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Aerial Radiological Survey of the Grants and Cebolleta Land Grant Areas in New Mexico

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Executive Summary

The United States Environmental Protection Agency (EPA), Office of Emergency Management (OEM), National Decontamination Team manages the Airborne Spectrophotometric Environmental Collection Technology (ASPECT) program. This program provides emergency response support to chemical and radiological incidents and can generate and transmit products within minutes of a sortie to decision makers in the field. In 2008, EPA initiated the ASPECT Gamma Emergency Mapper (GEM) project to develop an airborne gamma-screening and mapping capability of ground-based radiological contamination. The primary purpose is to develop an airborne detection system that can (1) quickly characterize wide-area contamination following radiological dispersal device (RDD) or improvised nuclear device (IND) attack, and (2) provide on-site characterization services throughout long-term recovery operations. It may also be used for wide-area characterization of environments containing variable concentrations of naturally occurring radioactive materials (NORM).

In September 2009, EPA Region 6 requested that the National Decontamination Team ASPECT program conduct aerial surveys of about 120 square miles of residential and near residential areas in the Ambrosia Lake and Laguna sub-districts of the Grants Mineral Belt in New Mexico and identify areas where surface uranium concentrations were out of balance with the surrounding environment. The survey was completed between October 7 and October 15, 2009. Several products were delivered and included contour plots of (1) total count rate in counts per second (cps), (2) uranium concentration in picocuries per gram (pCi/g), (3) exposure rate in microRoentgen per hour (µR/hr), and (4) a plot of individual data points color coded for statistical significance representing deviation from normal background conditions. Additionally, about 1,100 high resolution digital photographs were taken over the entire survey area. All these data are available in a Google Earth format so any user can dynamically review the data in higher resolution.

Over 27,000 one-second spectra were collected and only 31 indicated excess equivalent Uranium (eU) based on ^{214}Bi region of interest greater than 6 sigma; 28 greater than 4 sigma. These results suggest excess eU represents about 0.11% (or 186 acres). All of the areas exceeding 6 sigma were associated with past or present uranium mining activities. Based on aerial photographic interpretation, there were no residences identified as having excess eU greater than 6 sigma. Two locations were identified that fell between 4 and 6 sigma and were near residential areas. Care must be taken to properly interpret these data since airborne surveys are subject to a number of limitations, which are discussed in this report.

Acronyms and Abbreviations

A	argon
AGL	above ground level
ASPECT	aerial spectrophotometric environmental collection technology
Bi	bismuth
C	carbon
Ci	curie
cps	counts per second
DOE	Department of Energy
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
H	hydrogen
Hz	hertz
IND	improvised nuclear device
IR	infrared
K	potassium
$LaBr_3$:Ce	lanthanum bromide cerium doped detector
MeV	mega electron volts
MOU	memorandum of understanding
NaI(Tl)	sodium iodide thallium drifted detector
NORM	naturally occurring radioactive material
pCi	picocurie
Ra	radium
RDD	radiological dispersal device
Rn	radon
TENORM	technologically enhanced naturally occurring radioactive material
Th	thorium
Tl	thallium
U	uranium
μR/hr	microRoentgen per hour

1.0 Introduction

In 2008, the Environmental Protection Agency initiated the Airborne Spectrophotometric Environmental Collection Technology (ASPECT) Gamma Emergency Mapper (GEM) project to develop an airborne gamma-screening and mapping capability of ground-based radiological contamination. This project directly supports the EPA Office of Homeland Security focal area that directed the agency to *"Develop appropriate/effective technologies to lessen the time frame for characterization and decontamination of contaminated widespread and populated areas following an RDD."*[*] The primary purpose is to develop an airborne detection system that can (1) quickly characterize wide-area contamination following radiological dispersal device (RDD) or improvised nuclear device (IND) attack, and (2) provide on-site characterization services throughout long-term recovery operations. It may also be used for wide-area characterization of environments containing variable concentrations of naturally occurring radioactive materials (NORM).

The agency purchased state-of-the-art detection technology,[†] described in Section 4, and actively collaborates with the Department of Energy, National Nuclear Security Administration to ensure that the survey products are scientifically valid and technically defensible. Additionally, the EPA Office of Emergency Management and DOE Office of Emergency Response are in the process of signing a Memorandum of Understanding[‡] (MOU) to leverage assets and resources strengthening the country's response capacity and capabilities to large-scale radiological incidents.

In September 2009, EPA Region 6 requested that the National Decontamination Team ASPECT program conduct aerial surveys over about 200 square miles in New Mexico and identify areas where surface uranium concentrations were in excess of normal background concentrations.[§] While subsurface concentrations of uranium can be detected by the instrumentation, the self-shielding of the ground limits its effective detection to near surface concentrations to a depth of about one foot. The survey was completed between October 7 and October 15, 2009. DOE conducted a similar survey over 41 areas in the Navajo Nation covering about 1,100 square miles from October 1994 through October 1999.[1] The EPA ASPECT program adopted the DOE methods used during the 1990s with only minor modifications to identify areas with excess activity in this survey. Plots of gross count rate in counts per second (cps), uranium concentration in picocuries per gram (pCi/g) and exposure rate in microRoentgen per hour (μR/hr) were also developed for each area surveyed.

2.0 Survey Area Description

The Grants Mineral Belt is located in Cibola and McKinley counties of New Mexico, near the town of Grants. This area was the site of extensive uranium mining from 1950-until the early 1980's. During this time the economy of the region changed from

[*] Draft EPA Homeland Security Workplan dated March 2008. EPA, Office of Homeland Security
[†] Radiation Solutions, Inc. RS-500 Airborne Advanced Digital Gamma-Ray Spectrometer.
[‡] The MOU is scheduled to be signed in January 2010.
[§] Bismuth-214 activity is measured with an assumption of secular equilibrium to estimate uranium activity.

agriculture to uranium mining and uranium ore processing. Most uranium mining stopped in the recession of 1982-1983.

In northwestern New Mexico, houses were traditionally made with stone walls using mud as mortar, with mud and sand stucco. Some residents may have used the tailings piles from uranium mines and mills as a source of building materials for new houses or to repair old houses. These rocks and dirt from the tailings piles, as well as timbers and scrap metal, may have contained radioactive materials that have been incorporated into the structure of the houses. Additionally, radioactive materials may have been brought into the yards or deposited in the soils near these houses.

