uranium Sigma Plot
South Martha Boardman 2
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

Sigma Values (Excess Bismuth-214)

- Less than -6.0
- -6.0 to -4.0
- -4.0 to -2.0
- -2.0 to +2.0
- +2.0 to +4.0
- +4.0 to +6.0
- Greater than +6.0

Flight Parameters

500 ft altitude
500 ft line spacing
120 knots
1 second acquisition time

The point in the northern portion of the survey block is likely a topographic artifact arising from the rapidly changing elevation in the area.

This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related decisions.

4.2 Photographic Results

Approximately 300 high resolution digital aerial photographs were taken over the entire survey area (as depicted in Image 81). These photographs have been geo- and ortho-rectified for geospatial applications and are available to view within Google Earth. Each aerial photo provides coverage of about 350 acres with a pixel resolution of 15 inches. Image 82 is representative of the images that were collected during the survey. Access to the photographic imagery is available by contacting Lisa Price, Region 6.

Image 79: Digital Photo Outlines
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

The above image indicates the location of some of the nearly 600 downward looking digital photographs taken by the ASPECT aircraft on September 17-22, 2011. In addition, over 200 oblique photographs of various features were also taken. Oblique and downward looking photographs can all be viewed in the Google Earth software.

Image 80: Digital Images Spokane Reservation, Washington
September 17 - 22, 2011

(b)(4) copyright

(b)(4) copyright

Approximately 600 digital photographs were taken over the entire survey area. They have been geo-located for incorporation into Google Earth or other geospatial software applications. Digital photos are taken from the bottom of the aircraft and are located and georectified for topography. The outlined areas depict the coverage of the photograph. The digital photographs shown here are of Midnite Mine and Sherwood Mine. Access to the photos is available by contacting Ellie Hale, Region 9.

Image 81: Oblique Photo Tracks
Spokane Tribe of Indians Airborne Radiological Survey
September 17 - 22, 2011

(b)(4) copyright

ASPECT Program

Approximately 200 oblique photographs were taken over the entire survey area. They have been geo-located for incorporation into Google Earth or other geospatial software applications. Oblique photographs were taken out the right side of the plane at an angle consistent with the direction of the white arrows. The oblique photographs shown here are of Midnite Mine and Sherwood Mine. Access to the photos is available by contacting Ellie Hale, Region 9.

Appendix I

Background Radiation

Naturally occurring radioactive material (NORM) originates from cosmic radiation, cosmogenic radioactivity, and primordial radioactive elements that were created at the beginning of the earth. Cosmic radiation consists of very high energy particles from extraterrestrial sources such as the sun (mainly alpha particles and protons) and galactic radiation (mainly electrons and protons). Its intensity increases with altitude, doubling about every 6,000 ft, and with increasing latitude north and south of the equator. The cosmic radiation level at sea level is about 3.2 µR/h and nearly twice this level in locations such as Denver, CO.

Cosmogenic radioactivity results from cosmic radiation interacting with the earth's upper atmosphere. Since this is an ongoing process, a steady state has been established whereby cosmogenic radionuclides (e.g., ^{3}H and ^{14}C) are decaying at the same rate as they are produced. These sources of radioactivity were not a focus of this survey and were not included in the processing algorithms.

Primordial radioactive elements found in significant concentrations in the crustal material of the earth are potassium, uranium and thorium. Potassium is one of the most abundant elements in the Earth's crust (2.4% by mass). One out of every 10,000 potassium atoms is radioactive potassium-40 (^{40}K) with a half-life (the time it takes to decay to one half the original amount) of 1.3 billion years. For every 100 ^{40}K atoms that decay, 11 become Argon-40 (^{40}A) and emit a 1.46 MeV gamma-ray.

Uranium is ubiquitous in the natural environment and is found in soil at various concentrations with an average of about 1.2 pCi/g. Natural uranium consists of three isotopes with about 99.3% being uranium-238 (^{238}U), about 0.7% being uranium-235 (^{235}U), and a trace amount being uranium-234 (^{234}U). The tenth daughter product of ^{238}U, bismuth-214 (^{214}Bi), is used to estimate the presence of radium and uranium by its 1.76 MeV gamma-ray emission.

Thorium-232 is the parent radionuclide of one of the 4 primordial decay chains. It is about four times more abundant in nature than uranium and also decays through a series of daughter products to a stable form of lead. The thorium content of rocks ranges between 0.9 pCi/g and 3.6 pCi/g with an average concentration of about 1.3 pCi/g.[2] The ninth daughter product, thallium-208 (^{208}Tl), is used to estimate the presence of thorium by its 2.61 MeV gamma-ray emission.

Technologically enhanced naturally occurring radioactive material (TENORM) is NORM processed in such a manner that its concentration has been increased. TENORM is associated with various industries including energy production, water filtration, fertilizer production, mining and metals production. Concentrations of radionuclides in TENORM are often orders of magnitude greater than the naturally occurring concentrations. This survey was designed to identify areas where the TENORM concentrations were significantly higher than the natural background concentrations due to the mining and processing of uranium ore.

Appendix II

Uranium Decay Series, ^{238}U (4n+2)[†]

Nuclide[§]	Half-Life	α MeV	α %	β MeV	β %	γ MeV	γ %
		Major Radiation Energies (MeV) and Intensities[‡]					
$^{238}_{92}$U ↓	4.468 x 10^9 y	4.15 4.20	22.9 76.8			0.0496	0.07
$^{234}_{90}$Th ↓	24.1 d			0.076 0.095 0.096 0.1886	2.7 6.2 18.6 72.5	0.0633 0.0924 0.0928 0.1128	3.8 2.7 2.7 0.24
$^{234m}_{91}$Pa ↓	1.17 m			2.28	98.6	0.766 1.001	0.207 0.59
99.87% $^{234}_{91}$Pa ↓ 0.13% $^{234}_{91}$Pa IT ↓	6.7 h			22 βs E Avg = 0.224 Emax = 1.26		0.132 0.570 0.883 0.926 0.946	19.7 10.7 11.8 10.9 12.0
$^{234}_{92}$U ↓	244,500 y	4.72 4.77	27.4 72.3			0.053 0.121	0.12 0.04
$^{230}_{90}$Th ↓	7.7 x 10^4 y	4.621 4.688	23.4 76.2			0.0677 0.142 0.144	0.37 0.07 0.045
$^{226}_{88}$Ra ↓	1600 ± 7 y	4.60 4.78	5.55 94.4			0.186	3.28
$^{222}_{86}$Rn ↓	3.823 d	5.49	99.9			0.510	0.078
$^{218}_{84}$Po ↓	3.05 m	6.00	~100	0.33	0.02	0.837	0.0011
99.98% $^{214}_{82}$Pb ↓ 0.02% ↓	26.8 m			0.67 0.73 1.03	48.0 42.5 6.3	0.2419 0.295 0.352 0.786	7.5 19.2 37.1 1.1
$^{218}_{85}$At ↓	2 s	6.66 6.7 6.757	6.4 89.9 3.6			0.053	6.6

