US EPA ASPECT
An Aerial Radiological & Photo Survey of Abandoned Uranium Mines On or Near the Navajo Nation

June-July 2018

USEPA ASPECT

Prepared by:
CBRN Consequence Management Advisory Team
Airborne Spectral Photometric Environmental Collection Technology
ASPECT Program

Finalized by:
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Deployment in Support of:
EPA Regions 6 and 9

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Executive Summary

The aerial surveys were separated into two areas, the Eastern Navajo and Western Navajo locations. The purpose of these radiological surveys was to identify surface areas with radiation and uranium concentrations that are out of balance with natural background concentrations. This is done by comparing the measured results to a selected background location known not to contain abandoned uranium mine waste or large areas with natural geologic formations containing elevated concentrations of natural uranium material, known as outcroppings. Nevertheless, the results presented in this report do not conclusively distinguish between naturally-occurring uranium and technologically-enhanced uranium concentrations that are the result of human activities. Rather, as noted throughout this report, making this determination requires additional ground-based field work and examining multiple lines of evidence. The aerial radiological survey performed with ASPECT is useful for providing EPA with information about locations where such ground-based field work may be appropriate. The radiological and photo surveys were completed over 21 flights, covered nearly 400 square miles and collected more than 140,000 one-second spectra.

Eastern Agency

The ASPECT surveys in the Eastern Agency supplement the ground-based removal site evaluations for 22 mines in various stages in the cleanup process. These surveys can (1) quickly survey the larger area surrounding the mines to confirm that there are not significant areas of contamination that may be non-contiguous with the mine sites and (2) will provide another line of evidence that the Removal Site Evaluations adequately captured the extent of contamination. Any unanticipated areas identified with significant contamination may require supplemental ground investigations.

The Eastern Agency surveys were completed during 4 flights, covered more than 30 square miles of land, and collected about 13,000 one-second spectra. Radiological products requested by Region 9 included contour maps for equivalent uranium (eU) concentration contour maps, equivalent thorium (eTh) concentration contour maps, probability of uranium present (PUP) contour maps, and probability of thorium present (PThP) contour maps.

Western Agency

In the 1990s, EPA Region 9 requested the Department of Energy, Remote Sensing Laboratory to conduct aerial surveys within the Navajo Nation. Forty-one surveys covering just over 1,100 square miles were completed between 1994 and 1999. Since then, several areas have had cleanup activities performed by a several authorities. The ASPECT surveys in the Western Agency (1) contribute knowledge to earlier surveys, and (2) provide additional coverage in areas not included in the earlier surveys.

EPA has identified 111 abandoned uranium mines (AUMs) in the Western Agency of the Navajo Nation. Most of the mines are found within the former Bennett Freeze area. In 1966, Robert Bennett, the Bureau of Indian Affairs (BIA) director, halted development on tribal land claimed by both the Navajo and Hopi tribes. The Bennett Freeze limited Navajo and Hopi residents from developing their communities by prohibiting building and repairing homes, road and infrastructure improvements, including connecting structures to electric, gas, or water lines. In 2009, the Bennett Freeze was lifted and the impacted chapters are looking to develop but planning is complicated by the fact that dozens of uranium mines are in these areas. Options for future land use and development are also being considered on a regional level.

The Western Agency surveys were completed during 21 flights, covered more than 350 square miles of land, and collected nearly 130,000 one-second spectra. Radiological products requested by Region 9 included contour maps for equivalent uranium (eU) concentration contour maps, probability of uranium present (PUP) contour maps, and anomaly contour maps. The later product was developed for only one area that had severe topography challenges (e.g. altitude deviations greater than 400 ft).

Radiological products presented in this report are accompanied with descriptive captions to identify unique features or observations of the results (e.g., natural outcroppings, known mining areas, and other areas that may warrant further ground-based characterization).

Approximately 2,000 high resolution digital aerial photographs were taken over the survey areas. 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.

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Acronyms and Abbreviations

AGL	above ground level
ASPECT	Airborne Spectral Photometric Environmental Collection Technology
AUM	Abandoned Uranium Mines
Bi	Bismuth
CBRN	Chemical, Biological, Radiological and Nuclear
Ci	Curie
cps	counts per second
EPA	Environmental Protection Agency
eU	Equilibrium Uranium based on ^{214}Bi region of interest
eTh	Equilibrium Thorium based on ^{208}Tl region of interst
FOV	Field of view
ft	feet
FWHM	full width at half maximum
g	gram
GPS	Global Positioning System
K	Potassium
MeV	Mega electron volts
NaI(Tl)	Sodium iodide thallium drifted detector
NIST	National Institute of Standards and Technology
NORM	Naturally Occurring Radioactive Material
pCi	picocurie (10^{-12} Curies)
PThP	Probability of Thorium Present
PUP	Probability of Uranium Present
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 Introduction

This report summarizes the technologies, processing methods, and results for the aerial surveys to identify areas where uranium concentrations are out of balance with the surrounding environments within certain areas of the Eastern and Western Navajo Nation Mining Regions. Elevated concentrations of uranium at the ground surface were created as a result of mining activities, uranium ore waste piles, or from outcroppings of natural uranium deposits near the surface.

2 Background and Survey Area Descriptions

Portions of the Navajo Nation are located on geologic formations rich in radioactive uranium ores. Beginning in the 1940s, widespread mining of uranium ore on Navajo Nation tribal lands for national defense and energy purposes led to a legacy of abandoned uranium mines (AUM) and AUM waste sites.[1] Many Navajo people worked the mines, often living and raising families in close proximity to the mines and mills. Today the mines are closed, but a legacy of uranium contamination remains, including over 500 abandoned uranium mines (AUMs) as well as homes and water sources with elevated levels of radiation. EPA maintains a strong partnership with the Navajo Nation and, since 1994, the Superfund Program has provided technical assistance and funding to assess potentially contaminated sites and develop a response.

2.1 History of Aerial Surveys on the Navajo Nation and in the Grants Mining District

In the 1990s, EPA Region 9 requested that the Department of Energy, Remote Sensing Laboratory conduct aerial surveys within the Navajo Nation. Forty-one surveys covering just over 1,100 square miles were completed between 1994 and 1999. These surveys identified 15 square miles (about 1.3% of the survey land) had excess bismuth indications above the minimum reportable activity. [2]

In the summer of 2014, the US EPA Region 9 requested that the CBRN Consequence Management Advisory Division (CMAD) ASPECT Program conduct aerial radiological and photographic surveys over about 180 square miles in and near the Lukachukai Mountains (Cove area) within the Navajo Nation. That survey overlapped with some of the earlier aerial surveys conducted by the DOE. The ASPECT surveys were completed between December 2014 and May 2015 and those results are provided in another report.[3]

In addition, in the Fall of 2011, the US EPA Region 6 requested that the CBRN Consequence Management Advisory Division (CMAD) ASPECT Program conduct aerial radiological and photographic surveys aerial surveys of approximately 20 square miles of land in the Grants, New Mexico area. This survey included a few of the very easternmost Navajo Abandoned Uranium Mines in the Eastern Agency and those results are provided in another report (https://www.epa.gov/grants-mining-district/aerial-radiological-survey-poison-canyon-uranium-mines).

In 2018, the US EPA Regions 6 and 9 requested additional aerial radiological and photographic surveys covering about 400 square miles within the Navajo Nation. The 2018 aerial survey results are included in this report. The 2018 mission consisted of two distinct sub-missions. ASPECT flew mines in the Eastern Agency near Gallup, New Mexico and the Grants mining district at the request of Regions 9 and 6. ASPECT also flew a relatively contiguous area in Western Navajo at the request of Region 9 to discern the impacts, if any, of surface mines in that area.

2.2 ASPECT Eastern Agency Surveys

The Eastern Navajo Nation Mine Sites are mostly distinct from each other and scattered across the Eastern Agency. Typically mines on the Eastern Agency accessed underground (~300 ft to 1,800 ft below the ground surface) ore bodies such that most of these mines do not have surface expressions of the ore. Therefore, surface contamination can be easily attributed to mining activities for most Eastern Agency mines. EPA Region 9 out of San Francisco, CA has jurisdiction over mine sites on Navajo Nation and EPA Region 6 out of Dallas, TX has the lead for mines and Superfund sites located on private land in the state of NM, including the United Nuclear Corporation (UNC) Mill Site. EPA currently has funds available to oversee the cleanup process at 22 mines or approximately 26% of the mines in or near the Eastern Agency of the NavajoNation (Figure 1). Removal Site Evaluations have either been completed or are in progress for these 22 mines.

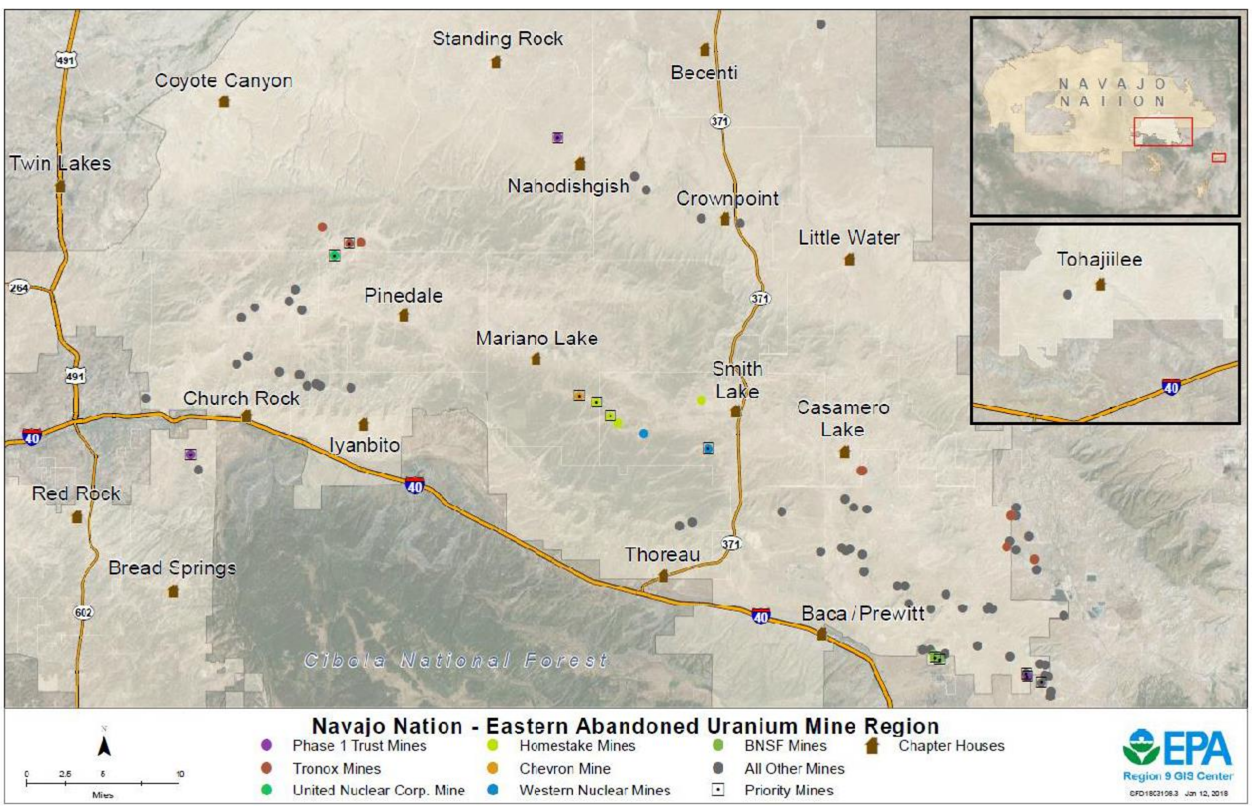


Figure 1: Abandoned Uranium Mines in the Eastern Agency of the Navajo Nation.

The purpose of the APECT flight in the Eastern Agency is to supplement the ground-based removal site evaluations for the above described mines in various stages in the cleanup process. Ground investigations focus efforts on known features based on existing records and information from the mining companies, employees, local residents, or other sources and step out from areas of known contamination until the contamination is bounded. However, the ASPECT flights can quickly survey the larger area surrounding the mines to confirm that there are not significant areas of contamination that may be non-contiguous with the mine sites. Areas such as undocumented vent holes, isolated truck spills, ponds, or transfer stations are examples of contaminated areas that may not be contiguous with the mine site that could be picked up by ASPECT if there are significant levels of contamination associated with these sites. The ASPECT flight will provide another line of evidence that the Removal Site Evaluations adequately capture the extent of contamination. Any unanticipated areas of significant contamination identified may require supplemental ground investigations.

The ten survey areas in the Eastern Agency included: (1) Blackjack No.1 (Blackjack1), (2) Northeast Church Rock Mine, Kerr-McGee-Quivira Mine, and United Nuclear Corporation Mill Site (NECR/Quivira/UNC) (3) Eunice Becenti, (4) Evelyn, (5) Haystack, (6) Mariano Lake/Mac1&2/Black Jack2/Ruby1, (7) Old Church Rock Mine, (8) Ruby3, (9) Section 32-33 and (10) Standing Rock (Figure 2). Of the 22 mines identified in Figure 1, some of these mines located in the most southeastern portion of the Navajo were flown as part of previous efforts flying survey areas within the Grants Mineral Belt Area. Between these two ASPECT deployments, all of the 22 mine sites will have been flown.

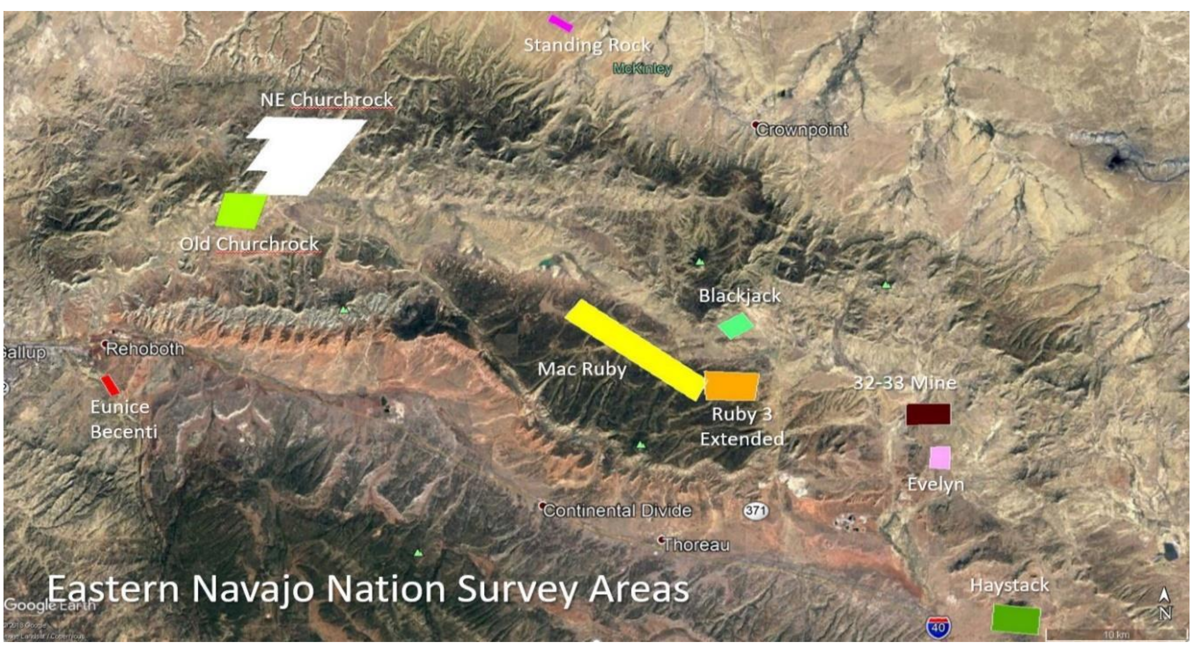


Figure 2: Eastern Navajo Nation agency survey areas designated by name. These surveys were completed during 4 flights, covered more than 30 square miles of land, included 16 abandoned uranium mine sites and one mill site. About 13,000 one-second spectra were collected.

2.3 ASPECT Western Agency Surveys

The Western agency is located entirely within Coconino County (AZ) on the western side of Navajo Nation, and includes the areas of Navajo Nation roughly between Flagstaff, AZ and Page, AZ. This agency is made up of 7 Navajo Nation Chapters (Cameron, Coalmine Canyon, Bodaway/Gap, Tuba City, Leupp, Coppermine, and Lechee) and AUMs are located in Cameron, Coalmine Canyon, Bodaway/Gap, and Leupp Chapters. Western agency also encompasses mines in the checkerboard area of Arizona which are all found within 1 mile of the Navajo Nation's southern border.