In 2007, EPA Region 9 began a project in coordination with the Navajo Nation to investigate residences on the Navajo Indian Reservation located in parts of Arizona, New Mexico, and Utah for radioactive contamination caused by uranium mining on the reservation. In 2009, EPA Region 6 initiated a similar project to investigate radioactive contamination in and around residences near uranium mining and ore processing areas outside of the Navajo Reservation in the Ambrosia Lake and Laguna sub-districts of the Grants Mineral Belt area of northwestern New Mexico. These areas will include non-Navajo lands adjacent to the eastern boundary of the Navajo Reservation with public and/or private ownership as well as lands within the Laguna Pueblo.

The areas that were selected for the aerial radiological surveys, were done in consultation with the New Mexico Environment Department and the New Mexico Energy, Minerals, and Natural Resources Department, Mining and Minerals Division. Throughout this report the regions will be referred to as two major areas; the Grants Area and the Cebolleta Land Grant Area (Image 1).

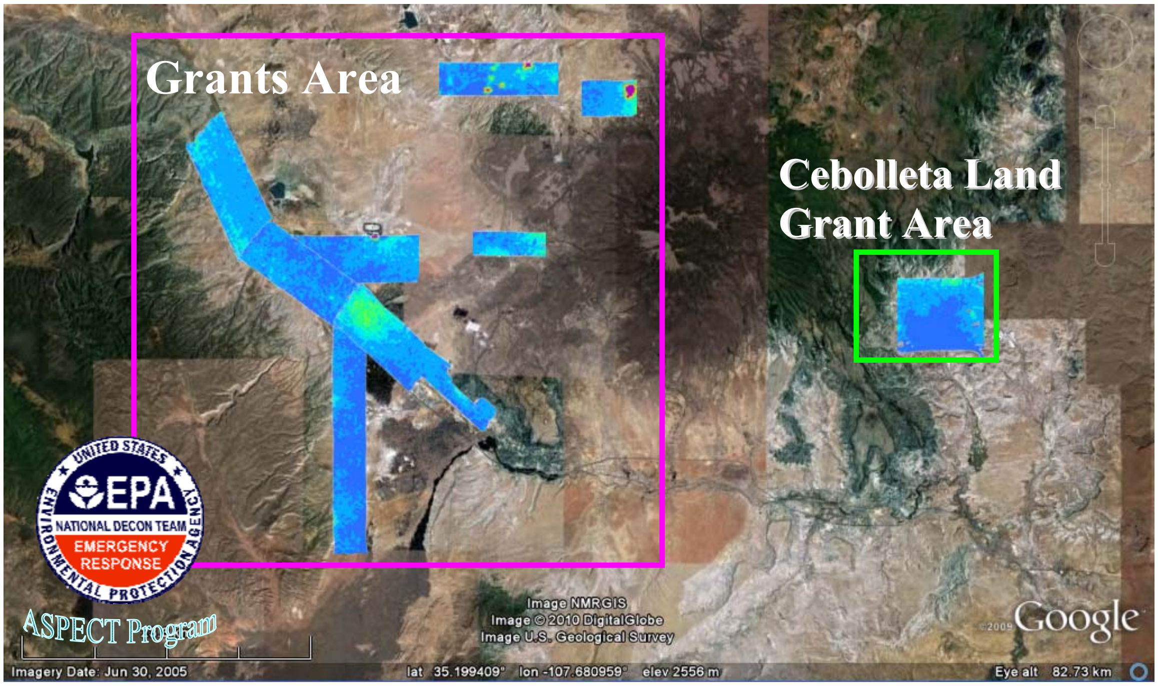

Image 1: New Mexico Uranium Survey Area, October 2009.

3.0 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 about 4.5 billion years ago. 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 and Albuquerque, NM. The cosmic radiation levels in the study region ranged between 6.1 μR/h to 7.7 μR/h. 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 did not need to be accounted for 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. This survey did not focus on ^{40}K characterization and the concentrations of ^{40}K were not calculated.

Uranium is ubiquitous in the natural environment and is found in soil at various concentrations with an average of about 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). Uranium deposits found in the Grants area were formed 65 to 345 million years ago and are classified as a sandstone and/or a limestone type.[2] Uranium ore grades in these deposits can range from 600 pCi/g to 2,000 pCi/g (0.1% to 0.3%)[*] and accounted for over 50% of world production in 1977. Uranium-238 decays by emitting an alpha particle (which travels less than one inch in air) and cannot be measured by airborne detection systems; therefore its presence must be inferred from one of its daughter products that emit gamma-rays. Uranium-238 decays through a series of daughter products and ultimately becomes a stable form of lead (Appendix 1). The tenth daughter product in this decay chain is Bismuth-214 (^{214}Bi) which emits a 1.76 MeV gamma-ray, and is traditionally used to determine the presence of uranium, radium and radon since no other significant interferences occur in this energy range due to naturally occurring radionuclides. This approach was used to estimate uranium concentrations in this survey but has potential limitations (i.e., radon interference, secular equilibrium, etc.) which are noted in the Discussion section. Additional information regarding uranium, its compounds and uses can be found at http://web.ead.anl.gov/uranium/guide/ucompound/whatisu/index.cfm.

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 tenth daughter product, thallium-208 (^{208}Tl), is used to estimate the presence of thorium by its 2.61 MeV gamma-ray emission. Thorium was not a focus of this survey but is commonly measured as a significant component of the terrestrial component of natural background.

All these primordial radionuclides are present in varied concentrations in building materials which make-up part our naturally occurring radioactive background (Table 1)[3].

Table 1: Average concentrations of potassium, uranium and thorium in some building materials

Material	Potassium (pCi/g)	Uranium (pCi/g)	Thorium (pCi/g)
Granite	32	1.7	0.22
Sandstone	11.2	0.2	0.19
Cement	6.4	1.2	0.57
Limestone concrete	2.4	0.8	0.23
Sandstone concrete	10.4	0.3	0.23
Wallboard	2.4	0.4	0.32
By-product gypsum	0.2	5.0	1.78
Natural gypsum	4	0.4	0.2
Wood	90	-	-
Clay brick	18	3	1.2

Technologically enhanced naturally occurring radioactive material (TENORM) is simply NORM processed in such a manner that its radioactive constituents have been increased. TENORM is associated with varied industries including energy production, water

[*] Based on a conversion factor of 2 pCi/g per 3 ppm.

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 natural uranium concentrations were significantly higher than the natural background concentrations either due to man-made activities or extreme variations of natural uranium deposits.