Uranium Decay Series, ^{238}U (4n+2)†

Nuclide§		Half-Life	Major Radiation Energies (MeV) and Intensities‡ α MeV	α %	β MeV	β %	γ MeV	γ %
$^{214}_{83}$Bi ↓		19.9 m	5.45	0.012	1.42	8.3	0.609	46.1
			5.51	0.008	1.505	17.6	1.12	15.0
					1.54	17.9	1.765	15.9
					3.27	17.7	2.204	5.0
99.979% $^{214}_{84}$Po ↓	0.021% ↓	164 µs	7.687	100			0.7997	0.010
↓	$^{210}_{81}$Tl ↓	1.3 m			1.32	25.0	0.2918	79.1
↓	↓				1.87	56.0	0.7997	99.0
	↓				2.34	19.0	0.860	6.9
	↓						1.110	6.9
	↓						1.21	17.0
	↓						1.310	21.0
							1.410	4.9
							2.010	6.9
							2.090	4.9
$^{210}_{82}$Pb ↓		22.3 y	3.72	0.000002	0.016	80.0	0.465	4.0
					0.063	20.0		
$^{210}_{83}$Bi ↓		5.01 d	4.65	0.00007	1.161	~100		
			4.69	0.00005				
~100% $^{210}_{84}$Po ↓	0.00013% ↓	138.378 d	5.305	100			0.802	0.0011
	$^{206}_{81}$Tl ↓	4.20 m			1.571	100	0.803	0.0055
$^{206}_{82}$Pb		Stable						

y	= Year	α	= alpha decay
d	= Day	β	= beta decay
h	= hour	γ	= gamma decay
m	= minute	IT	= Internal transition
s	= second	MeV	= million electron volts
µs	= microsecond (10^{-6} s)		

† This expression describes the mass number of any member in this series, where n is an integer. For example: ^{206}Pb (4n+2)...4(51) + 2 = 206.

‡ Intensities refer to percentage of disintegrations of the nuclide itself, not to original parent of series. Gamma %s in terms of observable emissions, not transitions.

Appendix III

Discussion about radiological uncertainties associated with airborne systems.

Ideally the airborne radiation measurements would be proportional to the average surface concentrations of radioactive materials (mainly NORM). However, there are several factors that can interfere with this relationship causing the results to be over- or under-estimated, as described below. Additionally, two other sections discuss how data are interpreted and airborne measurement data are compared to surface measurements.

Background radiation

Airborne gamma-spectroscopy systems measure radiation originating from terrestrial, radon, aircraft, and cosmic sources. To obtain only the terrestrial contribution, all other sources need to be accounted for (subtracted from the total counts), especially for this survey where small differences are important. Radon gas is mobile and can escape from rocks and soil and accumulate in the lower atmosphere. Radon concentrations vary from day to day, with time of day, with weather conditions (e.g., inversions and stability class), and with altitude. It is the largest contributor among background radiation and its daughter product, ^{214}Bi, is used to estimate radium and uranium concentration in the soil. Radon is accounted for in the processing algorithm by flying specific test lines before and after each survey and comparing the results. Cosmic and aircraft radiation (e.g., instrument panels and metals containing small amounts of NORM) also provide a small contribution to the total counts. These are accounted for in the processing algorithm by flying a “high-altitude” or “water-” test line and subtracting these contributions for the survey data.

Secular Equilibrium Assumption

Secular equilibrium is assumed in order to estimate thorium concentrations from one of its daughter products, ^{214}Bi. Secular equilibrium exists when the activity of a daughter product equals that of its parent radionuclide. This can only occur if the half-life of the daughter product is much shorter than its parent and the daughter product stays with its parent in the environment. In this case, the measurement of ^{214}Bi gamma emission is used to estimate the concentration of its parent radionuclide if one assumes all the intermediate radionuclides stay with each other. However, ^{222}Rn is a noble gas with a half-life of 3.8 day and may degas from soils and rocks fissures due to changes in weather conditions. Due to the relatively long half-life and the combined effect of radon gas mobility and environmental “chemical” migration, it is not certain whether the secular equilibrium assumption is reasonable. In addition, human intervention in this natural chain of events may have caused an increased uncertainty in uranium concentration estimates.

Atmospheric Temperature and Pressure

The density of air is a function of atmospheric temperature and pressure. Density increases with cooler temperatures and higher pressures, causing a reduction in detection of gamma-rays. This reduction in gamma-ray detection is called attenuation and it is also a function of the gamma-ray energy. Higher energy gamma-rays are more likely to reach the detectors than lower energy gamma-rays. For example, 50% of the ^{214}Bi 1.76 MeV gamma-rays will reach the detector at an altitude of 300 ft whereas only 44% of the ^{40}K 1.46 MeV gamma-rays will reach the detector.* Temperature and pressure changes contribute little to the overall uncertainties associated with airborne detection systems as compared to other factors.

Soil moisture and Precipitation

Soil moisture can be a significant source of error in gamma ray surveying. A 10% increase in soil moisture will decrease the total count rate by about the same amount due to absorption of the gamma rays by the water. Snow cover will cause an overall reduction in the total count rate because it also attenuates (shields) the gamma rays from reaching the detector. About 4 inches of fresh snow is equivalent to about 33 feet of air. There was no significant precipitation during this survey.

Topography and vegetation cover

Topographic effect can be severe for both airborne and ground surveying. Both airborne and ground-based detection systems are calibrated for an infinite plane source which is referred to as 2π geometry (or flat a surface). If the surface has mesas, cliffs, valleys, and large height fluctuations, then the calibration assumptions are not met and care must be exercised in the interpretation of the data. Vegetation can affect the radiation detected from an airborne platform in two ways: (1) the biomass can absorb and scatter the radiation in the same way as snow leading to a reduced signal, or (2) it can increase the signal if the biomass concentrated radionuclides found in the soil nutrients.