EPA has identified 111 AUMs in the Western agency. The majority of these mines are accessed using Highway 89 or Indian Route 6730 along the Little Colorado River. Most of the mines are found within the former Bennett Freeze area. In 1966, Robert Bennett, the Bureau of Indian Affairs (BIA) director, halted development on tribal land claimed by both the Navajo and Hopi tribes. The Bennett Freeze limited Navajo and Hopi residents from developing their communities by prohibiting building and repairing homes, road and infrastructure improvements, including connecting structures to electric, gas, or water lines. In 2009, the Bennett Freeze was lifted and the impacted chapters are looking to develop but planning is complicated by the fact that dozens of uranium mines are in these areas. Options for future land use and development are also being considered on a regional level.

The Western agency also contains the proposed haul route for uranium ore sourced from the Canyon Mine located on the South Rim of the Grand Canyon. The ore would be taken through jurisdictional boundaries of the Navajo Nation to the White Mesa Mill located in Blanding, UT. (Figure 2).

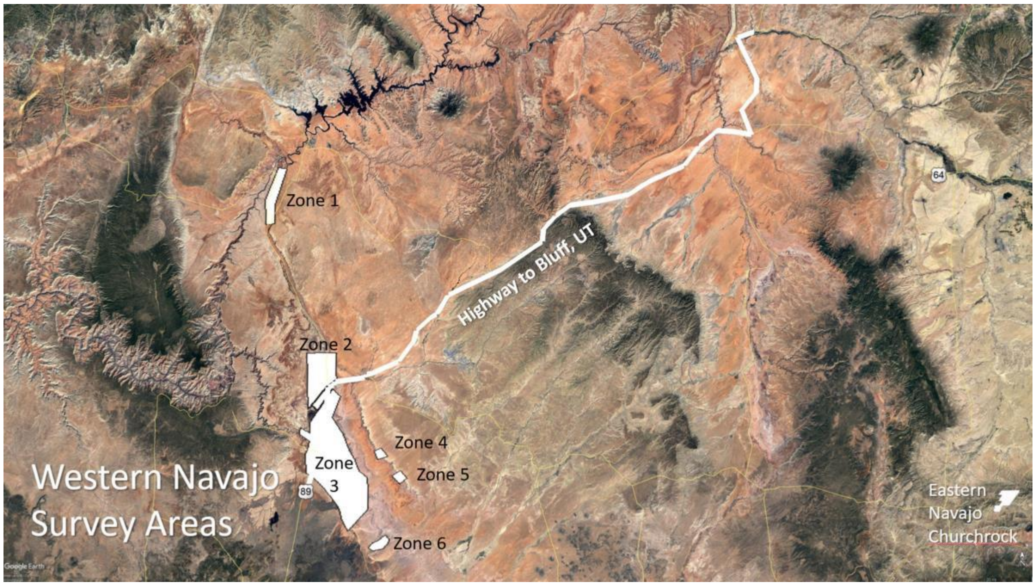


Figure 3: Western Navajo Nation agency survey areas designated by Zones and the main highway to Bluff, Utah where much of this uranium was transported to for processing. This area covered more than350 square miles of land.

3 Data Analyses

3.1 ASPECT Radiological Data Processing

The ASPECT program calibrates its radiological instrumentation according to the International Atomic Energy Agency specifications.[4] Radiological spectral data, GPS position, and radar altitude are collected at a one-second interval at all times during a survey. In order to provide optimal collection geometry, flight line parameters are loaded into the aircraft flight computer prior to conducting the survey. Typical airborne surveys were flown at 500 feet AGL, however, due to the extreme topography at some of the survey locations within the Navajo Nation, not all surveys were able to be flown at the target altitude. See the results section for actual flight parameters for each flight.

Most of the radiological products were processed automatically using standard routine airborne algorithms. Two products were requested for this report: (1) equivalent uranium (eU) concentration contour map when these could be generated with sufficient accuracy (e.g., minimal altitude artifacts, sensitivity coefficients, and radon correction), (2) the probability of uranium present (PUP) contour. In some cases, additional products for thorium were provided when higher concentrations of naturally occurring thorium were detected and an anomaly contour which identifies areas with abnormal spectral signatures relative to background that may require additional ground-based assessment (typically done for areas with torturous topography).

For a uranium survey, care must be taken to account for the background levels of uranium as described above. ASPECT uses algorithms that focus on the gamma emissions (609 keV and 1764 keV) from Bismuth-214 instead of uranium. An assumption that uranium decay products are in equilibrium is made.

Several environmental factors, such as moisture and topography, 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. Extreme topography changes, like mountainous terrain, introduce height correction anomalies that prevent an accurate representation of surface contamination. Appendix II provides more details on the equilibrium considerations for aerial spectroscopy. For these surveys, there were no rainfall events and only one area (Zone 1, Western Agency) had extreme topography challenges.

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 quality spectral 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 may be removed from further analyses. 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. Prior to the survey, a sixty second QA/QC spectrum is also collected. 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 RadAssist Software Application, Version 5.7.1.0 (Radiation Solutions, Inc., 386 Watline Avenue, Mississauga, Ontario, Canada) was used to produced contour maps of:

(1) **concentration contours for eU (equivalent uranium)** (pCi/g),
(2) **concentration contours for eTh (equivalent thorium) where applicable** (pCi/g), and
(3) **anomaly contours where applicable**.

The ENVI Software Application, Version 5.5 (API Version 3.2; Harris Geospatial Solutions, Inc., 385 Interlocken Crescent, Suite 300, Broomfield, CO 80021) was used with the ASPECT software (Version 12.12.3.0) to create contour maps of:

(4) **probability of uranium present (PUP) contours**, and
(5) **probably of thorium present (PThP) contours (where applicable).**

3.1.1 eU and eTh concentrations

Equivalent uranium or thorium concentrations are calculated using the algorithms described by the IAEA[4]. The steps are summarized in Figure 4. It should be noted that this approach works best when the land is flat. It is not recommended for torturous terrain common in mountainous areas due to significant deviations associated with height correction within the algorithm. All areas in the Eastern Agency were able to be characterized using this approach and all areas in the Western Agency, except for Zone 1, used this approach.

RadAssist eU & eTh concentration method

↓

Live time correction

↓

Subtract cosmic and aircraft background contribution (coefficients)

↓

Radon was accounted for when calibration coefficients were adjusted to produce eU concentration contour maps.

↓

Perform stripping correction only for eU and eTh concentration products

↓

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

↓

eUranium Concentration (pCi/g)
eThorium Concentration (pCi/g)

Figure 4: Steps to derived surface concentration estimates for uranium or thorium from ASPECT surveys.

3.1.2 Anomaly contours

The anomaly contour product is a function provided within the RadAssist Software package. It is a tool designed to identify abnormal spectral patterns as compared to an expected background spectrum based on a running average. The product is achi-square metric which is used to determine the statistical difference between the two spectral patterns. A high number suggests there is a greater probability of statistical difference and a low number suggests there is no difference. Values exceeding 5 may warrant further ground-based characterization activities. This function was used for Zone 1 in the Western Agency of the Navajo Nation because of the mountainous terrain in that area.

3.1.3 Probability of Uranium Present (PUP)

Probability of Uranium Present (PUP) and Probability of Thorium Present (PThP) products are derived from a new pattern recognition algorithm developed by the ASPECT team[5,6]. The approach consists of coupling digital filtering and nonparametric linear discriminant analysis to produce classification models (classifiers) to judge the presence or absence of the gamma-ray spectral signatures of specific radioisotopes. A novel feature of this work includes the development of confidence models to allow the output from the classification models to be associated with the percent probability of a correct detection.

3.2 How to Interpret ASPECT Products

3.2.1 Equivalent Uranium (eU) and Equivalent Thorium (eTh) products

The results are presented as equivalent uranium (eU) and equivalent thorium (eTh). The term "equivalent" simply means that the results were based on measurements of the gamma emissions of progeny that are easier to measure. The equivalent Uranium (eU) contours are calculated from the measurements of gamma emissions from Bismuth-214, one of the strongest gamma emitters in the Uranium-238 decay chain. The activity for Bi-214 is then representative for all products in the U-238 decay chain under secular equilibrium, so the result for eU in pCi/g is comparable to the concentration of Ra-226 in pCi/g.

The gamma readings from the instruments in the plane are converted to represent ground conditions based on several elements including topography, speed of the plane, height of the plane, and calibration factors. The calibration factors were determined from flying over areas of known uranium (and decay chain products) concentrations near Lake Mohave, NV (June 18, 2018) and calibration pads (June 17, 2018) at the municipal airport in Grand Junction, CO. Because topography like canyons and cliffs have a large effect on the readings, the correlations are better in areas with relatively flat terrain.

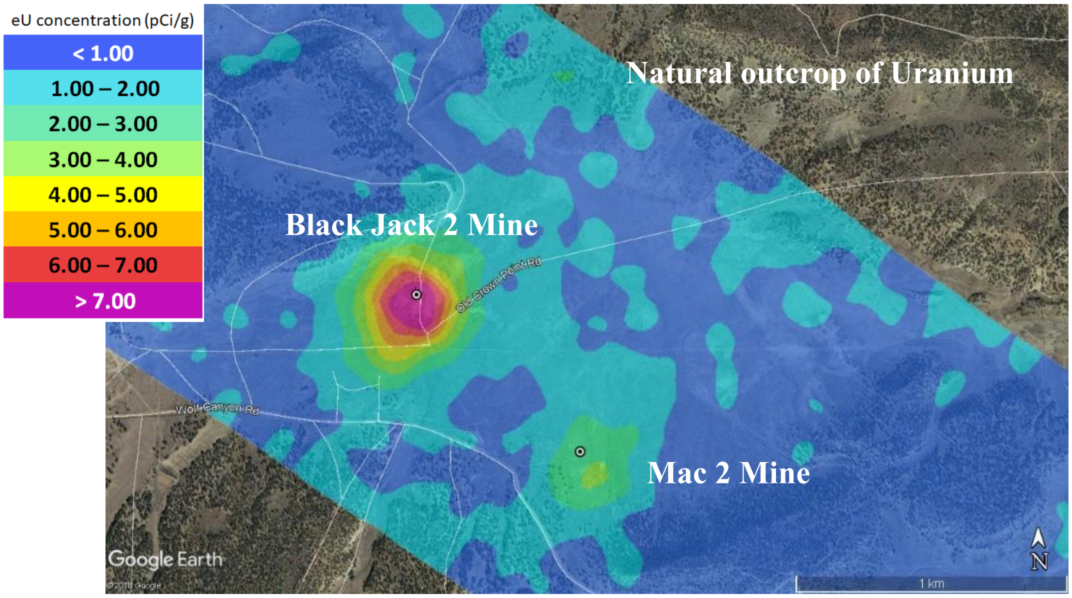


Figure 5: Example eU concentration contour showing two abandoned uranium mines and a small area of elevated uranium concentration associated with a natural outcrop. The dots represent the mine locations. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions****.*

The eU concentration contour map provides an estimate of uranium concentration on the surface including background (e.g., the blue to light blue colors). These may appear busy due to the narrow range of concentrations for each color selected to create the product. The range was arbitrarily selected to expose subtle changes in surface concentrations, helping to identify natural outcrops of uranium deposits. As described below, the probability of uranium present (PUP) product filters out the areas with concentrations associated with background levels and so reduces the business or noise associated with all of the color variations in the eU maps.

The Equivalent Thorium (eTh) contours are measurements of gamma emissions from Thallium-208, one of the strongest gamma emitters in the Thorium-232 decay chain. Similar to the eU process, secular equilibrium is assumed throughout the decay chain to estimate concentrations (pCi/g) for Thorium-232 based on the calibration flights and calibration pads described above. The eU and eTh concentration contour maps include naturally occurring background concentrations in soil for the Uranium-238 or Thorium-232 decay chain, respectively. However, each is exclusive such that the eU maps do not include radiation contributions from eTh (or other gamma emitters) and vice versa.

3.2.2 Probability of Uranium Present (PUP)

The Probability of Uranium Present (PUP) contour maps identify areas with Uranium concentrations that are at statistically significant levels above the natural background Uranium concentrations. Therefore, in the PUP product figures, all background has been filtered out. These maps can be used in conjunction with the eU concentration contour maps to understand what concentrations are associated with background levels from the Uranium-238 decay chain (shown in black on the PUP maps) and for the levels that are above background at statistically significant levels (shown in white on the PUP maps). Note that the PUP algorithms may mis-interpret background in some situations such as when a mine site is relatively large with a reclamation cover with lower surface concentrations of eU. Ruby 1, Ruby 3, and Quivira CR1 are examples of mines with this effect. (See Section 3.1 for additional discussion of background.)

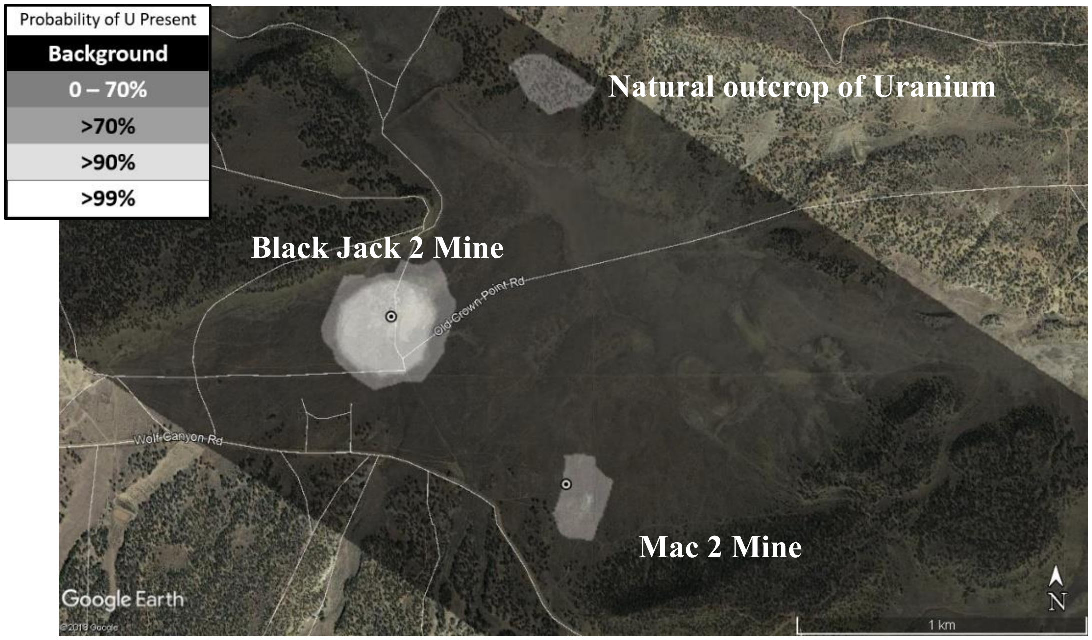


Figure 6: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). Highlighted areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

Other Considerations

1) **Surface vs. Subsurface Contamination**

The ASPECT plane can only detect surface contamination and does not reflect contamination that may be in the subsurface. Figure 39 shows an example of this effect. The UNC Mill tailings cells have a final cover in place except in the area of the evaporation ponds which are still being used for the groundwater pump and treat system. Because the majority of the mill tailings are below a thick layer of clean soil, including a radon barrier, the ASPECT detectors cannot detect the subsurface contamination that we know is present within the tailings repository. Another example is the Quivira CR-1 and the NECR-1 waste piles. These waste piles have temporary soil covers. Although we know that these piles include hundreds of thousands cubic yards of contaminated waste, they do not appear on the figures as significantly elevated due to the temporary cover. Only ground-based subsurface investigations can identify subsurface waste piles.

2) Naturally Occurring vs. Mining Related Uranium

While the eU and eTh maps combined with the PUP maps identify areas with radiation at statistically significant levels in the surface soils, these results alone do not provide an indication of what contamination is from natural surface expression of the ore bodies vs. anthropogenic mining activities. Figures 4 and 5 provide a good example of demonstrating where there is both mining contamination and surface expression of ore. We know where the mining contamination is located through research of historical records and aerial photographs as well as field investigations. The location of natural outcrops can similarly be determined through our knowledge of the local geology as well as field investigations and research of historical records. Since the Eastern Agency primarily had underground mining activities, it can be simple to distinguish between these two sources of contamination since most of the contamination is related to mining. However, in the Western Navajo Nation where there was surface mining, it can be more difficult to distinguish between the two sources of radiation.