4.0 Survey Equipment and Data Collection Procedures

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.

Image 2: ASPECT Aircraft. Aerocommander 680FL

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4.1 Radiation Detectors

The radiological detection technology consisted of two RSX-4 Units (Radiation Solutions, Inc., 386 Watline Avenue, Mississauga, Ontario, Canada) (Image 4). Each unit was equipped with three 2”x4”x16” thallium-activated sodium iodide (NaI[Tl]) scintillation crystals and one 3”x3” lanthanum-bromide doped with Cerium ($LaBr_3$:Ce) scintillation crystal. The aircraft was equipped with a total of 6 NaI[Tl] (12.6 L) and 2 $LaBr_3$:Ce (0.34 L) crystals.

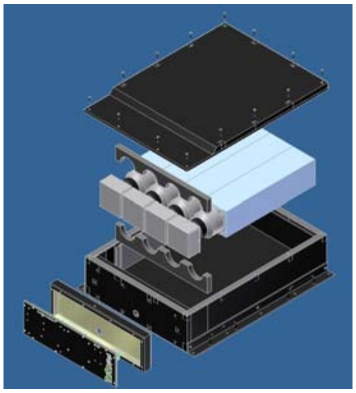


Image 3: RSX-4 unit showing four detector locations. The ASPECT was equipped with 6 NaI[Tl] and 2 $LaBr_3$:Ce scintillating detectors.

Detector packs for airborne spectroscopy are typically made up of clusters of NaI[Tl] crystals because they are relatively inexpensive compared to other scintillation crystals, have a high sensitivity with acceptable spectral resolution around 7 percent full width at half maximum (FWHM) peak*, and easy to maintain. The ASPECT program is assessing the use of the $LaBr_3$:Ce crystals because they provide better spectral resolution (around 4 percent FWHM) and are easy to maintain, but cost more and have a lower sensitivity. The

* The full width of the peak at half the maximum amplitude (FHWM), expressed as a percentage of the photopeak energy, is used as the measure of resolution.

primary advantage (better resolution) may prove to be worth the loss of sensitivity especially for environments with very high activity or that have a mix of gamma-emitting isotopes (e.g., following a nuclear detonation).

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 auto gain stabilization are implemented with an automatic error notification capability, assuring that the resulting maps and products are of high quality and accuracy.

4.2 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 885 x 590 meters is obtained when operated from the standard altitude of 850 meters.

F-stop, shutter, and timing control for the system is integrated into an automated camera control console composed of a non-volatile programmable microcontroller. Three trigger modes of operation are possible including single event manual, continuous timed operation, and IR collection slave. User selectable time intervals between successive frames can be programmed from 3 to 8 seconds.

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.

4.3 Flight Procedures

The ASPECT aircraft used the following flight procedures for data collection:

Altitude above the ground (AGL):	300 feet
Target Speed:	100 knots (115 mph)
Line Spacing:	450 feet
Data collection frequency:	1 second

At various locations through out the survey, the flight parameters were changed to follow the contour of the land due to severe terrain conditions causing dangerous flying conditions. In general, the flight lines were parallel to the long axis of the survey area.

Using these parameters, a general rule of thumb gives 60-70% of the counts originating in an oval of width twice the flying height, and length twice the flying height plus the distance travelled during data accumulation (1 second). For this survey, the area represented by each sample is about 10 acres with an effective FOV of about 6 acres.[*] For NORM mapping using fixed-wing aircraft, flying height above ground level has been more or less standardized at 400 ft (ASPECT target height was 300 ft).[4] In flat terrain, lower heights can be achieved providing a much stronger signal and can reduce signal to noise problems such as those associated with atmospheric radon (discussed later in this report).

Aircraft position is established using a 5 Hz Global Positioning Systems and a digital elevation map database. Positional accuracy has been established at better than 49 meters with typical accuracy better than 11 meters. Management of the flight track is established using a standard steering indicator associated with the flight GPS/flight computer.

4.4 Data Recording and Verification

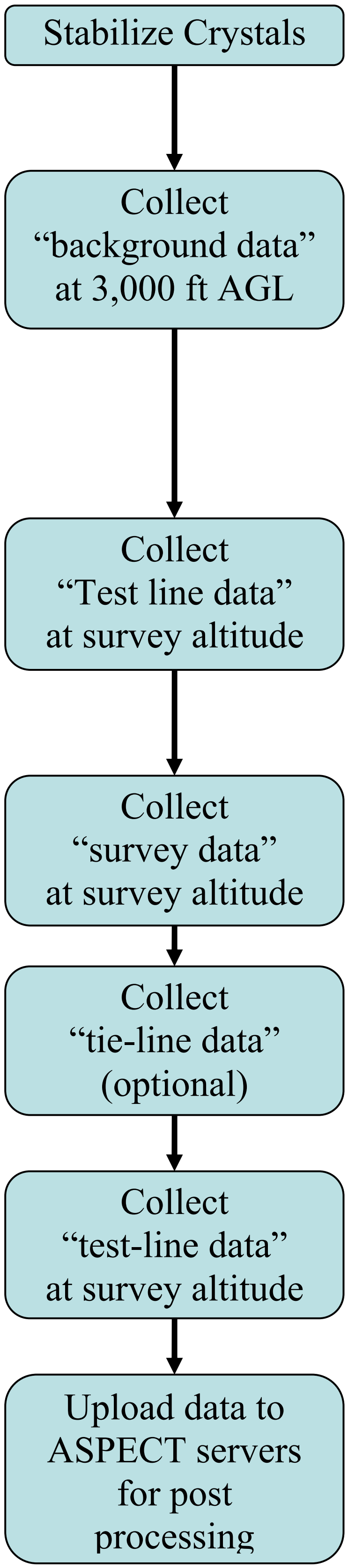
Radiological spectral data are collected every second along with GPS coordinates and other data reference information. These data are subject to quality checks within the Radiation Solutions internal processing algorithms (e.g., gain stabilization) to ensure a good signal. If any errors are encountered 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 RAD Assist software and RSX-4 units are turned on and go through a series of internal checks. If no problems are detected, then the user is notified by a green indicator 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. 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 in Figure 1.

[*] Effective FOV represents the area from which the majority of detection occurs and may vary greatly depending on terrain.