Spatial Considerations

Standard ground-based environmental measurements are taken 3 ft above the ground with a field of view of about 30 ft^2. The ASPECT collected data at about 300 ft above the ground with an effective field of view of about 6.5 acres. These aerial measurements provide **an average surface activity over the effective field of view**. If the ground activity varies significantly over the field of view, then the results from ground- and aerial-based systems may not agree. It is not unusual to have differences as much as several orders of magnitude depending on the survey altitude and the size and intensity of the source material. For example, in the figures below, if the “A” circle represents the detector field of view and the surrounding area had no significant differences in surface activity, a 300 ft aerial measured could correlate to a ground-based exposure rate of 3.5 µR/h. However, if all the activity was contained in a small area such as a single small structure containing thorium tailings (represented by the blue dot within the field of view of “B”), a 300 ft aerial measurement may still provide the same exposure rate measurement but the actual ground-based measurements could be as high as 3,150 µR/h.

* Attenuation coefficients of 0.0077m^{-1} for 1.76 MeV and 0.0064m^{-1} for 1.46 MeV.

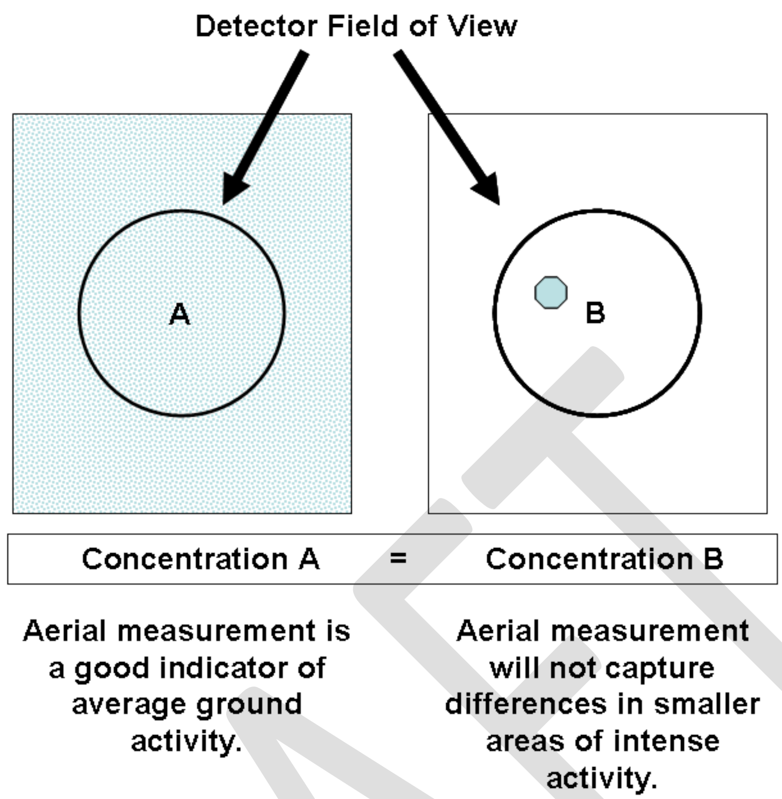


Illustration of aerial measurement capabilities and interpretation of the results

Comparing ground samples and airborne measurements

Aerial measurements are correlated to ground concentrations through a set of calibration coefficients. The ASPECT calibration coefficients for exposure-rate, potassium, uranium, and thorium concentrations were derived from a well characterized "calibration" strip of land near Las Vegas, Nevada. *In-situ* gamma spectroscopy and pressurized ionization chambers measurements were used to characterize the area. One must exercise caution when using a laboratory to analyze soil samples to verify or validate aerial measurements because differences will occur. In addition to local variations in radionuclide concentrations, which are likely to be the most significant issue, differences may arise due to laboratory processing. Laboratory processing typically includes drying, sieving and milling. These processes remove soil moisture, rocks and vegetation, and will disrupt the equilibrium state of the decay chains due to liberation of the noble gas radon. Thus reliance on ^{208}Tl and ^{214}Bi as indicators of ^{232}Th and ^{238}U (as is assumed for aerial surveying) is made more complex. In addition, aerial surveys cannot remove the effects of vegetation on gamma flux. Intercomparisons must minimize these differences and recognize the effects of differences that cannot be eliminated.

Geo-Spatial Accuracy

All aerial measurements collected by the ASPECT aircraft are geo-coded using latitude and longitude. The position of the aircraft at any point in time is established by interpolating between positional data points of a non-differential global positioning system and referencing the relevant position to the time that the measurement was made. Time of observation is derived from the aircraft computer network which is synchronized from a master GPS receiver and has a maximum error of 1 second*. Timing events based on the network running the Windows-based operating system and the sensor timing triggers have a time resolution of 50 milliseconds, so the controlling error in timing is the network time. If this maximum timing error is coupled to the typical ground velocity of 55 meter/sec of the aircraft, an instantaneous error of 55 meters is possible due to timing. In addition, geo-positional accuracy is dependent on the instantaneous precision of the non-differential GPS system which is typically better than 30 meters for any given observation. This results in an absolute maximum instantaneous error of about 80 meters in the direction of travel.

For measurements dependent on aircraft attitude (photographs, IR images) three additional errors are relevant and include the error of the inertial navigation unit (INU), the systemic errors associated with sensor to INU mounting, and altitude errors above ground. Angular errors associated with the INU are less than 0.5 degrees of arc. Mounting error is minimized using detailed bore alignment of all sensors on the aircraft base plate and is less than 0.5 degrees of arc. If the maximum error is assumed then an error of 1.0 degree of arc will result. At an altitude of 150 meters (about 500 feet) this error translates to about 10 meters. Altitude above ground is derived from the difference in the height above the geoid (taken from the GPS) from the ground elevation derived from a 30 meter digital elevation model. If an error of the model is assumed to be 10 meters and the GPS shows a typical maximum error of 10 meters, this results in an altitude maximum error of 20 meters in altitude error. If this error is combined with attitude and the instantaneous GPS positional error (assuming no internal receiver compensation due to forward motion) then an error of about 50 meters will result. The maximum forecasted error that should result from the aircraft flying straight and level is +/- 130 meters in the direction of travel and +/- 50 meters perpendicular to the direction of travel. Statistical evaluation of collected ASPECT data has shown that typical errors of +/- 22 meters in both the direction of and perpendicular to travel are typical. Maximum errors of +/- 98 meters have been observed during high turbulence conditions.

* The ASPECT network is synchronized to the master GPS time at system start-up. If the observed network/GPS time difference exceeds 1 sec. at any time after synchronization, the network clock is reset.

Appendix IV: ASPECT Instrumentation

Survey Instrumentation

The ASPECT aircraft is a twin engine, high wing AeroCommander 680FL capable of cruising speeds ranging from about 100 knots (115 mph) to 200 knots (230 mph) (Image 2). It is based in Waxahachie, Texas and operated by two pilots and one technician. A suite of chemical, radiological, and photographic detection technology is mounted within the airframe making it the only aircraft in the nation with remote chemical and radiological detection capabilities.