3) Field of View

The eU and eTh concentration contours and PUP and PThP contours provide a general trend of areas containing elevated uranium or thorium presence. They should be interpreted with the field-of-view of the system in mind when comparing these results to ground-based or soil samples. ASPECT products average the signal associated with a much larger area than ground-based *in-situ* measurements or soil samples, therefore, these results can vary by orders of magnitude (Figure 7). 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. See Appendix II for more explanation on the impact of field-of-view for these systems.

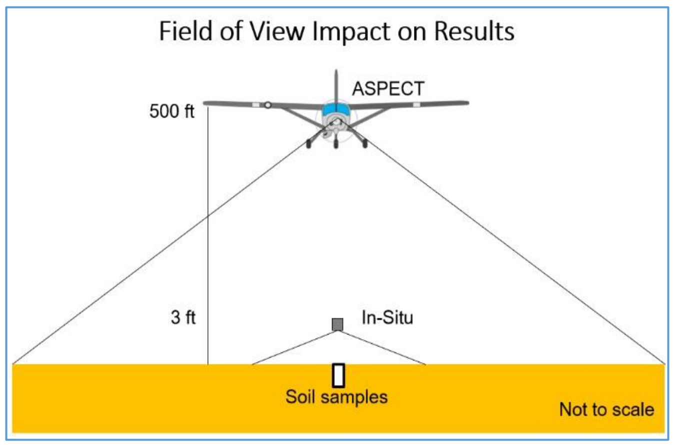


Figure 7: Field-of-view comparison between aerial, ground-based in-situ measurement, and soil samples.

3.2.3 Anomaly Contour

High numbers (>5) associated with the anomaly contour map suggest there is a greater probability of a statistical difference between the measured datum and an expected datum point (e.g., background). This result is not unique to uranium or thorium. It only provides an indication that the spectral data for that datum point is different from an expected background. A spectral analysis is conducted to determine if the difference is due to excess uranium, thorium, or any other radiation emitting nuclide. The method is useful for environmental surveys because it only compares spectral patterns which are less affected by mountainous terrain with extreme height variations. This product was only used for Zone 1 in the Western Agency of the Navajo Nation. See Figure 57 for more details.

3.3 Visible Imagery Data Processing

Visible imagery collected with the ASPECT System is ultimately processed into a geo-registered geo-jpeg or geo-tiff format image. Image processing is composed of two primary steps including image enhancement and geo-registration. Both of these processing steps can be processed while the aircraft is in flight status. Typically, imagery is processed in the aircraft at a moderate resolution that can be passed to the ground through a satellite communication system. Although the highest resolution images can be processed while the aircraft is in the air on a mission, these photos are generally processed on the ground after the aircraft lands. A standard flight mission often generates 600 aerial images and provides coverage of about 55 square miles.

The ASPECT aerial camera consists of a still frame 3x4 ratio digital camera that contains 24 million pixels. A wide field of view lens is utilized to match the ground width coverage of the line scanner system. Due to the speed of the aircraft and the fact that ASPECT may fly in low light conditions, the camera uses a fixed focus that can be adjusted remotely and shutter speed configuration set upon flight conditions. Raw imagery is subsequently processed to balance contrast and saturation of each image. In addition, since a wide-angle lens is used, edge distortion is corrected using a custom-built camera model. Both of these overall algorithms are executed automatically in a batch processing system.

The ASPECT camera is fix-mounted to the primary optical base plate. The camera axis is bore sighted to within 0.5 degrees to the axis centers of the other optical systems. While images are being collected, a concurrent system collects both GPS data and inertial data to provide a high-resolution pitch, roll, and yaw correction dataset. An automatic software package merges these data set and geo-corrects each image using a triangular correction mode. The resulting images statistically show less than 11 meters of center frame positional error and less than 1 degree of rotational error. As with the frame enhancement processing, geo-registration is accomplished in a batch mode at a rate of approximately 800 images per hour. Following registration, images can be directly used by the responder or further corrected with minor positional and rotation corrections (Figure 8).

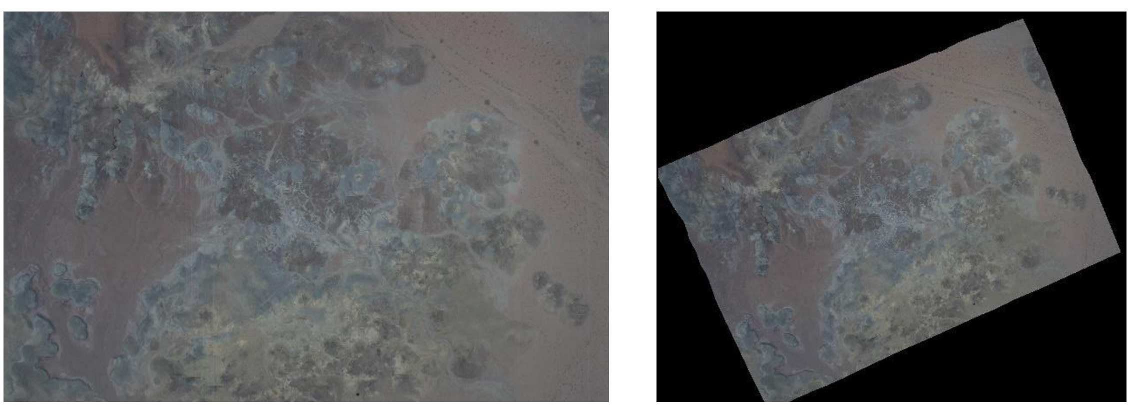


Figure 8:(Left) Uncorrected Aerial image taken from ASPECT at about 2,800 feet. (Right) Same image that has been geo- and ortho-corrected corrected that can be displayed in any GIS software applications (e.g. Google Earth, ESRI).

Oblique digital photography is processed to capture the situational environment from the perspective of the flight crew (See Section 3.3). All frames are collected from the right side of the aircraft at approximately 45 degrees from the nose of the aircraft. During automated processing, GPS data is used to provide the position that the frame was collected and the direction that the frame was collected is determined from the track of the aircraft and the relative direction that the camera was operated from within the aircraft.

4 Results

4.1 Overall Radiological Results

ASPECT conducted aerial radiological surveys over the Navajo Nation Eastern Agency region from June 19th through June 23rd, 2018. These surveys were completed during 4 flights, covered more than 30 square miles of land, included 22 abandoned uranium mine sites, and collected nearly 13,000 one-second spectra. Table 5 lists flight-specific details for the Eastern Agency region.

Aerial surveys over the Navajo Nation Western Agency region were completed between June 25th through July 6th, 2018. These surveys were completed during 21 flights, covered 350 square miles, and collected nearly 130,000 one-second spectra. Table 6 lists flight-specific details for the Western Agency region.

Radiological products included contour maps for equivalent uranium (eU) concentration, Probability of eU Present (PUP) contour maps, and an anomaly contour map. Areas where naturally occurring high concentrations of Thorium were present, additional eTh concentration contours and the Probability of eTh Present contour maps were developed.

Each product is accompanied by a descriptive caption that summarizes the key observations from the survey.

TABLE 5: ASPECT Flight Metrics for Radiological Surveys in Eastern Agency Navajo Nation

Survey Area	*Date*	*Flight #*	*Area (miles^2)*	*# Data Points*	*Avg AGL (ft)*	*Temp (ºF)*	*Pressure (mbar)*	*Comments*
Black Jack 1	6/20	3	1.2	453	565 ± 31	86	1011	1700 – 1745 hrs UTC.
Eunice Becenti	6/20	3	0.4	188	496 ± 70	91	1010	1800 – 1830 hrs UTC.
Evelyn	6/20	3	0.9	427	487 ± 37	77	1012	1500 – 1530 hrs UTC.
Haystack	6/20	3	2.6	1029	604 ± 140	57	1012	1330 – 1430 hrs UTC.
Mariano Lake Mac1&2 Black Jack 2 Ruby 1	6/20	3	7.8	2950	517 ± 56	90	1010	2000 – 2100 hrs UTC
NECR Quivira UNC	6/19	1	12.8	4571	451 ± 87	82	1005	1600 – 2000 hrs UTC.
Old Church Rock Mine	6/23	4	3.0	1215	577 ± 59	92	1000	2315 – 0045 hrs UTC
Ruby 3	6/20	3	3.2	1177	511 ± 43	90	1010	2115 – 2200 hrs UTC.
Section 32-33	6/20	3	2.1	806	518 ±68	82	1012	1545 – 1630 hrs UTC
Standing Rock	6/19	2	0.4	140	430 ± 56	86	1009	2200 – 2330 hrs UTC.

* Flight times are approximate and exclude travel to and from the survey area. UTC is coordinated universal time. Local time in the Eastern Navajo Nation is six hours behind UTC. The sensitivity coefficient to convert cps to pCi/g was 16.38. There were no significant radon interferences for the Eastern Agency surveys.

TABLE 6: ASPECT Flight Metrics for Radiological Surveys in Western Agency Navajo Nation

Zone	*Date*	*Flight #*	*Area (miles^2)*	*# Data Points*	*Avg AGL (ft)*	*Temp (F)*	*Pressure (mbar)*	*Sen Coef (cps per pCi/g)*	*Comments**
1a	7/6	21	21	4291	765 ± 212	79	1034	NA	1300 – 1730 hrs UTC. Rough terrain prevented conversion to pCi/g so the anomaly function was used to identify area that may warrant further ground-based activities. Line spacing was 500 ft.
1b	7/6	21	13.2	2828	643 ± 222	79	1034	NA	
2a	6/25	1	13.6	5869	522 ± 43	81	1023	16.38	1830 – 2230 hrs UTC.
2b	6/26	2	21.5	9068	543 ± 71	79	1026	27	1400 – 1830 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects.
2c	6/26	3	20.3	8055	542 ± 90	88	1024	16.38	2030 – 0000 hrs UTC.
2d	6/27	4	12.3	5017	516 ± 61	78	1026	27	1430 – 1700 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects.
3a	6/27	4	2.4	957	518 ± 54	86	1025	16.38	1730 - 1830 hrs UTC.
3b	6/27	5	6.8	2670	525 ± 60	86	1023	16.38	2200 – 2400 hrs UTC.
3c	6/28	6	33.1	10950	502 ± 54	67	1022	30	1300 – 1730 hrs UTC Radon interference. Sensitivity coefficient was changed to reduce radon affects.

Zone	Date	Flight #	Area (miles²)	# Data Points	Avg AGL (ft)	Temp (F)	Pressure (mbar)	Sen Coef (cps per pCi/g)	Comments*
3d	6/28	7	19.4	7087	518 ± 55	82	1022	16.38	1930 - 2100 hrs UTC.
3e	6/29	8	34.9	12174		64	1022	30	1300 - 1730 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects.
3f	6/29	9	23.4	8540	527 ± 59	77	1021	16.38	1930 - 2300 hrs UTC.
3g	7/1	11	32.1	10807	505 ± 70	70	1027	27	1300 – 1700 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects.
3h	7/1	12	12.4	4197	488 ± 66	84	1024	16.38	2115 - 2300 hrs UTC.
3i	7/2	13	24.3	7799	499 ± 54	73	1026	27	1330 – 1730 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects.
3j	7/2	14	24.6	8421	497 ± 66	84	1023	16.38	1930 – 2315 hrs UTC.
3k	7/3	15	4.9	1714	574 ± 77	73	1025	27	1300 – 1730 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects.
4a	7/3	16	1.6	738	497 ± 38	79	1024	16.38	1900 – 2030 hrs UTC.
4b	7/4	17	3.4	1386	625 ± 127	79	1028	30	1300 – 1730 hrs UTC. Radon interference. Sensitivity coefficient was changed to reduce radon affects for each Zone.
5	7/4	17	6.0	2231	537 ± 63	79	1028	30	
									1300 – 1730 hrs UTC.

Zone	Date	Flight #	Area (miles²)	# Data Points	Avg AGL (ft)	Temp (F)	Pressure (mbar)	Sen Coef (cps per pCi/g)	Comments*
6a	7/4	17	0.8	295	478 ± 28	79	1028	30	Radon interference. Sensitivity coefficient was changed to reduce radon affects for each Zone.
6b	7/5	19	9.4	3414	503 ± 39	70	1031	40	1300 – 1700 hrs UTC
Bridge	7/5	19	8.6	3318	531 ± 45	70	1031	40	Radon interference. Sensitivity coefficient was changed to reduce radon affects for each Zone
Route 89, 160, & 161	6/30	10	148#	6091	430 ± 79	70	1025	16.38	1400 – 1530 hrs UTC. Tuba City Airport Open House. Flight altitude was targeted for 400 ft above ground level
	7/1	12	30#	1319	399 ± 85	84	1025	16.38	2000 – 2030 hrs UTC.
TOTALS			**350**	**129236**					

* Flight times are approximate and exclude travel to and from the survey area. UTC is coordinated universal time. Local time in the Western Navajo Nation is seven hours behind UTC.

Linear miles of roadway surveyed not included in the area total.

4.2 Eastern Agency Results

4.2.1 Black Jack 1 Mine

Black Jack No. 1 is a closed underground uranium mine located in McKinley County, NM within the Smith Lake Chapter of the Navajo Nation. The mine workings consisted of an 825 foot, three-compartment shaft with multiple drifts. The mine was operated from 1959 through 1967, although uranium deliveries from the mine continued until 1971. In total, the mine produced approximately 1.4 million tons of ore yielding approximately 6.5 million pounds of concentrate. Homestake Mining Co. is the responsible party and will finish the Removal Site Evaluation for the site in 2018.

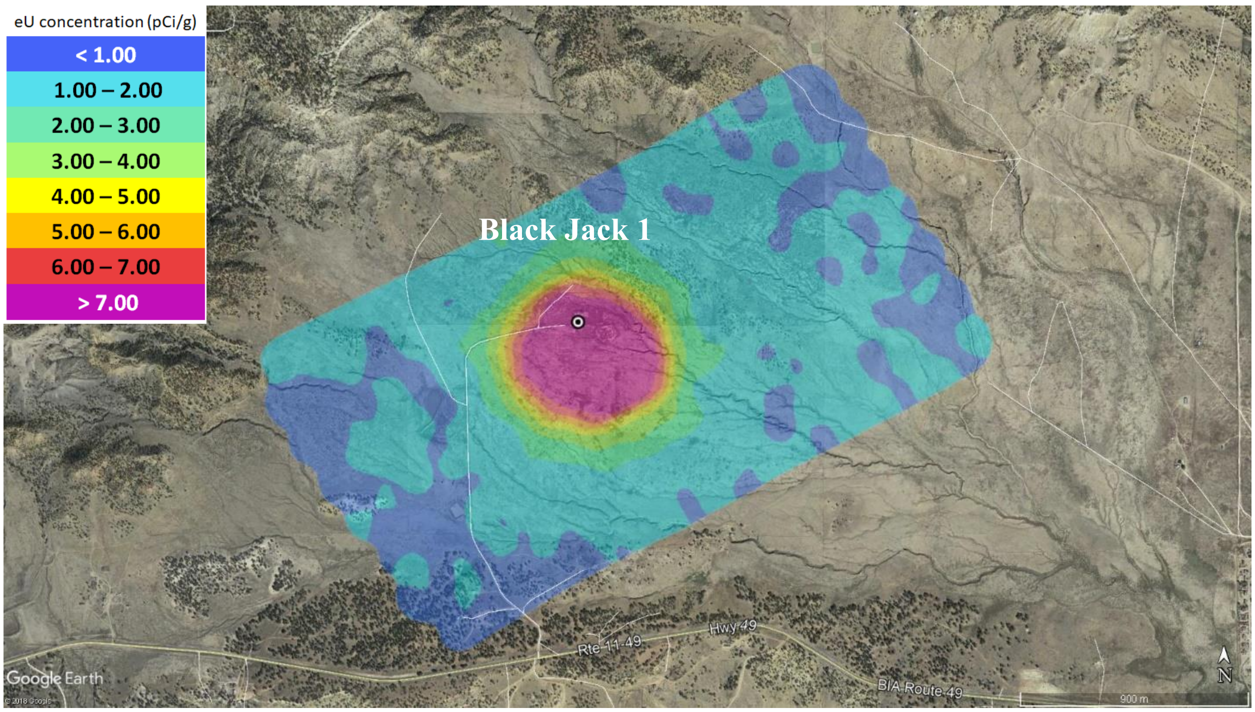


Figure 9: eU concentration (pCi/g) contour of the Black Jack 1 mine. This product was derived from 453 data points covering 1.2 square miles. The dot represents the mine location. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. Much of red area exceeds 7.0 pCi/g surrounded by background concentrations ranging between <1 pCi/g to 2 pCi/g. ***This image should not be used to independently assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