Figure 1: Data collection Process



When powered up, the crystals go through an automatic 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, this data is 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.[2] At this altitude atmospheric attenuation reduces the terrestrial radiation to a negligible level but is still low enough where cosmic radiation is not significant.

A "test line" is a location close to or within the survey area but not over any known sources. It should reflect the topography of the area and be capable of being flown at survey altitude accurately. The background data are subtracted from these data to provide radiation contributions from only terrestrial sources. These data are then used to calculate the K-values (described later).

Survey data are collected according to predefined flight paths, usually in a pattern parallel to the long axis of the survey area.

If the survey area is large enough where more than several flights are necessary to complete the survey, then "tie-line" data may be collected. A "tie-line" crosses the survey flight lines at 90 degrees and is used to adjust the survey data to account for radon interference if necessary.

Another "test line" is flown after all the survey data has been collected. Sometimes the aircraft may need to refuel to complete the survey. In that case, additional test line data will be collected. If the initial test line data is within 10 percent of the final test line data, the initial test line data is applied to the post processing algorithms. The average of the two can be applied as well. If the difference between the test line exceeds 10 percent, then the survey data are corrected accordingly using a time-dependent linear interpolation correction factor.

5.0 Data Analysis

Two software packages were used to produce four products. The first was "RAD Assist" Version 3.14.4.2 Beta 2 (Radiation Solutions, Inc., 386 Watline Avenue, Mississauga, Ontario, Canada) which produced contour plots of:

(1) **total count rate** (counts per second),
(2) **exposure rate** (μR/h), and
(3) **equivalent uranium concentration** (pCi/g).

The second was ENVI® Version 4.6; ASPECT Version 8.5.4, Build 100102019 (ITT Visual Information Solutions, Boulder, CO) which produced:

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

Gross counts measure total gamma activity from all terrestrial sources after subtracting the "background data" for contributions from radon, cosmic and aircraft sources, as described earlier. They can be used to assess the wide range of radioactivity present even in areas not associated with uranium mining. Exposure rates were estimated using the RAD Assist software which uses a proprietary algorithm that weighs each energy channel in the spectrum. Uranium concentrations were determined using RAD Assist and ASPECT-specific calibration coefficients (Appendix II). The calibration coefficients were determined based on methodology published by the International Atomic Energy Agency.[4] Radon corrections were not performed within RAD Assist but were done within the ENVI process. The lack of radon correction in the RAD Assist products will tend to overestimate potential eU concentrations.

RAD Assist Method

↓
Live time correction
↓
Subtract cosmic and aircraft background contribution (coefficients)
↓
Radon contribution correction was not performed using RAD Assist
↓
Perform stripping correction (ASPECT specific calibration coefficients)
↓
Perform height correction (μ=0.0054m^{-1})
↓
Convert to radioelement concentrations
↓
Create contour plots
(1) Total Count Rate (cps)
(2) Exposure Rate (μR/h)
(3) Uranium Concentration (pCi/g)

Figure 2: RAD Assist Data Processing Steps

ENVI ASPECT Method

↓
Live time correction
↓
Subtract radon, cosmic and aircraft background contribution (3,000 ft AGL)
↓
"Test Line" Comparisons
Height correction (μ=0.0054m^{-1})
Calculate ^{214}Bi ROI K-value (median)
↓
Determine net count rate for ^{214}Bi (equivalent Uranium), 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 eU point plots

Figure 3: ENVI ASPECT Data Processing Steps

Excess eU sigma points were determined using an algorithm developed 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 4).

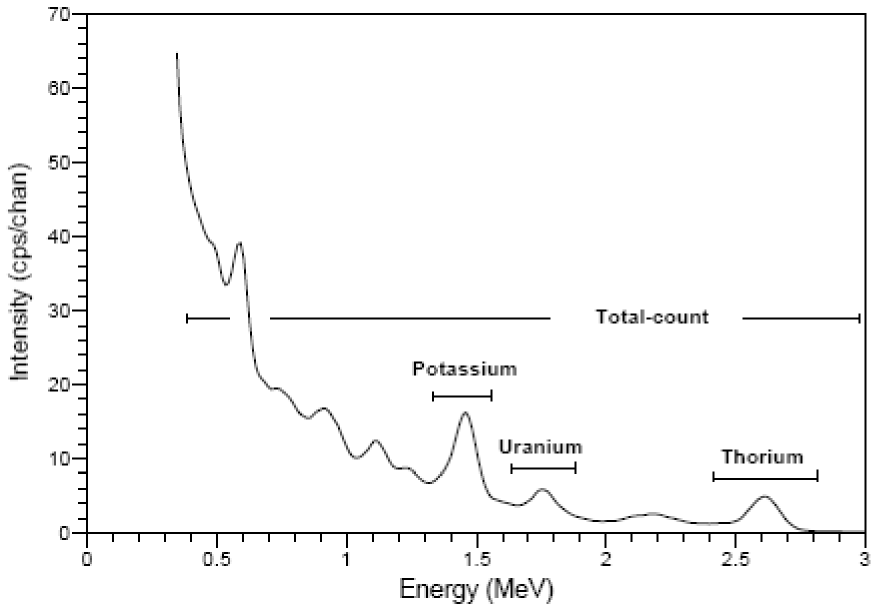


Figure 4: Typical airborne gamma ray spectrum showing positions of the conventional energy windows. *Adapted from IAEA-TECDOC-1363.*

To determine excess eU activity, the region-of-interest around ^{214}Bi (labeled Uranium above) is compared to another region-of-interest (ROI) usually represented by higher gamma energy levels such as the Thorium window. The count rate ratio between these windows (e.g., Uranium window / Thorium window) is relatively constant and is referred to as the "K" value. The actual windows (ROIs) are listed in Appendix II. 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 eU.