Radiation Detectors

The radiological detection technology consisted of two RSX-4 Units (Radiation Solutions, Inc., 386 Watline Avenue, Mississauga, Ontario, Canada) (Image 9). Each unit was equipped with four 2”x4”x16” thallium-activated sodium iodide (NaI[Tl]) scintillation crystals for a total of 8 NaI[Tl] (16.8 L) crystals.

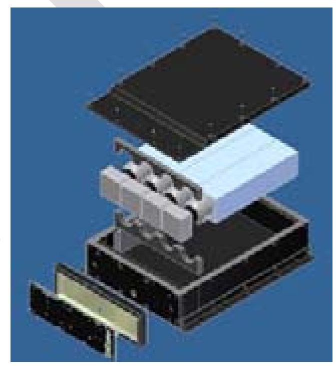


Image A1: RSX-4 unit showing four detector locations. The ASPECT was equipped with 6 NaI[Tl] and 2 $LaBr_3$:Ce scintillating detectors.

Detector packs for airborne spectroscopy typically consist of clusters of NaI[Tl] crystals because they are relatively inexpensive compared to other scintillation crystals. In addition, NaI crystals have high sensitivity with acceptable spectral resolution (approximately seven percent full width at half maximum (FWHM)[*] at 662 keV), and are easy to maintain.
The Radiation Solutions RSX-4 unit was specifically designed for airborne detection and measurement of low-level gamma radiation from both naturally occurring and man-made sources. It uses advanced digital signal processing and software techniques to produce spectral data equivalent to laboratory quality. The unit is a fully integrated system that includes an individual high resolution (1,024 channel) advanced digital spectrometer for each detector. A high level of self diagnostics and performance verification routines such as auto gain stabilization are implemented with an automatic error notification capability, assuring that the resulting maps and products are of high quality and accuracy.

The ASPECT program calibrates it radiological instrumentation according to the International Atomic Energy Agency specifications.[3]

Chemical Sensors

Image A2: View of chemical sensors: high speed infrared spectrometer, lower left corner; infrared line scanner is out of view behind the line scanner.

The chemical sensors installed in the aircraft detect the difference in infrared spectral absorption or emission of a chemical vapor. The first sensor is a model RS-800, multi-spectral IR-Line Scanner (Raytheon TI Systems, McKinney, TX) (Image 4). It is a multi-spectral high spatial resolution infrared imager that provides two-dimensional images. Data analysis methods allow the operator to process the images containing various spectral wavelengths into images that indicate the presence of a particular chemical species.
The second sensor is a modified model MR254/AB (ABB, Quebec, Quebec City, Canada). It is a high throughput Fourier Transform Infrared Spectrometer (FT-IR) that collects higher spectral resolution of the infrared signature from a specific plume location. The instrument is capable of collecting spectral signatures with a resolution selectable between 0.5 to 32 wave-numbers.

The principle of measurement involves the detection, identification, and quantification of a chemical vapor species using passive infrared spectroscopy. Most vapor compounds have unique absorption spectral bands at specific frequencies in the infrared spectral region. Careful monitoring of the change in total infrared radiance levels leads to concentration estimations for a particular vapor species.

Camera

The ASPECT aircraft uses a high resolution digital camera to collect visible aerial images. The camera consists of a Nikon D2X SLR camera body with a fixed focus (infinity) 24mm F1.2 Nikor lens. The camera sensor has 12.5 million pixels (12.2 Mpixels viewable) giving a pixel count of 4288 x 2848 in a 3:2 image ratio. An effective ground coverage area of 3200 x 4800 feet is obtained when operated from the standard altitude of 5000 feet.

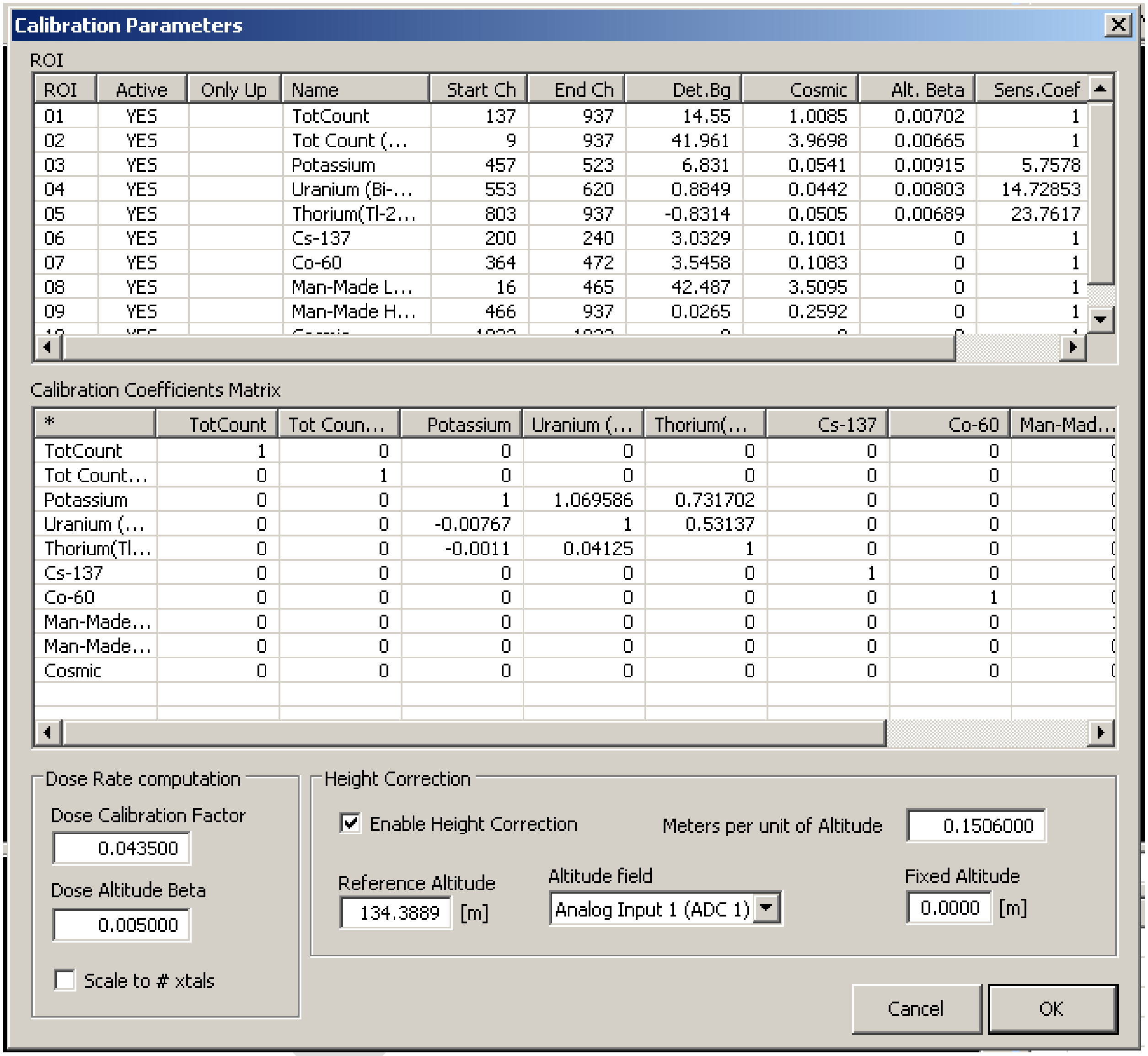
Image ortho-rectification, which corrects for optical distortion and geometric distortion due to the three dimensional differences in the image, is accomplished using an inertial navigation unit (pitch, roll, and heading) coupled with a dedicated 5 Hz global positioning system (GPS). Aircraft altitude above ground is computed using the difference between the indicated GPS altitude and a 30 meter digital elevation model (DEM). Full ortho-rectification is computed using a camera model (lens and focal plane geometric model) and pixel specific elevation geometry derived from the digital elevation model to minimize edge and elevation distortion. Documented geo-location accuracy is better than 49 meters.