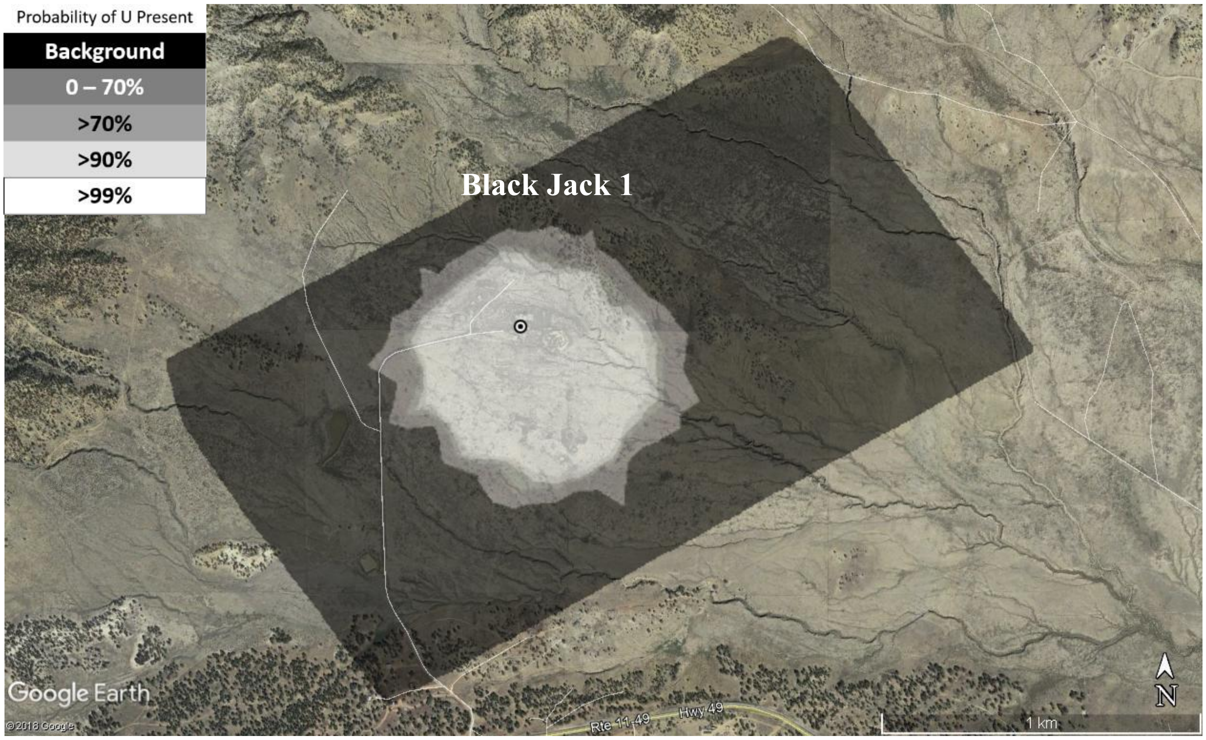


Figure 10: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.

4.2.2 Eunice Becenti Mine

The uranium deposit on the Site was mined from an open pit that had a short decline off of the pit wall. In June 1952, the first shipment of ore from the Site was delivered to the USAEC ore-buying station in Shiprock, NM. In 1953, 1954, 1956, 1958, and 1959 subsequent shipments of ore were delivered from the Site to either Shiprock or Bluewater ore-buying stations, both of which were located in New Mexico. The USAEC records reported total ore production from the site was 846 tons (approximately 1.7 million pounds) or ore that contained 3,350 pounds of 0.20 percent U3O8 (triuranium octoxide) and 2,266 pounds of 0.14 percent V2O5 (vanadium oxide).[7, 8] Chenoweth, 1989).

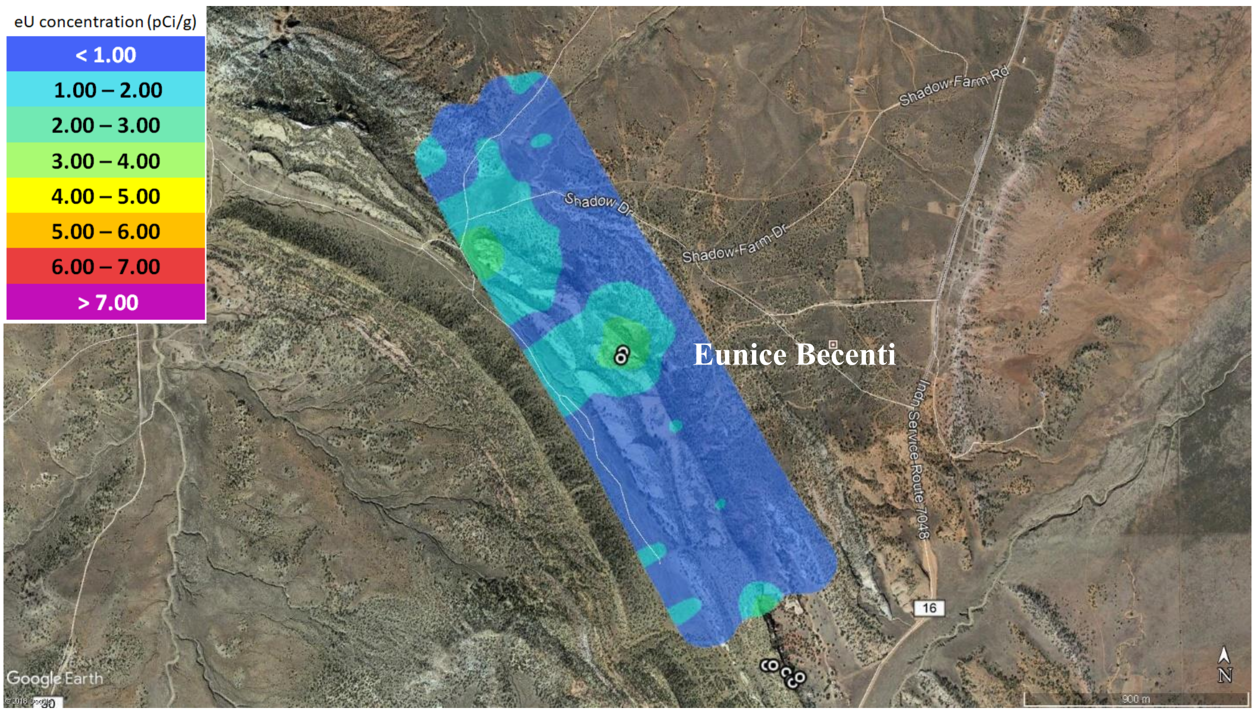


Figure 11: eU concentration (pCi/g) contour of the Eunice Becenti mine. This product was derived from 188 data points covering 0.4 square miles. The dots represent mine locations. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. Most this area has concentrations less than 4 pCi/g surrounded by background concentrations ranging between <1 pCi/g to 2 pCi/g ***This image should not be used to independently assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

Figure 12: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (dark grey to white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted. Note the area to the east of the mine may be associated with migration of the ore residues due to topography as shown in Figure 13.

Figure 13: This figure provides a 3D view of the Eunice Bencenti mine with the Probability of Uranium Present (PUP) product overlay. The PUP product suggests that uranium may have migrated to the eastern side of the mountain. This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.

4.2.3 Evelyn Mine

Evelyn mine is a former underground uranium and vanadium mine located on private property in McKinley County, New Mexico. According to state records, mining occurred intermittently between 1953 and 1970. Three adits were used to access the ore body at approximately 350 feet below the surface. A 2009 EPA assessment of the mine determined the disturbed area to be about 19,022 square meters. One residential structure with a private drinking water well is located about 0.5 miles from the mine.

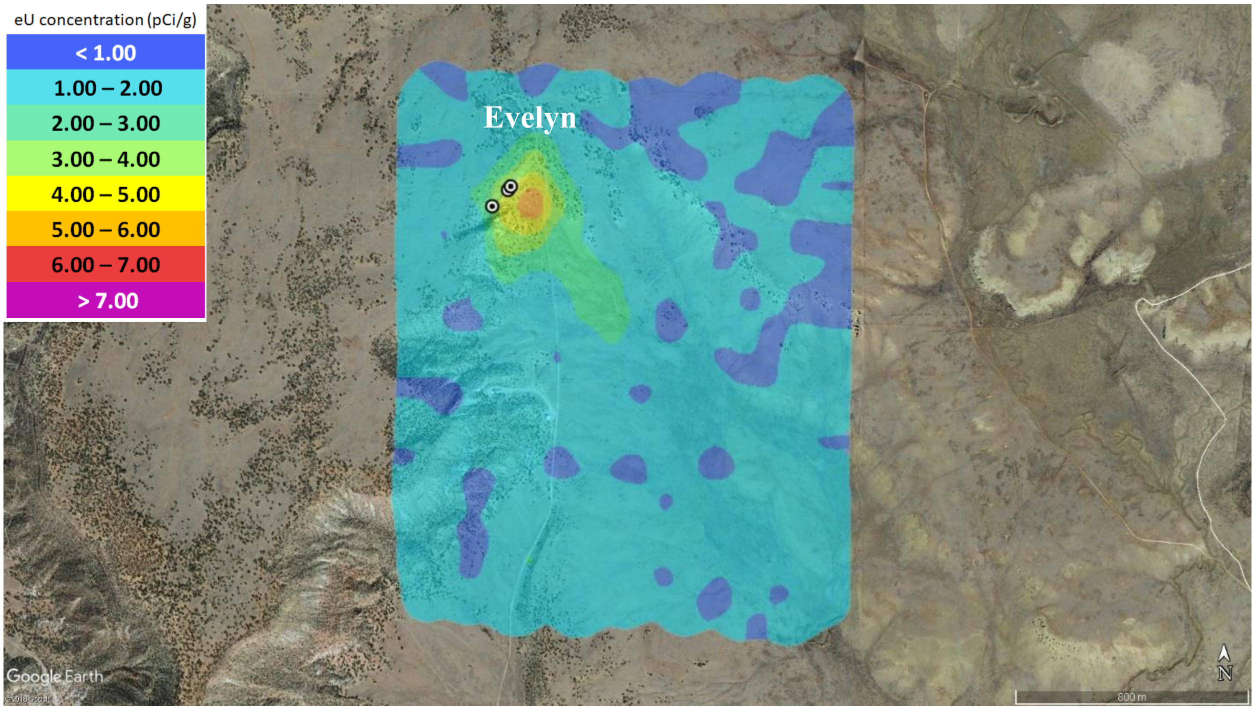


Figure 14: eU concentration (pCi/g) contour of the Eunice Becenti mine. This product was derived from 427 data points covering 0.9 square miles. The dots represent mine locations. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. The area just east of the mine shown surface concentrations up to 6 pCi/g surrounded by background concentrations ranging between <1 pCi/g to 2 pCi/g. ***This image should not be used to independently assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

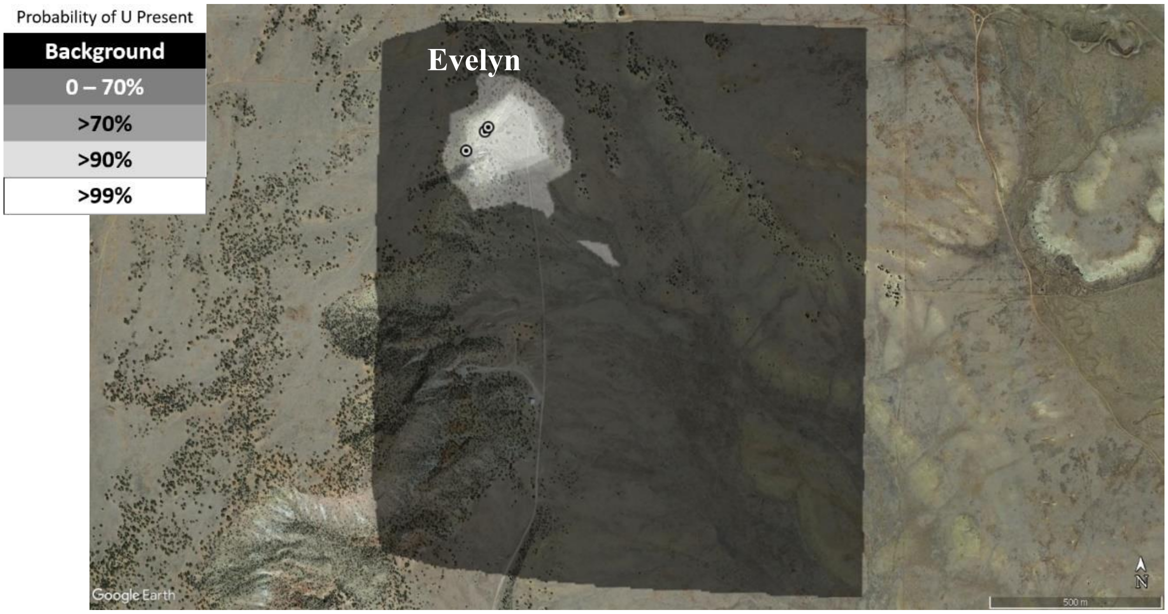


Figure 15: Evelyn mine. Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

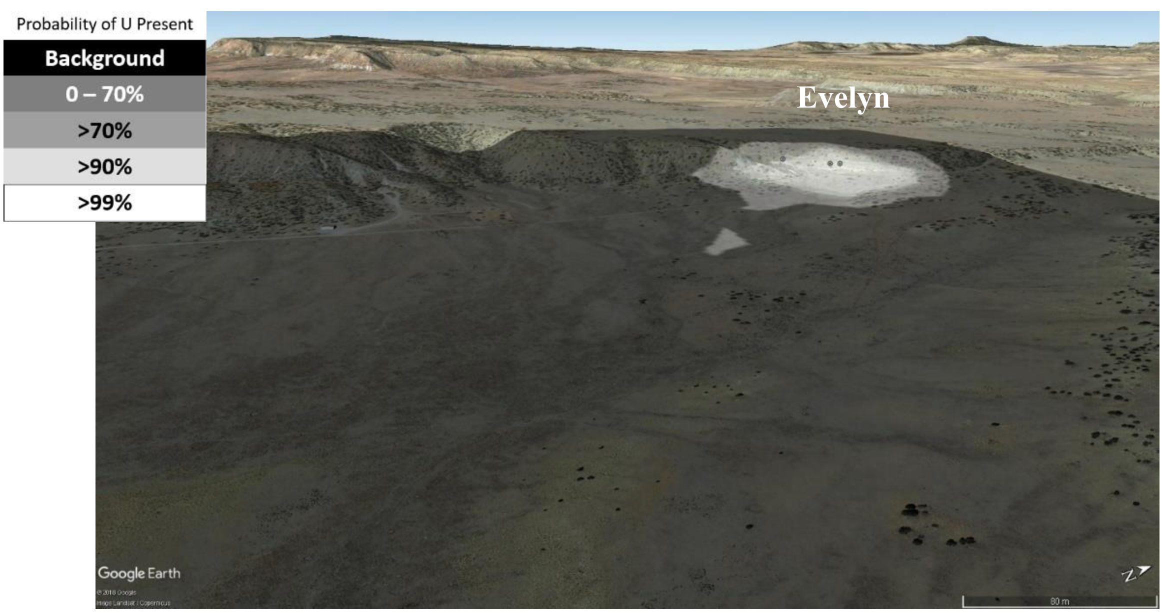


Figure 16: This figure provides a 3D view of the Evelyn mine with the Probability of Uranium Present (PUP) product. The PUP product suggests that uranium has migrated to the east-southeast due to topography. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

4.2.4 Haystack Mines

The Haystack mines are located about 5 miles east of Prewitt, New Mexico. These sites sit atop the Haystack Butte next to County Road 41. The Site contains three adjacent AUMs, including Haystack No. 1, Bibo Trespass, and Section 24. Mining-related activities occurred from approximately 1952 to 1981, under various persons and entities, and more than 400,000 tons of uranium ore were extracted. The Site was reclaimed in the early 1990s through a combination of USEPA, U.S. Department of Energy, and private party coordination. Site Specific AUM details include:

- Mine operations occurred on Haystack No. 1 and included numerous surface pits. The pits were reclaimed in 1991 and are no longer present.
- Mine operations at Bibo Trespass (22 acres) included at least one surface pit, which was reclaimed in 1992 and is no longer present.
- Mining operations in Section 24 (27 acres) included at least three pits, which were reclaimed in 1991 and are no longer present.

Site-specific investigations include a Site Screening Report completed for each of the three AUMs in 2009 by Weston Solutions, Inc. (Weston): Haystack No. 1 AUM Site Navajo AUM Eastern Region (Weston 2009a), Bibo Trespass AUM Site Navajo AUM Eastern Region (Weston 2009b), and Nan-a-bah Vandever AUM Site Navajo AUM Eastern Region (Weston 2009c). EPA completed a Removal Site Evaluation in 2015 and determined a time-critical removal action was warranted. In 2017 BNSF entered AOC for conducting the TCRA. The BNSF led TCRA is still underway.