K-value = Count rate in ***target*** region-of-interest / Count rate in ***background*** region-of-interest

Excess activity can be estimated using the following formula:

Excess eU activity = **Measured** eU activity – **Estimated** eU activity

Where:

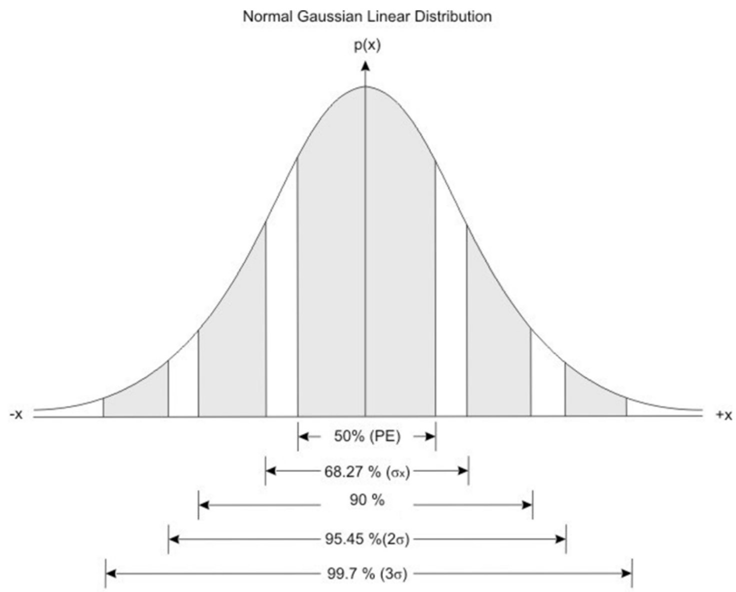
Measured eU activity = the measured count rate within the ***eU*** ROI during the survey

Estimated eU activity = **K-value** * measured count rate in ***background*** ROI during the survey

The equation for excess activity becomes:

EXCESS eU = Measured eU ROI – (K * Measured Background ROI)

For this survey, the most likely value of net "excess eU" was zero, but since radiological disintegrations are randomly occurring events, the second-by-second "excess eU" results are statistically distributed about zero in a normal Gaussian distribution (Figure 5).



Standard deviation (σ, sigma) represents the spread of the data about the mean. In this survey, the mean value (net "excess eU") 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 5: 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 6. The color code was based on conversations with the On-Scene Coordinator to limit the risk of false positives to 1 in about 15,800,000 samples.

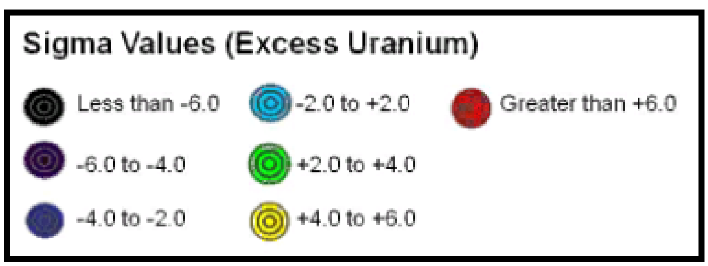


Figure 6: Standard Deviation Legend for Excess eU

6.0 Results

The results for (1) total count rate, (2) exposure rate, (3) eU concentration, and (4) excess eU are provided in Appendix III. Additionally, about 1,100 high resolution digital photographs were taken over the entire survey area. These photographs have been geo- and ortho-rectified for geospatial applications and provide information of surface activity at the time of the surveys. Contour plots and sigma point plots are also available in a Google Earth format so any user can review the data in higher resolution than presented in this document.

Access to the electronic data (e.g., contour plots, raw data files, and photographs) can be provided by contacting:

Warren Zehner, OSC Region 6
Zehner.warren@epa.gov

A summary of the results are provided in Table 2. The approximate area covered in this survey was about 120 square miles. Over 27,000 one-second spectra were collected and only 31 indicated excess eU greater than 6 sigma; 28 greater than 4 sigma. The areas represented by greater than 6 sigma represent about 0.11% (or 186 acres) of the total area. All of these areas are associated with legacy Uranium mining activities. Based on aerial photographic interpretation, there were no residences identified as having excess eU greater than 6 sigma.

Table 2: New Mexico Uranium Survey Summary Results

Area Name	Sub-Area Name	Survey Date	Area (sq miles)	Approx. # samples	Excess eU (sigma) >6 σ	Excess eU (sigma) 4<σ<6
Grants	San Mateo	7 Oct 2009	3.9	1,100	8	10
	Lobo Canyon	8 Oct 2009	4.6	830	0	0
	Crossroads	8 Oct 2009	14.4	2,430	17	12
	Grants North	10 Oct 2009	14.7	3,920	0	0
	Grants Central	10 Oct 2009	14.6	3,400	0	1
	Grants South	9 Oct 2009	18.6	4,130	0	0
	Grants East	12 Oct 2009	14.1	3,380	6	2
	Grants Southernmost	12 Oct 2009	18.9	4,380	0	0
Cebolleta Land Grant	Cebolleta Land Grant	15 Oct 2009	14.1	2,510	0	3
			117.9	**27,080**	**31**	**28**

The DOE used 4 sigma or higher to indicate excess eU in their 1990s surveys of abandoned uranium mines in the Navajo Nation. Of the 28 locations that fell between 4 and 6 sigma in the New Mexico surveys, 25 were in the Grants area and 3 were in the Cebolleta Land Grant area. All but one location within the Grants area were associated with legacy uranium mining activities. The one location (35.19272129, -107.89945597) exceeding 4 sigma in an urban area appears to be a plot of disturbed land next to a roadway and baseball field (Image 4). The yellow circle represents the detector field-of-view (radius is about 300 ft) and the area associated with potential excess eU.