Radiological spectral data are collected every second along with GPS coordinates and other data reference information. These data are subject to quality checks within the Radiation Solutions internal processing algorithms (e.g. gain stabilization) to ensure a good signal. If any errors are encountered with a specific crystal during the collection process, an error message is generated and the data associated with that crystal are removed from further analyses.

Prior to the survey, the RSX-4 units go through a series of internal checks. If no problems are detected, a green indicator light notifies the user that all systems are good. A yellow light indicates a gain stabilization issue with a particular crystal. This can be fixed by waiting for another automatic gain stabilization process to occur or the user can disable the particular crystal via the RadAssist Software application. A red light indicates another problem and would delay the survey until it can be resolved.

Appendix V: Calibration Parameters

RadAssist calibration parameters for Spokane Survey on September 17 - 22, 2011.



Calibration Parameters

ROI

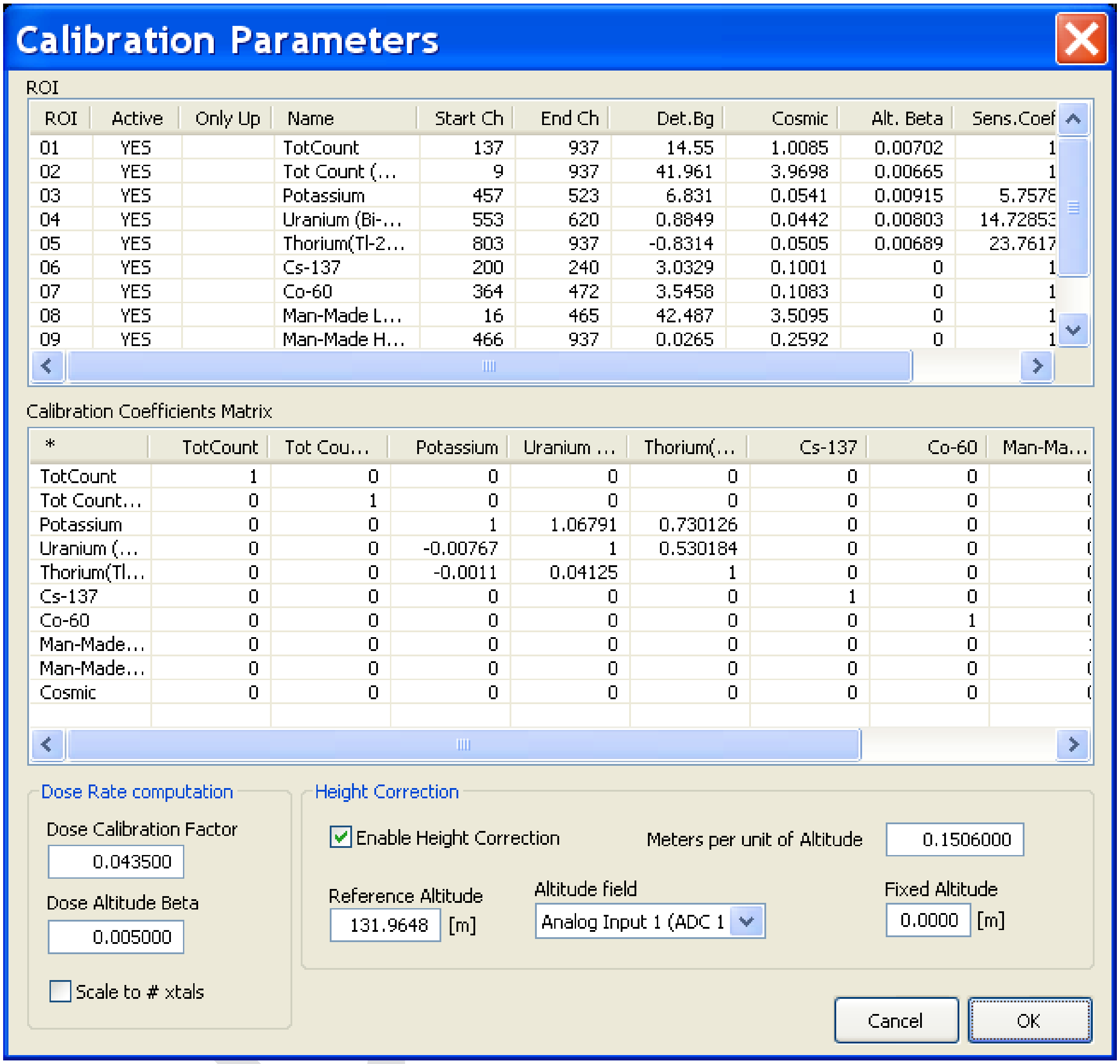
ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	14.55	1.0085	0.00702	1
02	YES		Tot Count (...	9	937	41.961	3.9698	0.00665	1
03	YES		Potassium	457	523	6.831	0.0541	0.00915	5.7578
04	YES		Uranium (Bi-...	553	620	0.8849	0.0442	0.00803	14.72853
05	YES		Thorium(Tl-2...	803	937	-0.8314	0.0505	0.00689	23.7617
06	YES		Cs-137	200	240	3.0329	0.1001	0	1
07	YES		Co-60	364	472	3.5458	0.1083	0	1
08	YES		Man-Made L...	16	465	42.487	3.5095	0	1
09	YES		Man-Made H...	466	937	0.0265	0.2592	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	Co-60	Man-Mad...
TotCount	1	0	0	0	0	0	0	0
Tot Count...	0	1	0	0	0	0	0	0
Potassium	0	0	1	1.069586	0.731702	0	0	0
Uranium (...	0	0	-0.00767	1	0.53137	0	0	0
Thorium(Tl...	0	0	-0.0011	0.04125	1	0	0	0
Cs-137	0	0	0	0	0	1	0	0
Co-60	0	0	0	0	0	0	1	0
Man-Made...	0	0	0	0	0	0	0	1
Man-Made...	0	0	0	0	0	0	0	0
Cosmic	0	0	0	0	0	0	0	0