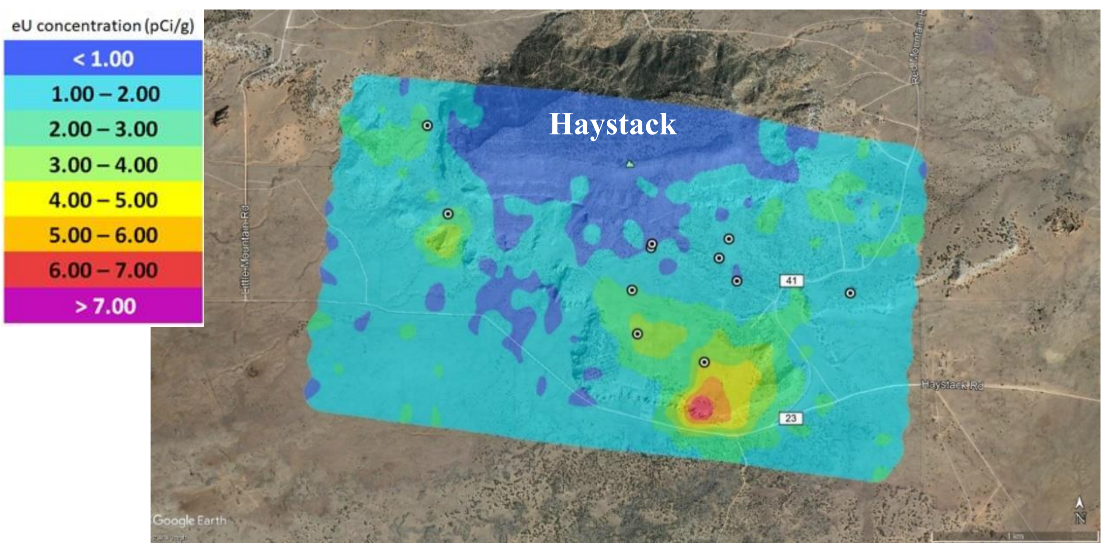


Figure 17: eU concentration (pCi/g) contour of the Haystack mine. This product was derived from 1029 data points covering 2.6 square miles. The dots represent mine locations. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. Background concentrations in this area appear to range between <1 pCi/g to 3 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

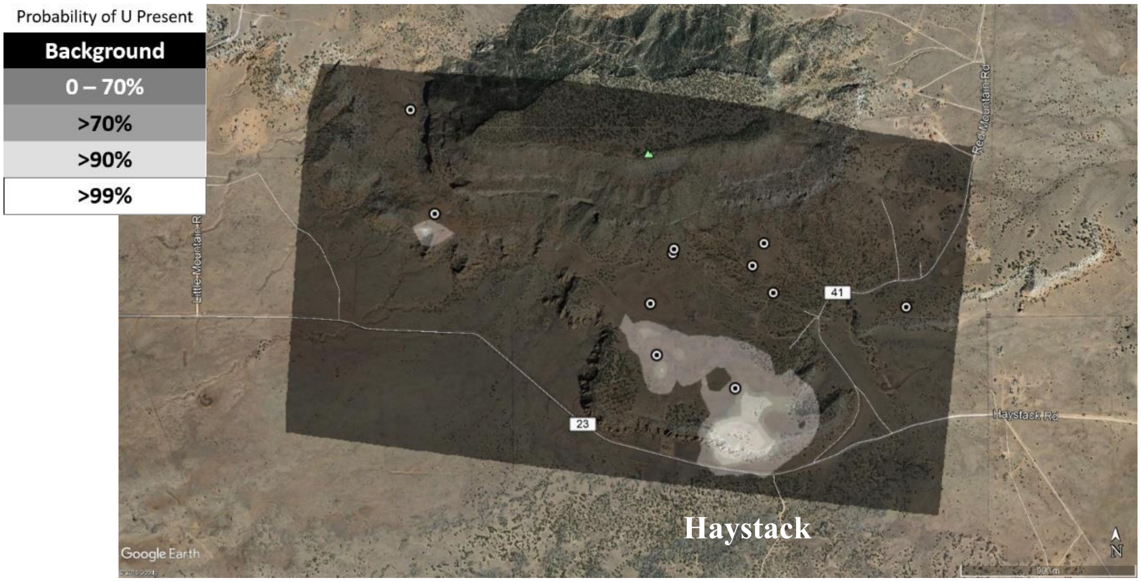


Figure 18: Haystack Mine. Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

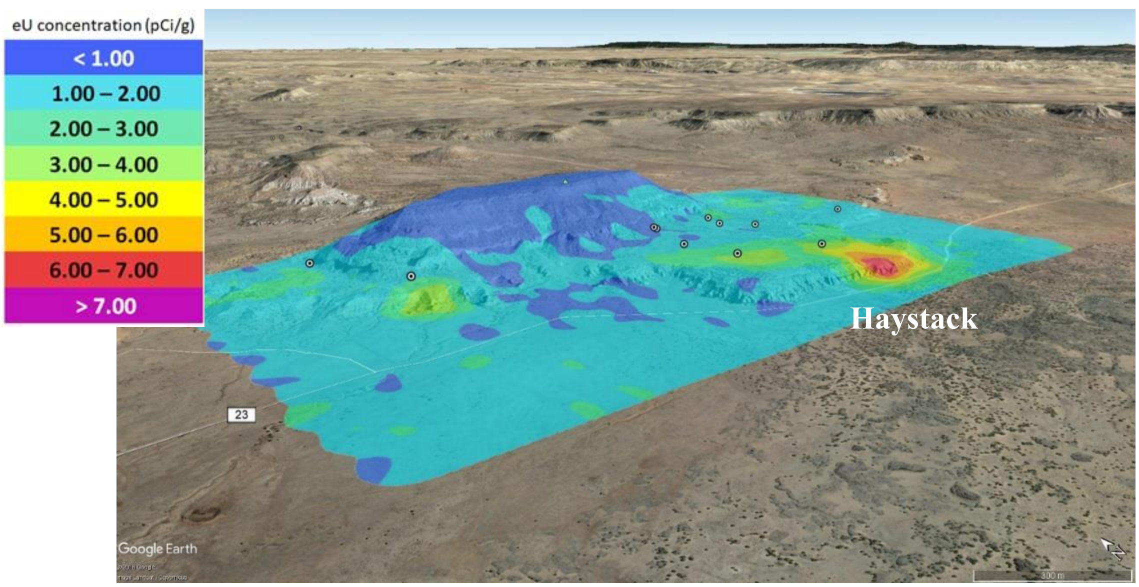


Figure 19: This figure provides a 3D view of the Haystack mine with the eU concentration (pCi/g) contour overlay. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

4.2.5 Mariano Lake, Mac1&2, Black Jack 3, & Ruby1

Mariano Lake (or Old Gulf Mine) is located 25 miles east of Gallup, NM and was operated from about 1977 to 1982 by Gulf Mineral Resources Company. Gulf Mineral Resources has since merged with Chevron who is currently to company responsible for cleanup. The mine was a wet mine and is about 520ft below ground. In total 505,489 tons of ore was produced. (website: https://www.epa.gov/navajo-nation-uranium-cleanup/mariano-lake-mine)

The Ruby Mines are located in the Smith Lake Chapter of the Navajo Nation. They were operated from 1975 to 1985 by Western Nuclear Inc. Ruby Mines Nos. 1 and 2 were connected by underground tunnels, and ore was produced through the adit at Ruby No. 1. (website: https://www.epa.gov/navajo-nation-uranium-cleanup/ruby-mines)

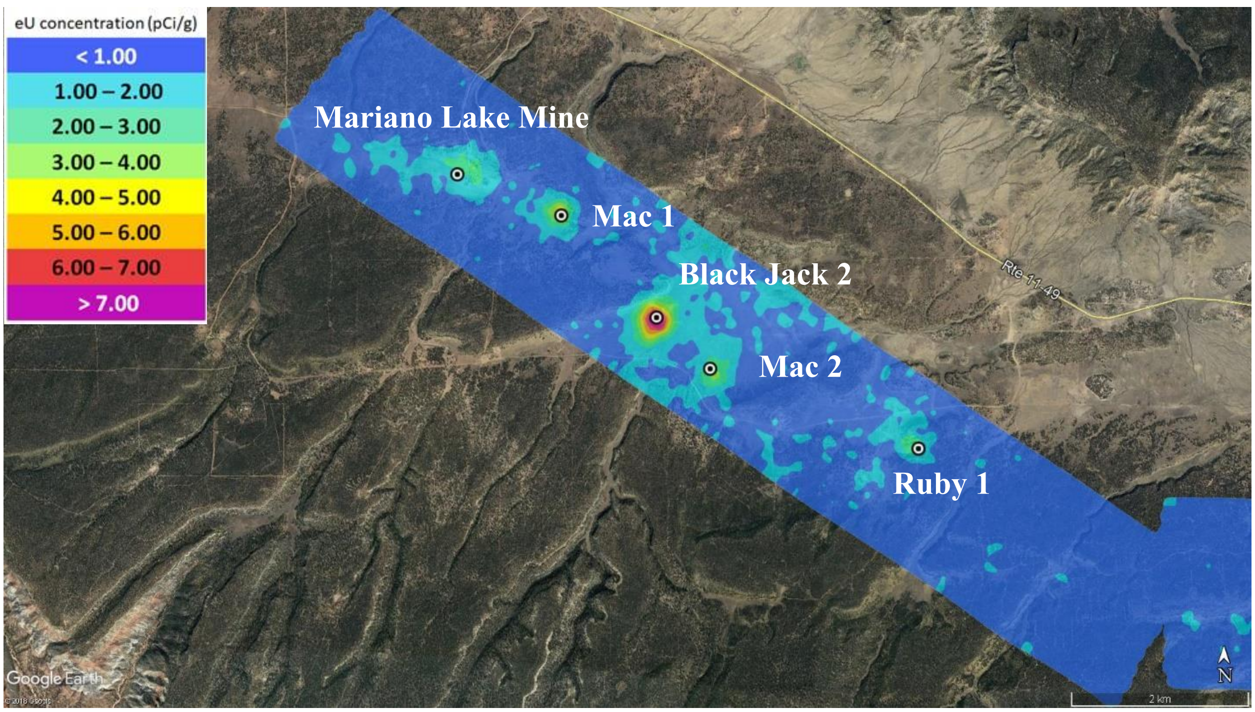


Figure 20: eU concentration (pCi/g) contour of the Mariano Lake, Mac 1 &2, Black Jack 2 and Ruby 1 mines. This product was derived from 2950 data points covering 7.8 square miles. The dots represent mine locations. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. Background concentrations in this area mostly appear to be <1 pCi/g. Close-up view of each mine are provided in the following figures. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

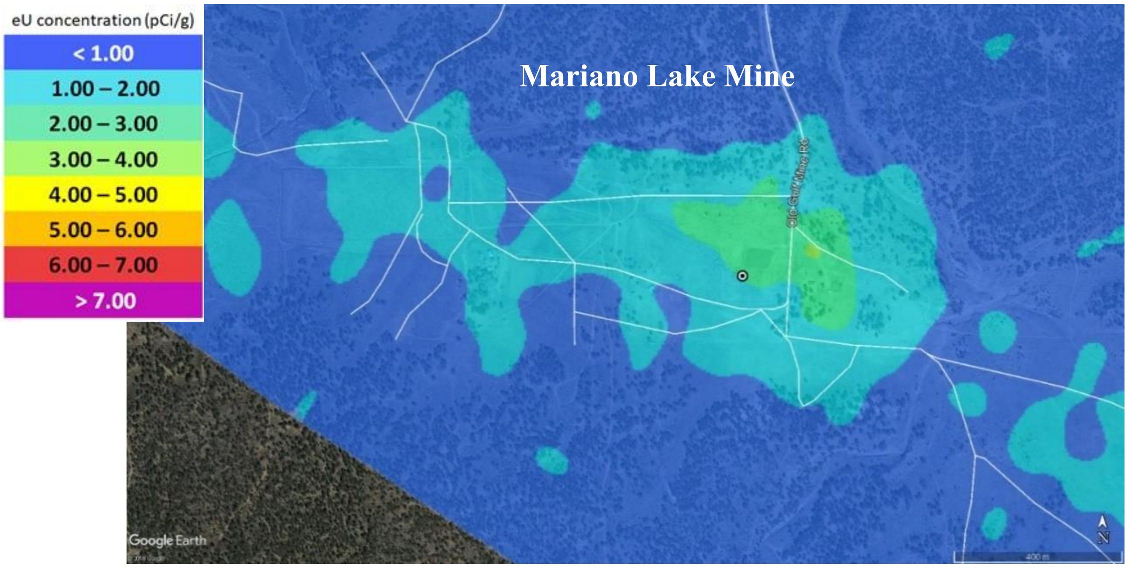


Figure 21: Close-up view of Mariano Lake mine with the eU concentration (pCi/g) overlay. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

Figure 22: Close-up view of Mariano Lake mine with the PUP product. Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

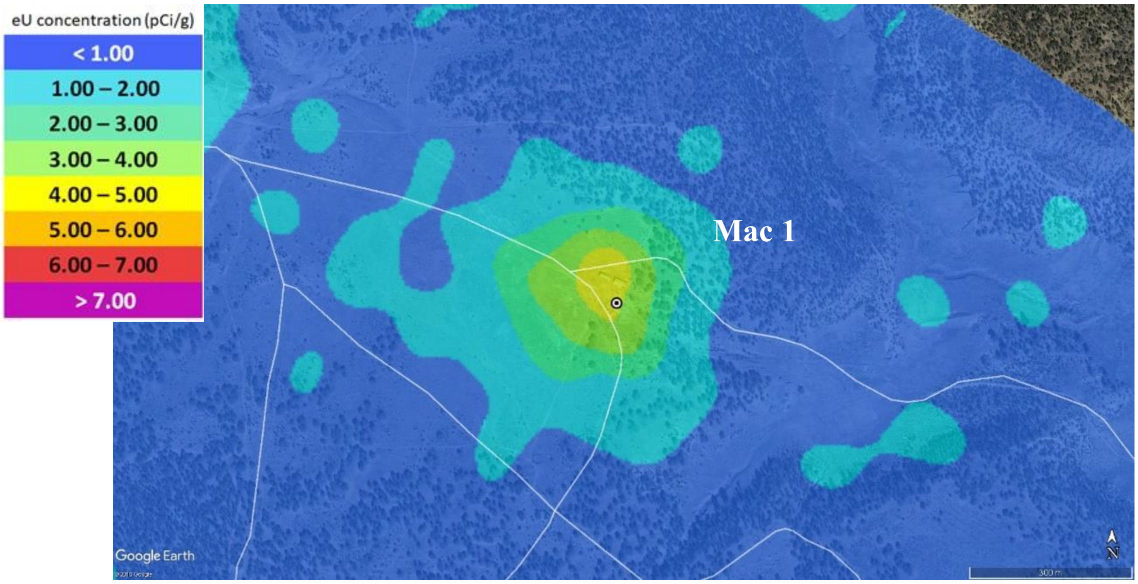


Figure 23: Close-up view of Mac 1 mine with the eU concentration (pCi/g) overlay. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

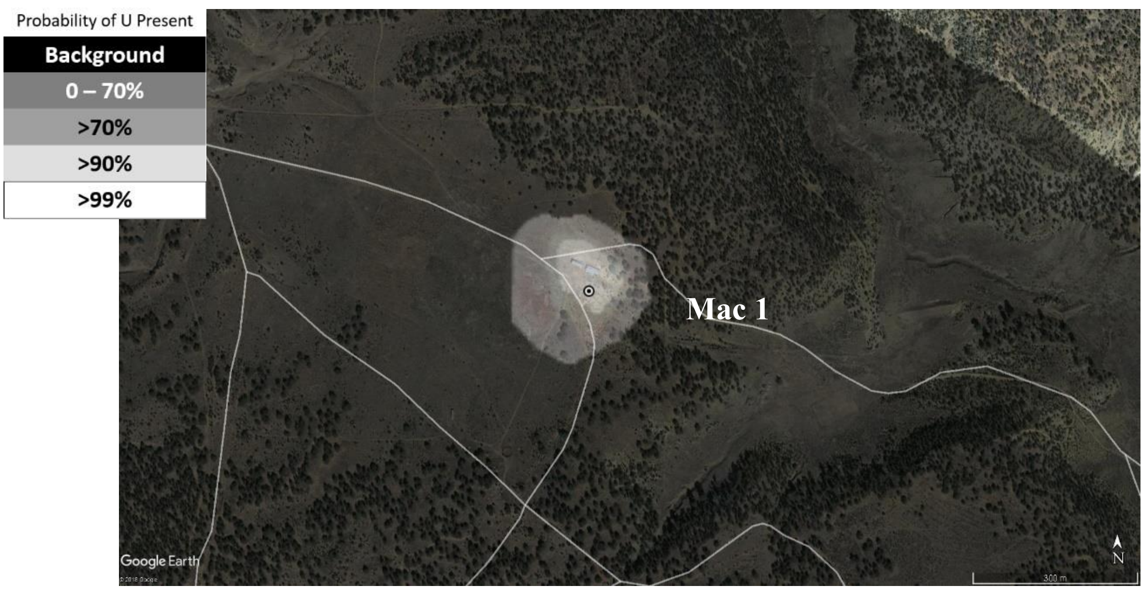


Figure 24: Close-up view of Mac 1 mine with the PUP product. Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