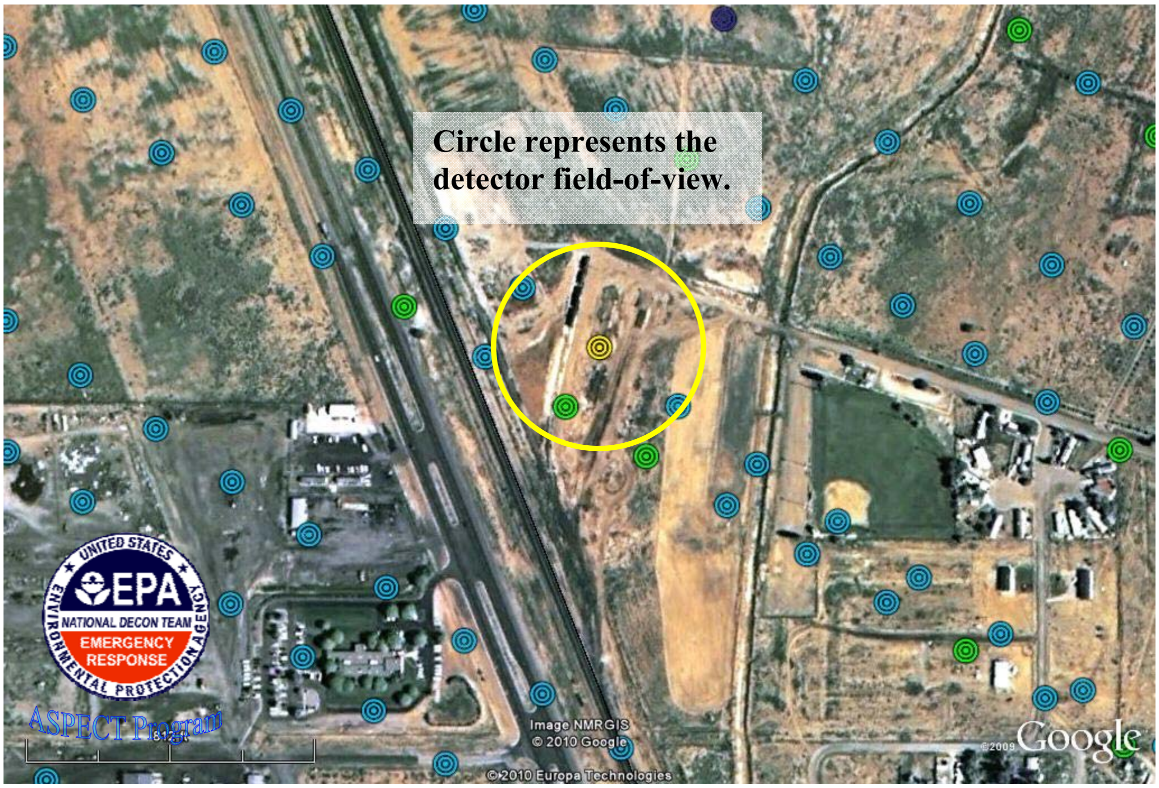


Image 4: Location within the Grants area that fell between 4 and 6 sigma, suggesting potential excess eU.

All three locations within the Cebolleta Land Grant area were in rural locations with no apparent human presence such as building structures or roadways.

7.0 Discussion

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.

7.1 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.

7.2 Secular Equilibrium Assumption

Secular equilibrium is assumed in order to estimate uranium concentrations from one of its daughter products, ^{214}Bi. It exists when the concentration 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, ^{214}Bi half-life is about 20 minutes and its parent radionuclides (^{222}Rn, ^{226}Ra, and ^{238}U) all have much longer half lives. Therefore, the measurement of ^{214}Bi gamma emission can be used to estimate the concentration of its parent radionuclides if one assumes all these radionuclides stay with each other. However, ^{222}Rn is a gas and degasses readily from soils and rocks fissures due to changes in weather conditions. A similar situation can occur in the environment between uranium and its immediate daughters, namely ^{226}Ra. For example in an oxidizing environment uranium is more mobile than radium, causing the uranium to be transported while the radium and its decay products are not. In a reducing environment, the opposite is true. The combined effect of radon gas mobility and environmental “chemical” migration can begin to break down the secular equilibrium assumption causing an increased uncertainty of uranium concentration estimates.

7.3 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.* During this survey the weather conditions were fairly constant which tended to minimize the impact these factors could have on the measurements. Further, temperature and pressure changes contribute very little to the overall uncertainties associated with airborne detection systems as compared to other factors.

7.4 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. Although there may be an overall lowering of the total count rate, high soil moisture contents could lead to an overestimation of surface uranium concentrations. This can occur because radon that would have escaped into the air is trapped and its daughter product, ^{214}Bi, is used to estimate uranium concentrations. In addition, rain "washes out" the airborne radon daughter products and deposits them on the ground, causing an increased count rate and an overestimation of uranium. This anomalous surface activity is usually resolved in about three hours after rainfall.[5] 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. Therefore, surveys to measure surface concentrations of uranium should only be flown when the ground is relatively dry and snow-free. There were no significant rainfalls or snow present during this survey.

7.6 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.

7.7 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 collects data at about 300 ft above the ground with an effective field of view of about 6 acres (260,000 ft^2). 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, 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.

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

However, if all the activity was contained in a small area such as a single small hogan built of uranium 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.[1] (Figure 7)

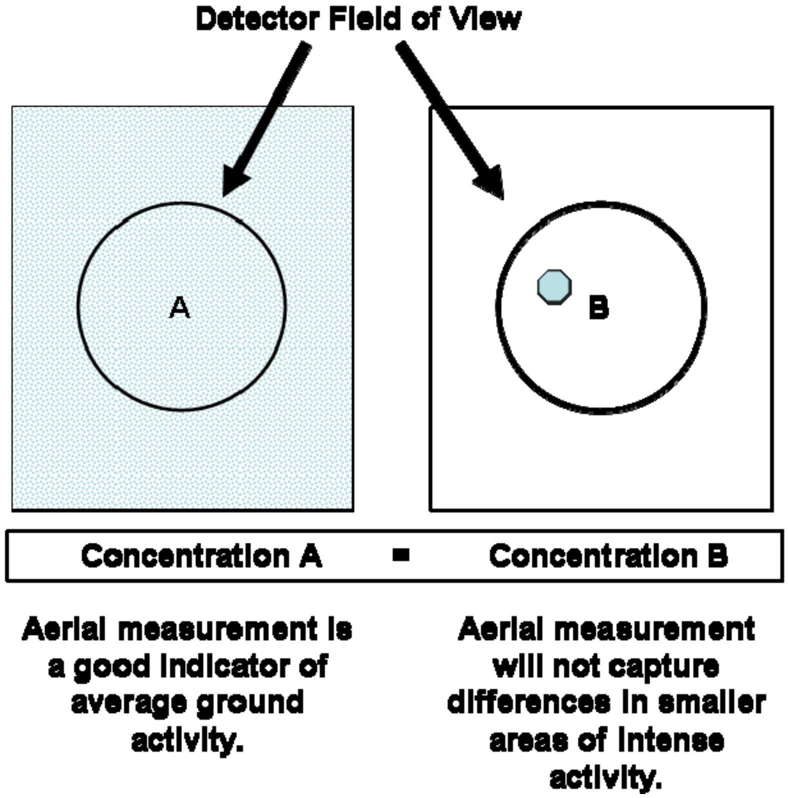


Figure 7: Illustration of aerial measurement capabilities and interpretation of the results

7.8 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 spectrometry measurements and pressurized ionization chambers were used to characterize the area. One should exercise caution when using a laboratory to process soil samples to verify or validate aerial measurements because differences will occur. Laboratory analyses of soil samples are not recommended because radon concentrations and soil moisture changes occur in the soil between sample collection and analysis.[4]

When ground-based measurements are made using pressurized ion-chambers (PICs), those measurements include cosmic contribution to the background. For example, the cosmic contribution to normal background in this area is about 7 µR/h. The PIC measurement may provide a measurement of 20 µR/h. So 35% of the measurement is due to cosmic radiation. The aircraft is calibrated to provide an exposure rate estimate (at 1 meter) that *excludes* cosmic contribution. In an ideal condition (measurements taken at the same time and location) the aircraft exposure rate estimate and ground based measurements should be identical. For example, an airborne exposure rate estimate of 13 μR/h plus 7 μR/h from cosmic radiation will equal 20 μR/h as measured by a PIC. If you are going to compare airborne exposure rate results with PIC data, you will need to subtract surface cosmic radiation from your measurements to make an accurate comparison.