This screen-shot from the RadAssist Program shows the calibration coefficients used in the determination of Uranium concentrations for this report.

September 18, 2011



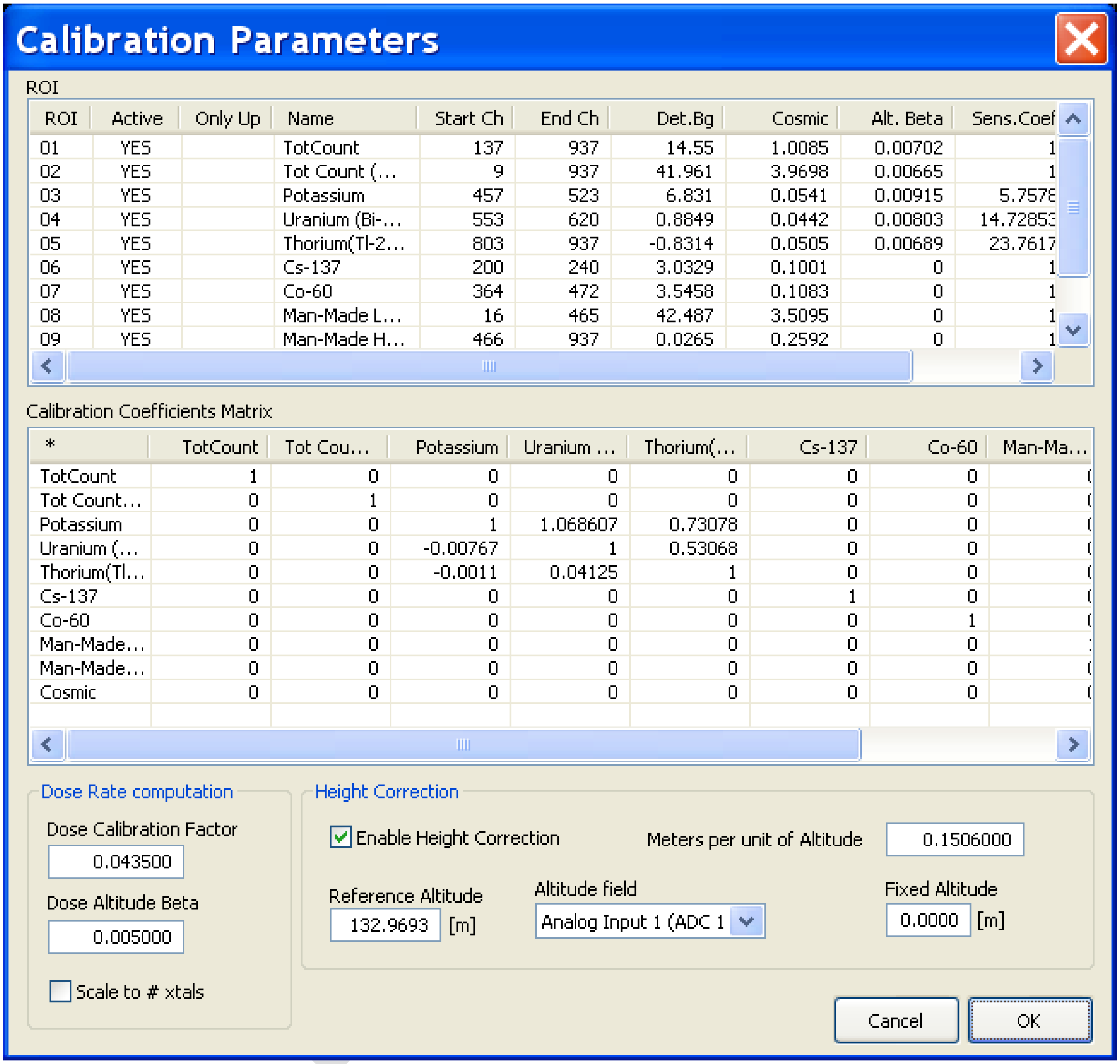
ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	14.55	1.0085	0.00702	1
02	YES		Tot Count (…	9	937	41.961	3.9698	0.00665	1
03	YES		Potassium	457	523	6.831	0.0541	0.00915	5.7578
04	YES		Uranium (Bi-…	553	620	0.8849	0.0442	0.00803	14.72853
05	YES		Thorium(Tl-2…	803	937	-0.8314	0.0505	0.00689	23.7617
06	YES		Cs-137	200	240	3.0329	0.1001	0	1
07	YES		Co-60	364	472	3.5458	0.1083	0	1
08	YES		Man-Made L…	16	465	42.487	3.5095	0	1
09	YES		Man-Made H…	466	937	0.0265	0.2592	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Cou…	Potassium	Uranium …	Thorium(…	Cs-137	Co-60	Man-Ma…
TotCount	1	0	0	0	0	0	0	[illegible]
Tot Count…	0	1	0	0	0	0	0	[illegible]
Potassium	0	0	1	1.06791	0.730126	0	0	[illegible]
Uranium (…	0	0	-0.00767	1	0.530184	0	0	[illegible]
Thorium(Tl…	0	0	-0.0011	0.04125	1	0	0	[illegible]
Cs-137	0	0	0	0	0	1	0	[illegible]
Co-60	0	0	0	0	0	0	1	[illegible]
Man-Made…	0	0	0	0	0	0	0	[illegible]
Man-Made…	0	0	0	0	0	0	0	[illegible]
Cosmic	0	0	0	0	0	0	0	[illegible]

This screen-shot from the RadAssist Program shows the calibration coefficients used in the determination of Uranium concentrations for this report.