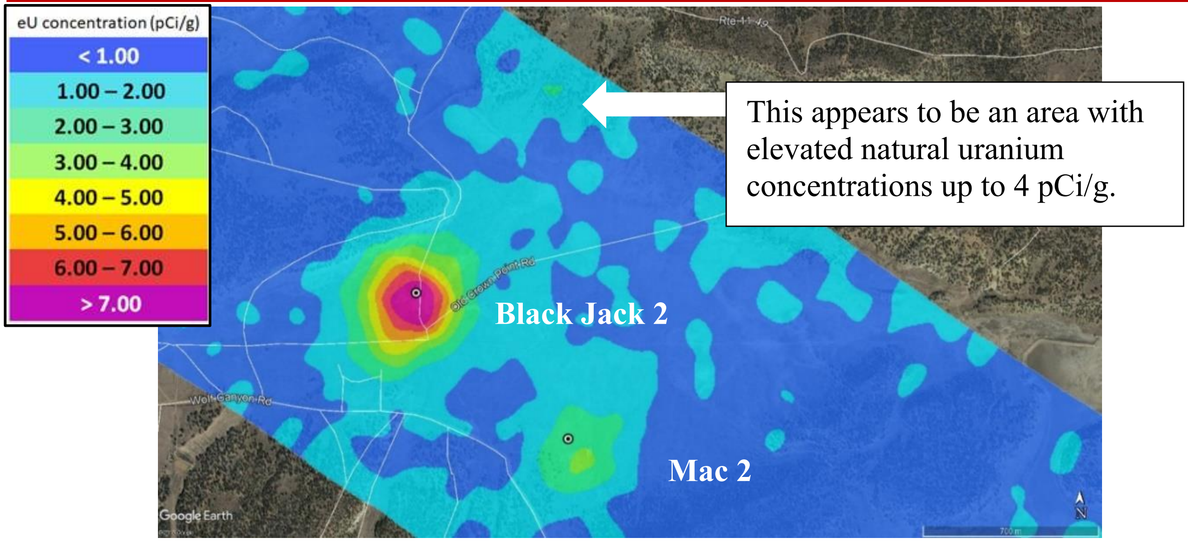


Figure 25: Close-up view of the Black Jack 2 and Mac 2 mines. The area just north of Black Jack 2 mine suggests a natural outcrop of uranium near the surface with concentrations up to 4 pCi/g. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

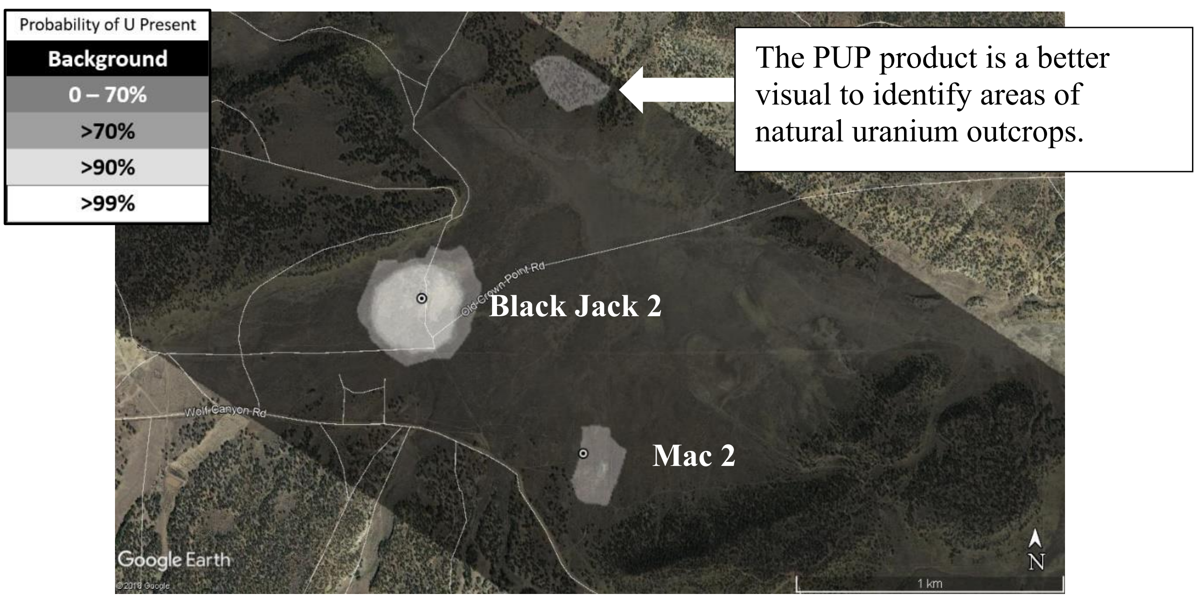


Figure 26: Close-up view of the Black Jack 2 and Mac 2 mines with the PUP product. Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

Since there appeared to be an area with elevated uranium concentration not directly associated with mining activities, an additional analysis was performed to look for Thorium, another naturally occurring radionuclide. The thorium results show a similar pattern as the uranium pattern but with more intense results over a larger geologic formation

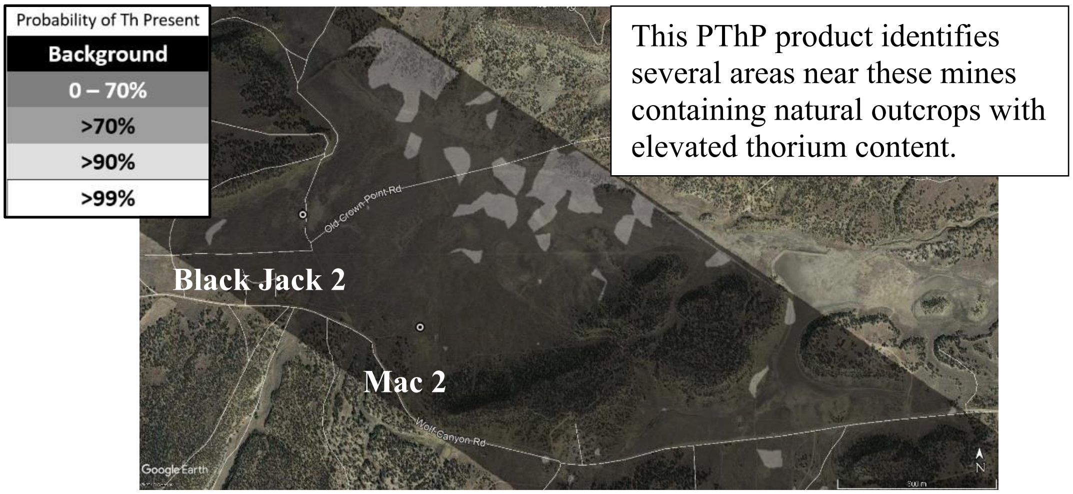


Figure 27: Close-up view of Black Jack 2 and Mac 2 mines overlaid with the Probability of Thorium Present (PThP) contour. Probability of Thorium Present (PThP) product shows areas where natural thorium is out of balance (white) with the natural background (black). White areas indicate where thorium spectral signatures are statistically significantly present for thorium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted****.*

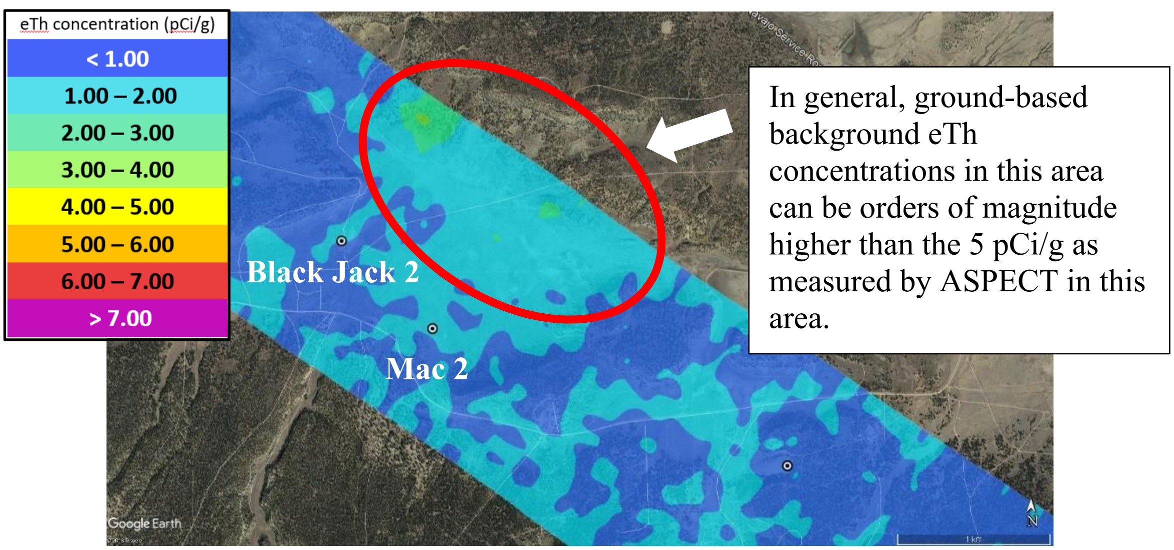


Figure 28: eTh concentration (pCi/g) contour of the Black Jack 2 and Mac 2 areas shows a natural outcrop of Thorium ranging from 1 pCi/g to 5 pCi/g. Please note that ground-based in-situ measurements may be orders of magnitude greater than 5 pCi/g due to a smaller field-of-view. ASPECT altitude target was 500 ft above ground level for this survey.

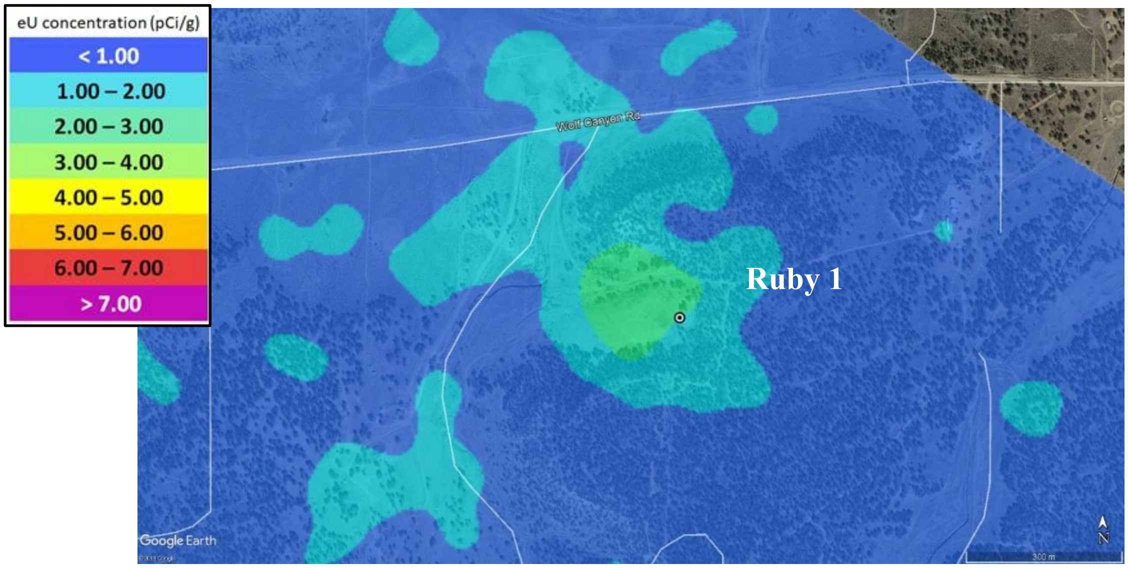


Figure 29: Close-up view of the Ruby 1 mines shows surface eU concentrations up to 3 pCi/g west of the mine. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

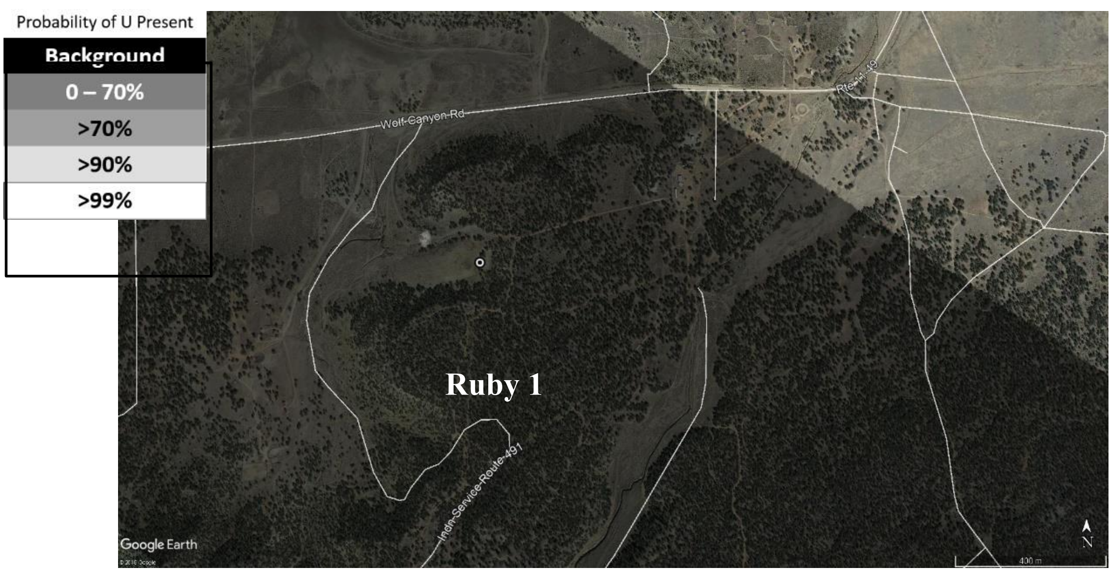


Figure 30: Close-up view of the Ruby 1 mine Probability of Uranium Present (PUP) contour. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

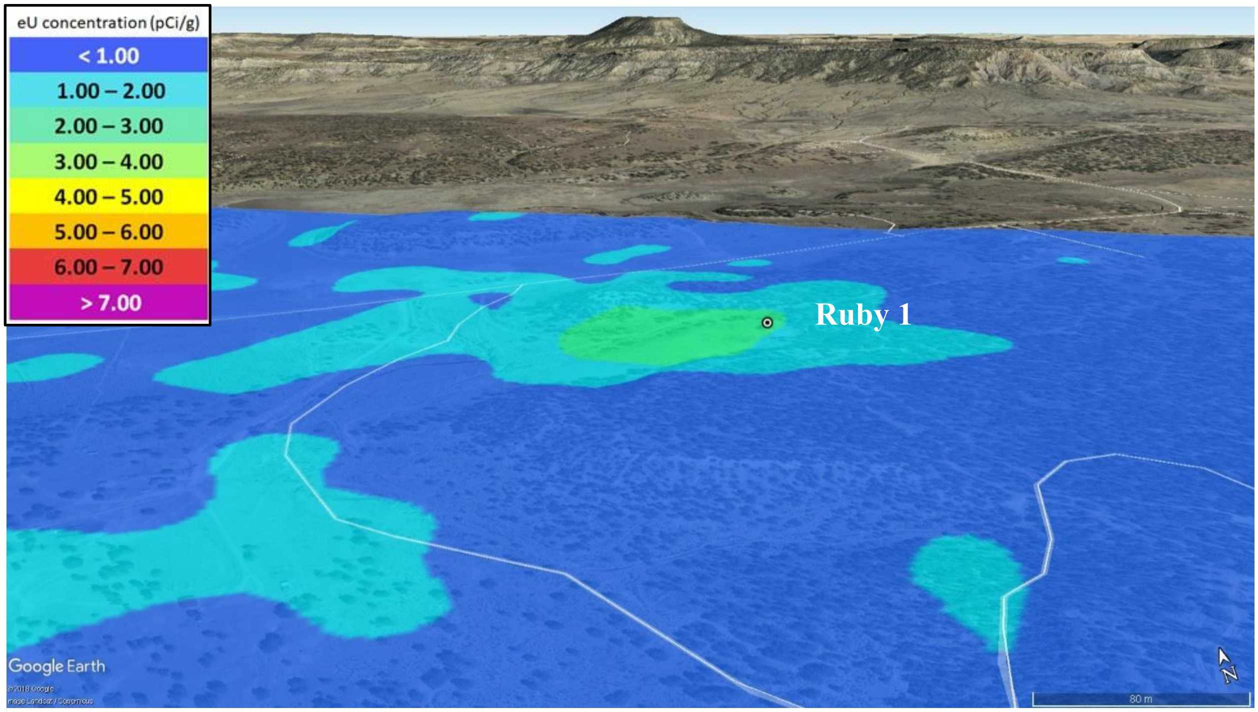


Figure 31: This figure provides a 3D view of the Ruby 1 mine with the eU concentration (pCi/g) contour overlay. The surface contamination west of the site is likely due to migration. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

4.2.6 Ruby 3

The Ruby Mines are located in the Smith Lake Chapter of the Navajo Nation. They were operated from 1975 to 1985 by Western Nuclear Inc. Ruby Mines Nos. 3 and 4 were connected by underground tunnels, and ore was produced through the adit at Ruby No. 3.