7.9 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 1524 meters (5000 feet) this error translates to 26 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 at any time after synchronization, the network clock is reset.

8.0 Appendices

Appendix I
Uranium-238 Decay Series (4n + 2)[a]

Nuclide	Half-life	Major Radiation Energies (MeV) and Intensities[b]					
		α		β		γ	
		MeV	**%**	**MeV**	**%**	**MeV**	**%**
$^{238}_{92}U$	$4.468 \times 10^{9}\ y$	4.15 4.20	22.9 76.8			0.496	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
↓							
$^{234}_{91}Pa$	$1.17\ m$			2.28	98.6	0.766 1.001	0.207 0.59
↓							
$^{234}_{91}Pa$	$6.7\ h$			22 *ßs* *E Avg* = 0.224 *Emax* = 1.26		0.132 0.570 0.883 0.926 0.946 0.053 0.121	19.7 10.7 11.8 10.9 12 0.12 0.04
↓							
$^{234}_{92}U$	$244{,}500\ y$	4.72 4.77	27.4 72.3				
↓							
$^{230}_{90}Th$	$7.7 \times 10^{4}\ y$	4.621 4.688	23.4 76.2			0.0677 0.142 0.144	0.37 0.07 0.045
↓							
$^{226}_{88}Ra$	$1600 \pm 7\ y$	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
↓							

Appendix I Continued

Major Radiation Energies (MeV) and Intensities[b]

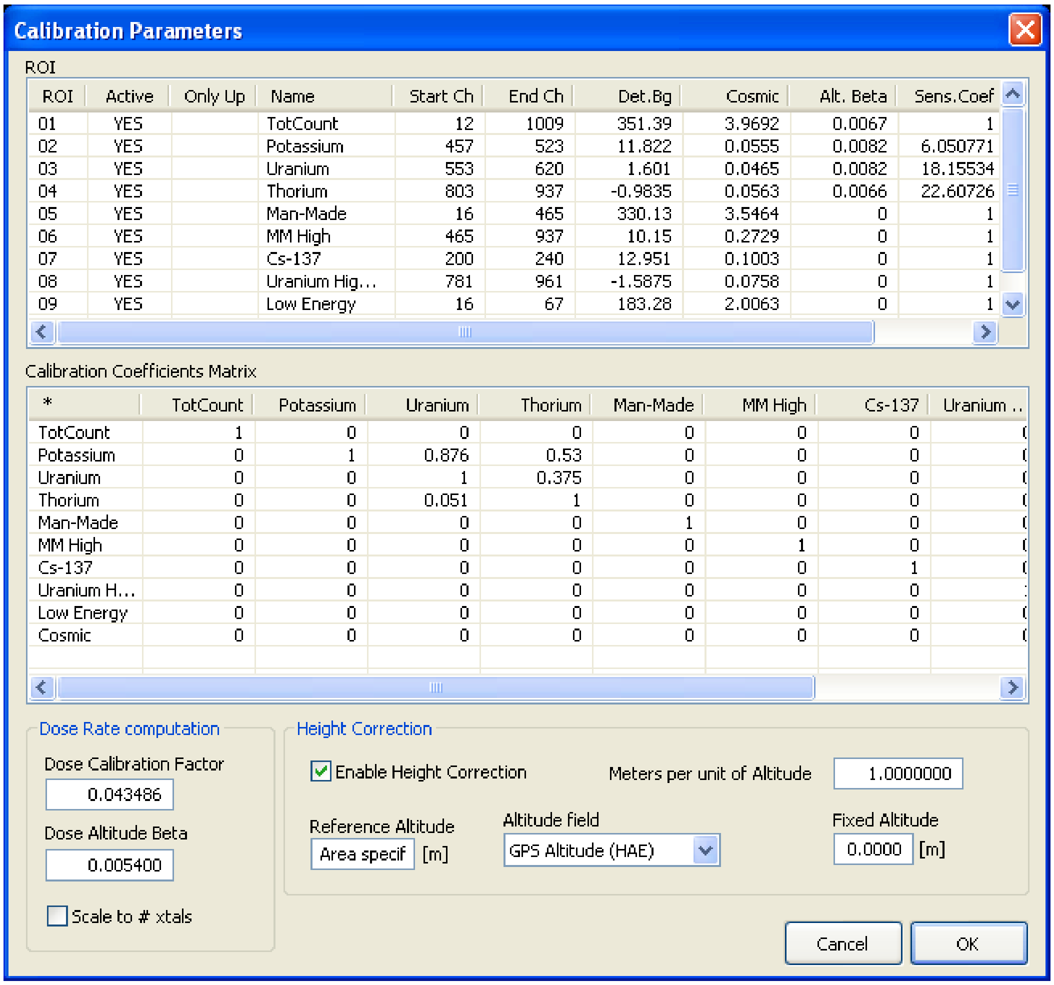
Nuclide	Half-life	α MeV	α %	β MeV	β %	γ MeV	γ %
$^{214}_{82}Pb$	26.8 *m*			0.67 0.73 1.03	48 42.5 6.3	0.2419 0.295 0.352 0.786	7.5 19.2 37.1 1.1
↓							
$^{214}_{83}Bi$	19.9 *m*	5.45 5.51	0.012 0.008	1.42 1.505 1.54 3.27	8.3 17.6 17.9 17.7	0.609 1.12 1.765 2.204	46.1 15.0 15.9 5.0
↓							
$^{214}_{84}Po$	164 μs	7.687	100			0.7997	0.010
↓							
$^{210}_{82}Pb$	22.3 *y*	3.72	0.000002	0.016 0.063	80 20	0.0465	4
↓							
$^{210}_{83}Bi$	5.01 *d*	4.65 4.69	0.00007 0.00005	4.65 4.69	0.00007 0.00005		
↓							
$^{210}_{84}Po$	138.378 *d*	5.305	100	5.305	100	0.802	0.0011
↓							
$^{206}_{82}Pb$	*stable*						

[a] This expression describes the mass number of any member in this series, where n is an integer. For example: $^{206}_{82}Pb$ (4n + 2)…(4 x 51) + 2 = 206

[b] 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 II

RAD Assist NaI[Tl] calibration parameters for the ASPECT program.