September 19, 2011



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	14.55	1.0085	0.00702	1
02	YES		Tot Count (…	9	937	41.961	3.9698	0.00665	1
03	YES		Potassium	457	523	6.831	0.0541	0.00915	5.7578
04	YES		Uranium (Bi-…	553	620	0.8849	0.0442	0.00803	14.72853
05	YES		Thorium(Tl-2…	803	937	-0.8314	0.0505	0.00689	23.7617
06	YES		Cs-137	200	240	3.0329	0.1001	0	1
07	YES		Co-60	364	472	3.5458	0.1083	0	1
08	YES		Man-Made L…	16	465	42.487	3.5095	0	1
09	YES		Man-Made H…	466	937	0.0265	0.2592	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Cou…	Potassium	Uranium …	Thorium(…	Cs-137	Co-60	Man-Ma…
TotCount	1	0	0	0	0	0	0	(
Tot Count…	0	1	0	0	0	0	0	(
Potassium	0	0	1	1.068607	0.73078	0	0	(
Uranium (…	0	0	-0.00767	1	0.53068	0	0	(
Thorium(Tl…	0	0	-0.0011	0.04125	1	0	0	(
Cs-137	0	0	0	0	0	1	0	(
Co-60	0	0	0	0	0	0	1	(
Man-Made…	0	0	0	0	0	0	0	:
Man-Made…	0	0	0	0	0	0	0	(
Cosmic	0	0	0	0	0	0	0	(

Dose Rate computation

Dose Calibration Factor 0.043500

Dose Altitude Beta 0.005000

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude 0.1506000

Reference Altitude 132.9693 [m]

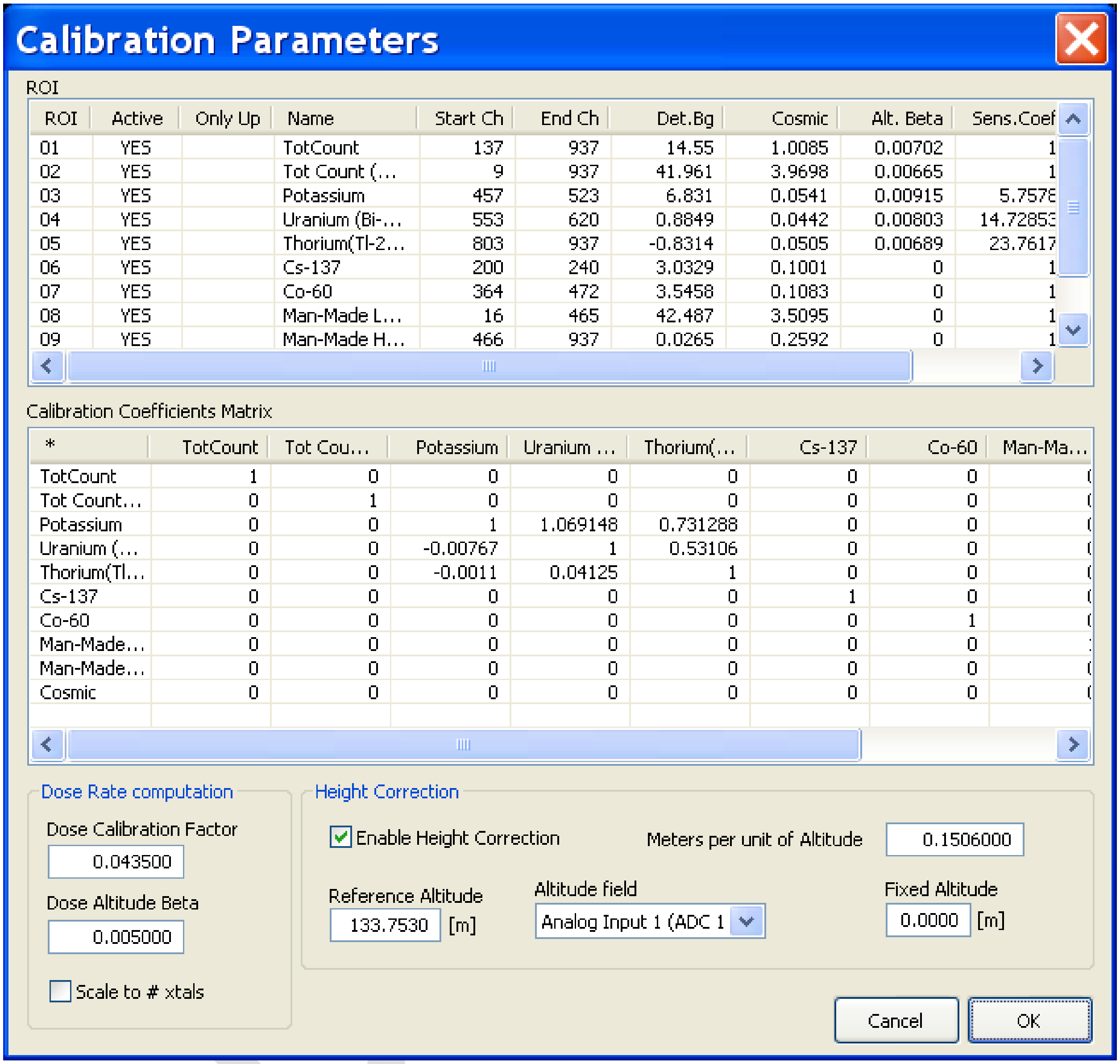
Altitude field Analog Input 1 (ADC 1

Fixed Altitude 0.0000 [m]

Cancel OK

This screen-shot from the RadAssist Program shows the calibration coefficients used in the determination of Uranium concentrations for this report.