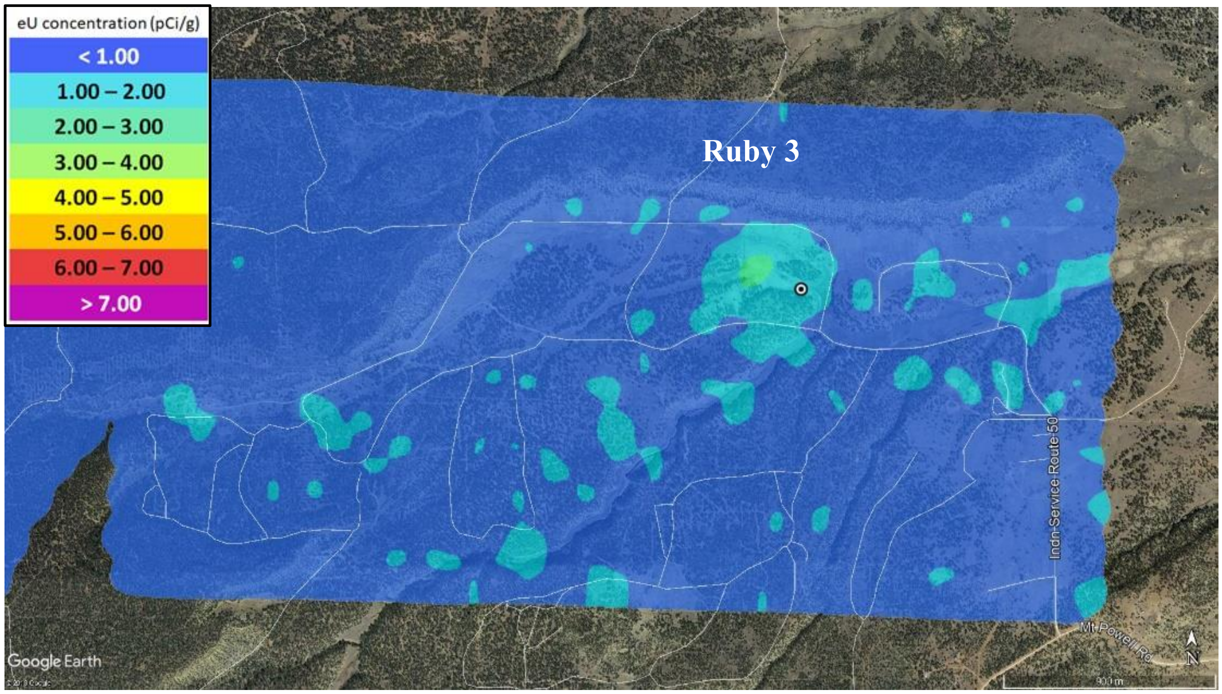


Figure 32: eU concentration (pCi/g) contour of the Ruby 3 mine. This product was derived from 1177 data points covering 3.2 square miles. Background concentrations in this area mostly appear to be <1 pCi/g. Uranium concentrations near the site range between 2 pCi/g to 3 pCi/g. The dot represents the mine location. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

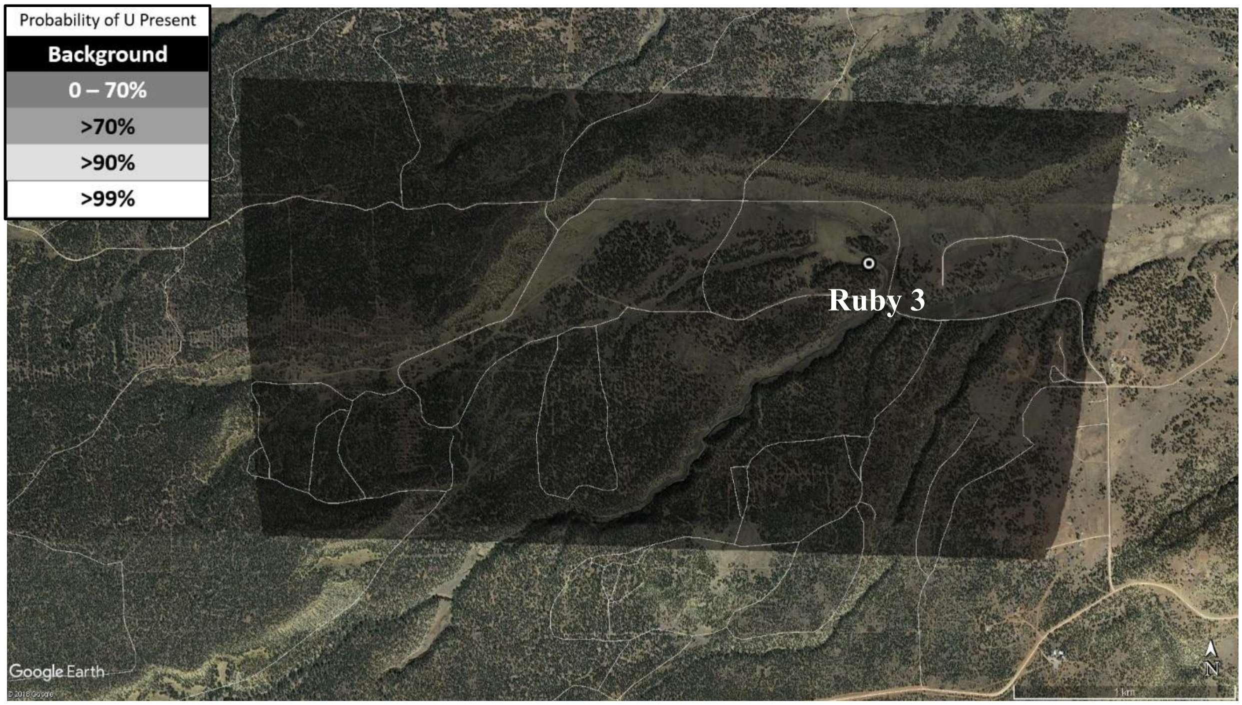


Figure 33: Probability of Uranium Present (PUP) contour shows no significant detections of uranium. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should only be used to identify areas where further ground-based characterization efforts may be warranted.***

4.2.7 NECR, Quivira, & UNC

The Northeast Church Rock Mine (NECR) is located at the northern end of State Highway 566 approximately 17 miles northeast of Gallup, NM in the Pinedale Chapter of the Navajo Nation. NECR was operated by UNC from 1967 to 1982. During this time, about 3.5 million tons of ore was extracted making this the second highest producing mine on the Navajo Nation. The uranium ore body is located up to 1,800 feet below grade at the NECR Mine Site. Therefore, the mining was conducted over 1,000 feet below the ground surface and was accessed through two main underground shafts. Uranium ore from the UNC mine was processed at the adjacent UNC Mill Site, located on private property across Highway 566. Contamination discovered on the Navajo Reservation and in the residential areas was addressed through a series of short-term cleanup actions in 2007, 2009, and 2012. Due to the proximity of the residents to the mine site, this mine was identified as the highest priority for cleanup by US EPA and Navajo Nation EPA and is therefore farthest along in the cleanup process, having completed the design of a waste repository on the nearby UNC Mill Site. This cleanup is contingent upon a license amendment decision from the Nuclear Regulatory Commission which is anticipated to take between 2 to 5 years including two years for a safety and environmental review and additional time if a hearing is requested.

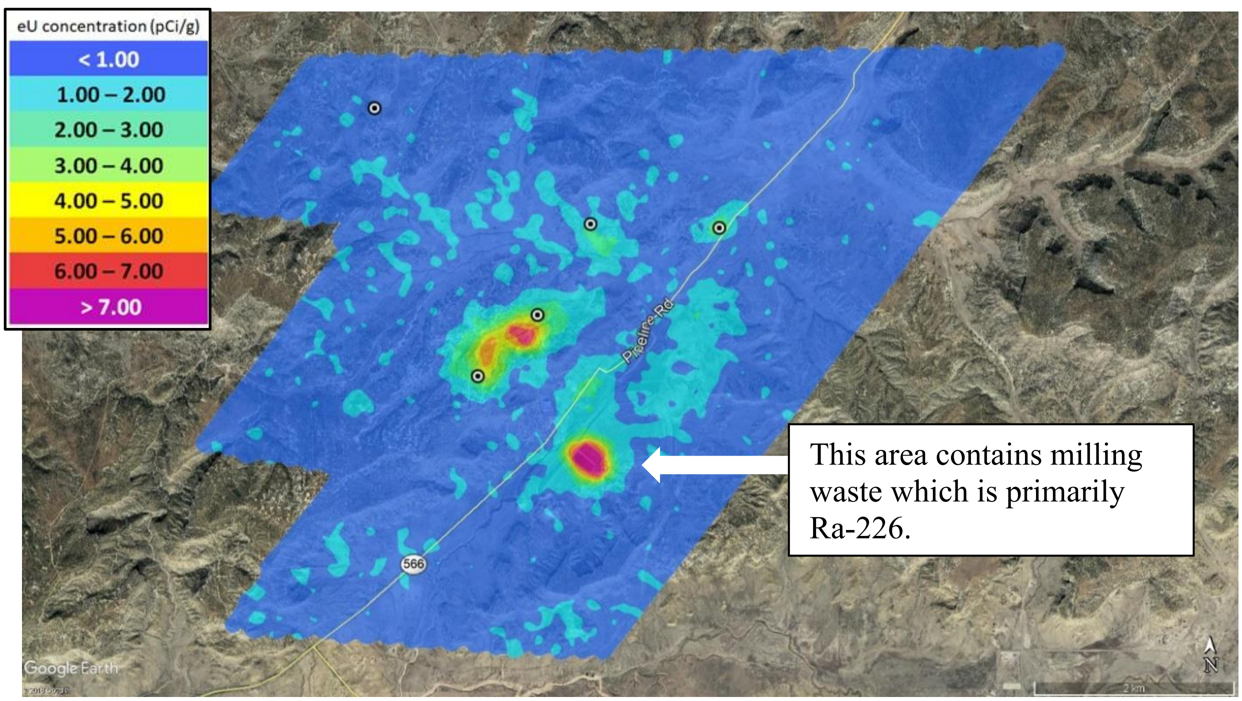


Figure 34: eU concentration (pCi/g) contour of the NECR and Quivira mines and the UNC mill. This product was derived from 4571 data points covering 12.8 square miles. The dots represent mine locations. The NECR mining area contains areas exceeding 5 pCi/g. The red area to the east is a waste pit containing mostly Ra-226. This shows up because the uranium algorithm is based on Bi-214, which is also a decay product of Ra-226. The surrounding background concentrations are mostly <1 pCi/g, but a few areas reach up to 2 pCi/g. Close-up views of these mining areas are provided in the following figures.

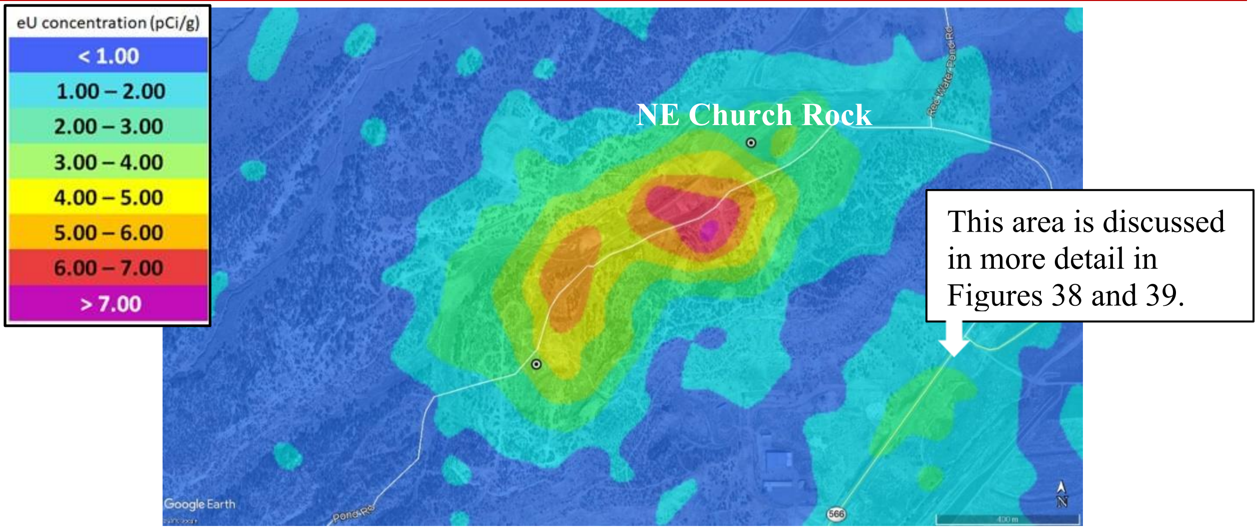


Figure 35: Close-up view of the NECR mine shows surface eU concentrations exceeding 7 pCi/g. The legend represents surface uranium concentrations in pCi/g and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

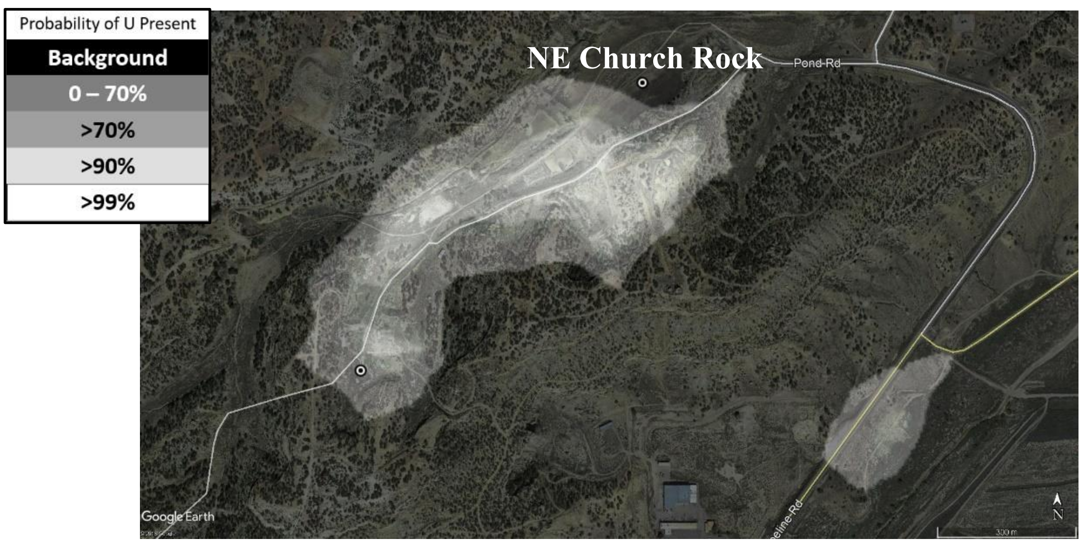


Figure 36: Close-up view of the NECR mine Probability of Uranium Present (PUP) contour. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