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	12	1009	351.39	3.9692	0.0067	1
02	YES		Potassium	457	523	11.822	0.0555	0.0082	6.050771
03	YES		Uranium	553	620	1.601	0.0465	0.0082	18.15534
04	YES		Thorium	803	937	-0.9835	0.0563	0.0066	22.60726
05	YES		Man-Made	16	465	330.13	3.5464	0	1
06	YES		MM High	465	937	10.15	0.2729	0	1
07	YES		Cs-137	200	240	12.951	0.1003	0	1
08	YES		Uranium Hig...	781	961	-1.5875	0.0758	0	1
09	YES		Low Energy	16	67	183.28	2.0063	0	1

Calibration Coefficients Matrix

*	TotCount	Potassium	Uranium	Thorium	Man-Made	MM High	Cs-137	Uranium ..
TotCount	1	0	0	0	0	0	0	(
Potassium	0	1	0.876	0.53	0	0	0	(
Uranium	0	0	1	0.375	0	0	0	(
Thorium	0	0	0.051	1	0	0	0	(
Man-Made	0	0	0	0	1	0	0	(
MM High	0	0	0	0	0	1	0	(
Cs-137	0	0	0	0	0	0	1	(
Uranium H...	0	0	0	0	0	0	0	:
Low Energy	0	0	0	0	0	0	0	(
Cosmic	0	0	0	0	0	0	0	(

Dose Rate computation

Dose Calibration Factor 0.043486

Dose Altitude Beta 0.005400

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude 1.0000000

Reference Altitude Area specif [m]

Altitude field GPS Altitude (HAE)

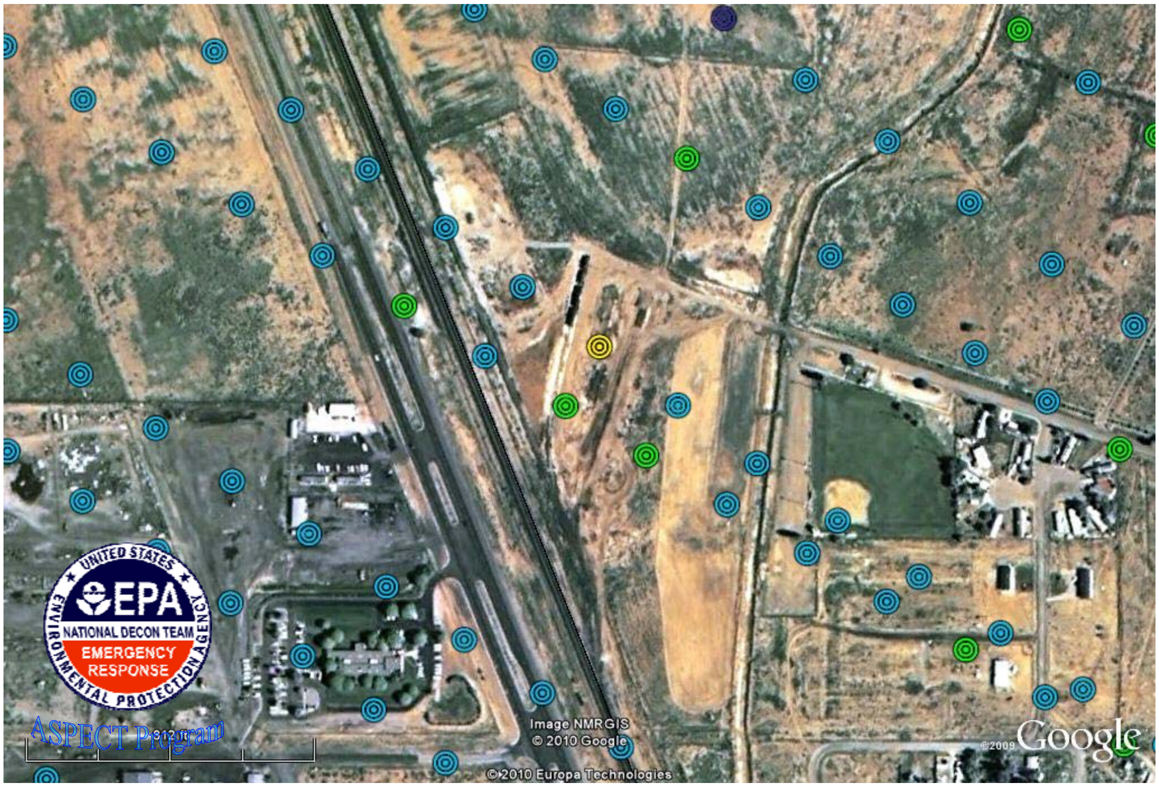
Fixed Altitude 0.0000 [m]

Cancel OK

Image 6: This screen-shot from the RAD-Assist Program shows the calibration coefficients used in the determination of Uranium concentrations for this report.

Appendix III

Images of Contour Plots and Sigma Points



References

[1] Department of Energy [2001]. An Aerial Radiological Survey of Abandoned Uranium Mines in the Navajo Nation. Overview of Acquisition and Processing Methods Used for Aerial Measurements of Radiation Data for the U.S. Environmental Protection Agency by the Department of Energy. Authored by Thane J. Hendricks. DOE/NV/11718—602.

[2] Bristow, Q. Airborne γ-Ray Spectrometry in Uranium Exploration. Principles and Current Practice. Int. J. Appl. Radiat. Isot. Vol 34. No.1 pp. 199-239, 1983.

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[4] International Atomic Energy Agency [1991]. Airborne Gamma Ray Spectrometer Surveying. Technical Report Series No. 323. IAEA, Vienna.

[5] International Atomic Energy Agency [2003]. Guidelines for radioelement mapping using gamma ray spectrometry data. IAEA-TECDOC-1363, Vienna.