September 20, 2011

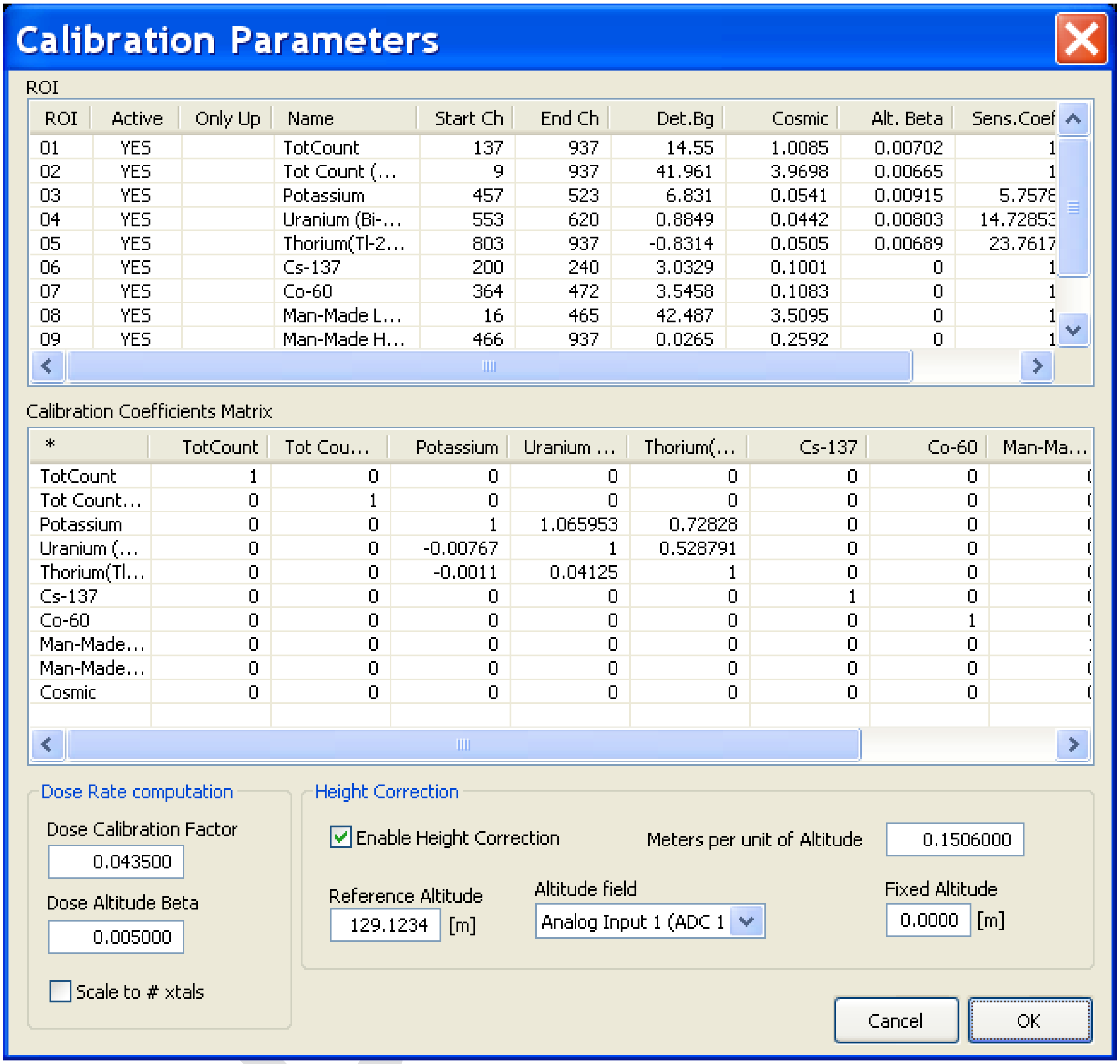


ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	14.55	1.0085	0.00702	1
02	YES		Tot Count (...	9	937	41.961	3.9698	0.00665	1
03	YES		Potassium	457	523	6.831	0.0541	0.00915	5.7578
04	YES		Uranium (Bi-...	553	620	0.8849	0.0442	0.00803	14.72853
05	YES		Thorium(Tl-2...	803	937	-0.8314	0.0505	0.00689	23.7617
06	YES		Cs-137	200	240	3.0329	0.1001	0	1
07	YES		Co-60	364	472	3.5458	0.1083	0	1
08	YES		Man-Made L...	16	465	42.487	3.5095	0	1
09	YES		Man-Made H...	466	937	0.0265	0.2592	0	1

*	TotCount	Tot Cou...	Potassium	Uranium ...	Thorium(...	Cs-137	Co-60	Man-Ma...
TotCount	1	0	0	0	0	0	0	[illegible]
Tot Count...	0	1	0	0	0	0	0	[illegible]
Potassium	0	0	1	1.069148	0.731288	0	0	[illegible]
Uranium (...	0	0	-0.00767	1	0.53106	0	0	[illegible]
Thorium(Tl...	0	0	-0.0011	0.04125	1	0	0	[illegible]
Cs-137	0	0	0	0	0	1	0	[illegible]
Co-60	0	0	0	0	0	0	1	[illegible]
Man-Made...	0	0	0	0	0	0	0	[illegible]
Man-Made...	0	0	0	0	0	0	0	[illegible]
Cosmic	0	0	0	0	0	0	0	[illegible]

This screen-shot from the RadAssist Program shows the calibration coefficients used in the determination of Uranium concentrations for this report.

September 21, 2011



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	14.55	1.0085	0.00702	1
02	YES		Tot Count (...	9	937	41.961	3.9698	0.00665	1
03	YES		Potassium	457	523	6.831	0.0541	0.00915	5.7578
04	YES		Uranium (Bi-...	553	620	0.8849	0.0442	0.00803	14.72853
05	YES		Thorium(Tl-2...	803	937	-0.8314	0.0505	0.00689	23.7617
06	YES		Cs-137	200	240	3.0329	0.1001	0	1
07	YES		Co-60	364	472	3.5458	0.1083	0	1
08	YES		Man-Made L...	16	465	42.487	3.5095	0	1
09	YES		Man-Made H...	466	937	0.0265	0.2592	0	1

*	TotCount	Tot Cou...	Potassium	Uranium ...	Thorium(...	Cs-137	Co-60	Man-Ma...
TotCount	1	0	0	0	0	0	0	(
Tot Count...	0	1	0	0	0	0	0	(
Potassium	0	0	1	1.065953	0.72828	0	0	(
Uranium (...	0	0	-0.00767	1	0.528791	0	0	(
Thorium(Tl...	0	0	-0.0011	0.04125	1	0	0	(
Cs-137	0	0	0	0	0	1	0	(
Co-60	0	0	0	0	0	0	1	(
Man-Made...	0	0	0	0	0	0	0	:
Man-Made...	0	0	0	0	0	0	0	(
Cosmic	0	0	0	0	0	0	0	(

This screen-shot from the RadAssist Program shows the calibration coefficients used in the determination of Uranium concentrations for this report.

References

[1] Bristow Q., Airborne γ-ray spectrometry in Uranium Exploration. Principles and Current Practice. International Journal of Applied Radiation and Isotopes. Vol. 34. No. 1. Pp 199-229, 1983.

[2] Eisenbud, M. Environmental Radioactivity; From Natural, Industrial, and Military Sources. 3rd Edition. Academic Press, Inc., New York, NY. 1987.

[3] International Atomic Energy Agency [2003]. Guidelines for radioelement mapping using gamma ray spectrometry data. Technical Report Series No. 1363. IAEA, Vienna.