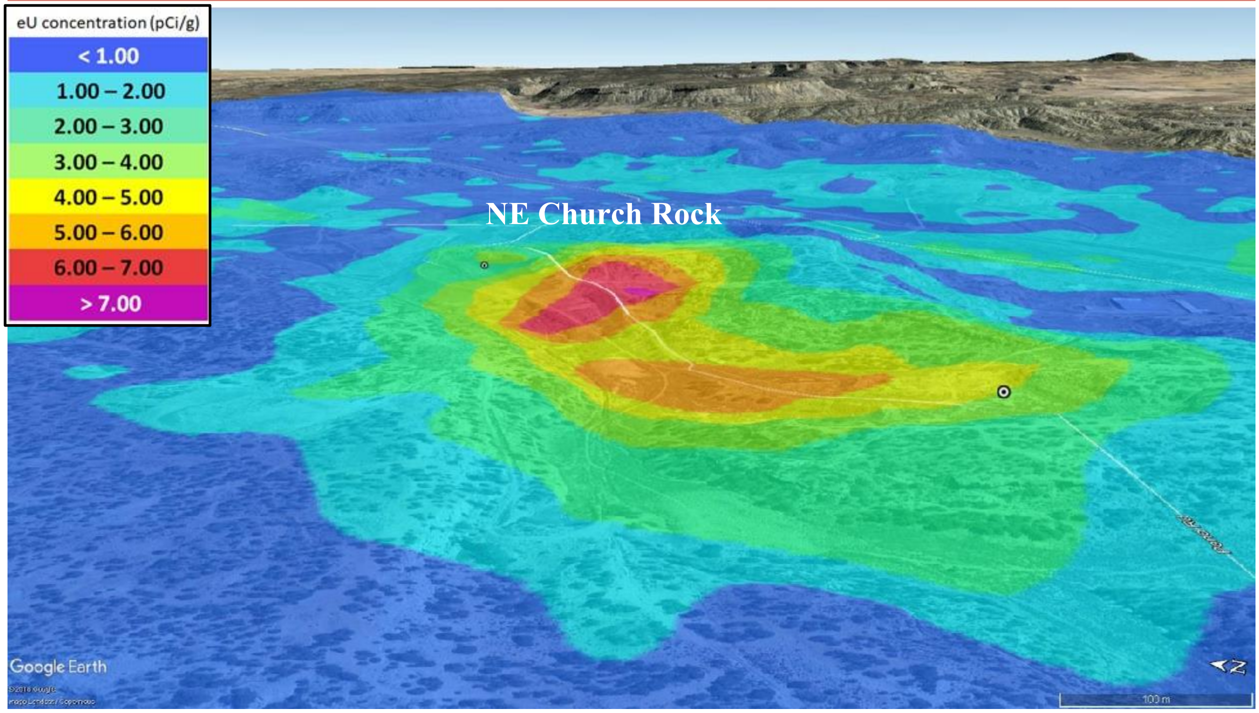


Figure 37: This figure provides a 3D view of the NECR mine with the eU concentration (pCi/g) contour overlay. The highest surface contamination appears to reside in the low-lying areas. The legend represents surface uranium concentrations in pCi/g and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

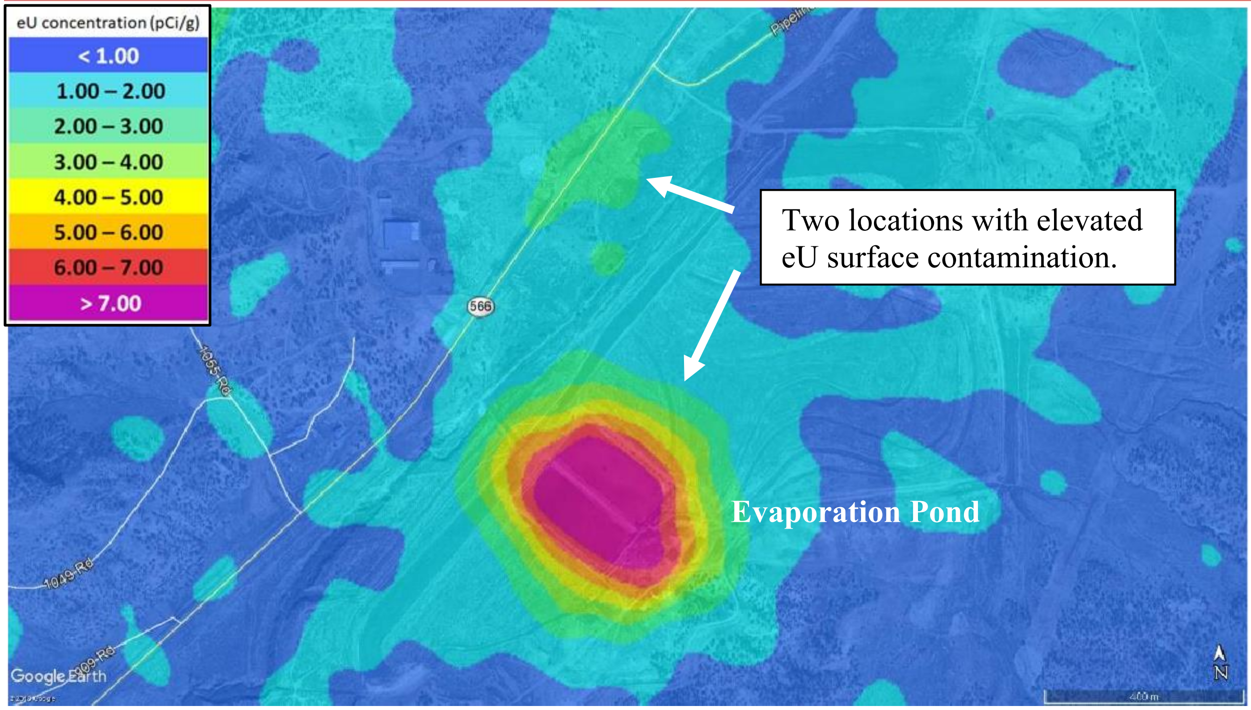


Figure 38: Close-up view of two locations on the UNC Mill Site private property with the eU concentration contour. It has average concentrations up to 3 pCi/g. Note that cleanup levels for this private property in the State of New Mexico is 5 piC/g above background based on the Nuclear Regulatory Commission cleanup levels. The southern location is an evaporation pond for the current groundwater remediation efforts at the UNC Mill Site. This shows up because the uranium algorithm is based on Bi-214, which is also a decay product of Ra-226. The contouring algorithm interpolates between data points giving a false impression that the contaminants are not fully contained in the ponds. In reality, the waste is fully contained within the tailings impoundment. The legend represents surface uranium concentrations in pCi/g and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

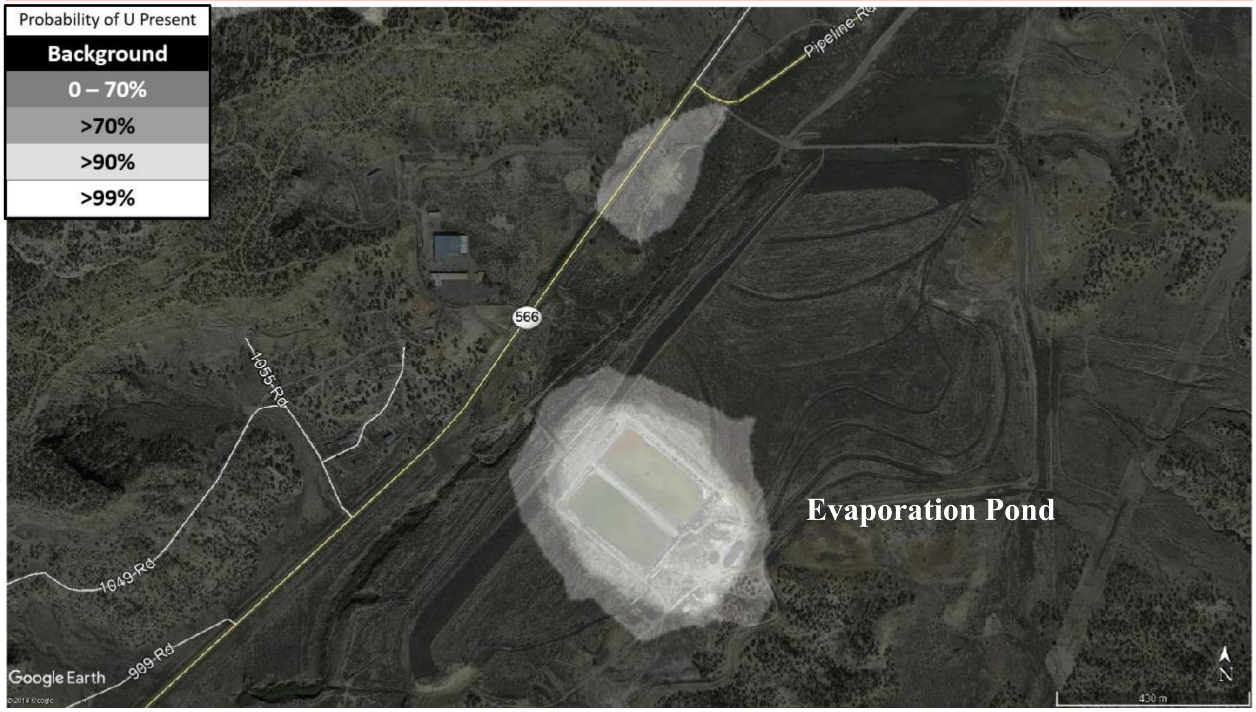


Figure 39: Close-up view of the two locations on the UNC Mill Site private property with the Probability of Uranium Present (PUP) contour. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

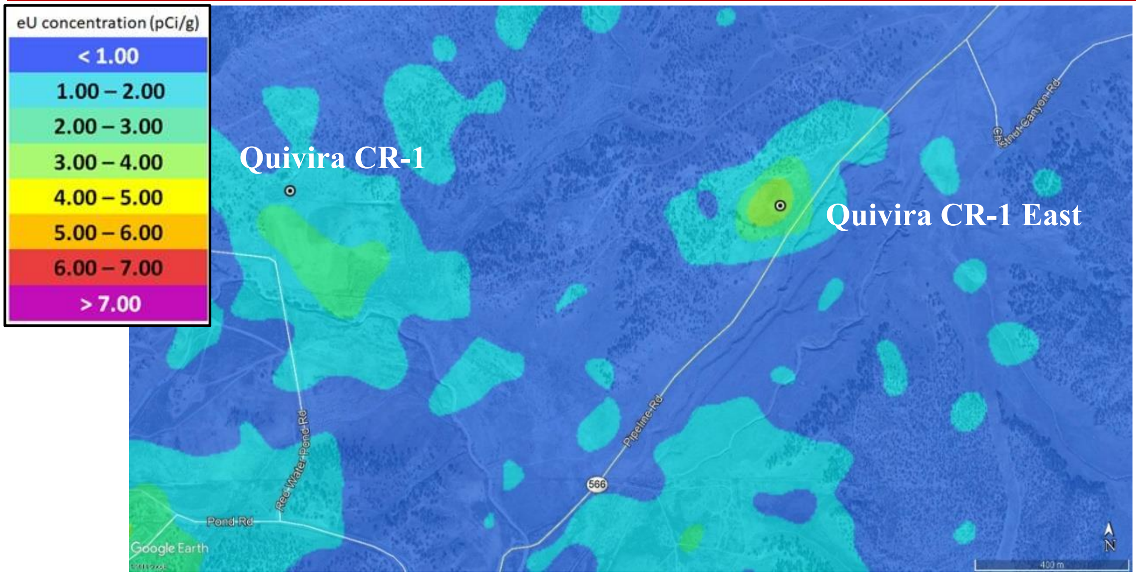


Figure 40: Close-up view of the Quivira CR-1 and Quivira CR 1-East Mines with the eU concentration contour. These locations show eU concentrations ranging between 3 pCi/g to 5 pCi/g. The legend represents surface uranium concentrations in pCi/g and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

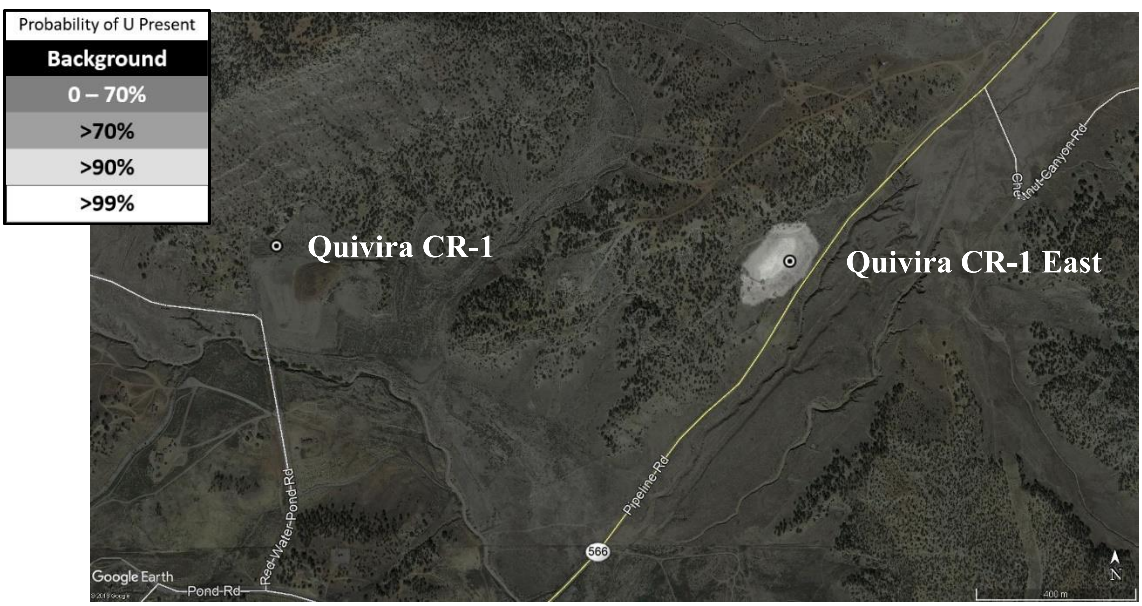


Figure 41: Close-up view of the Quivira CR-1 and Quivira CR 1-East Mines with the Probability of Uranium Present (PUP) contour. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

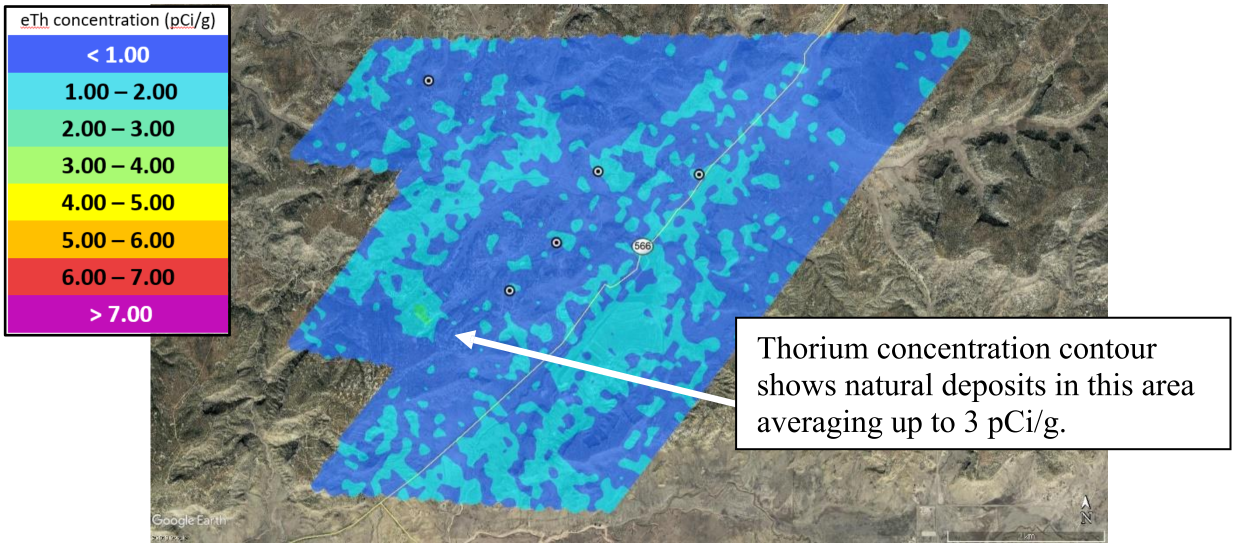


Figure 42: eTh concentration (pCi/g) contour of the NECR and Quivira mines show a natural outcrop of Thorium averaging up to 3 pCi/g. Please note that ground-based in-situ measurements may be orders of magnitude greater than 5 pCi/g due to a smaller field-of-view. ASPECT altitude target was 500 ft above ground level for this survey.

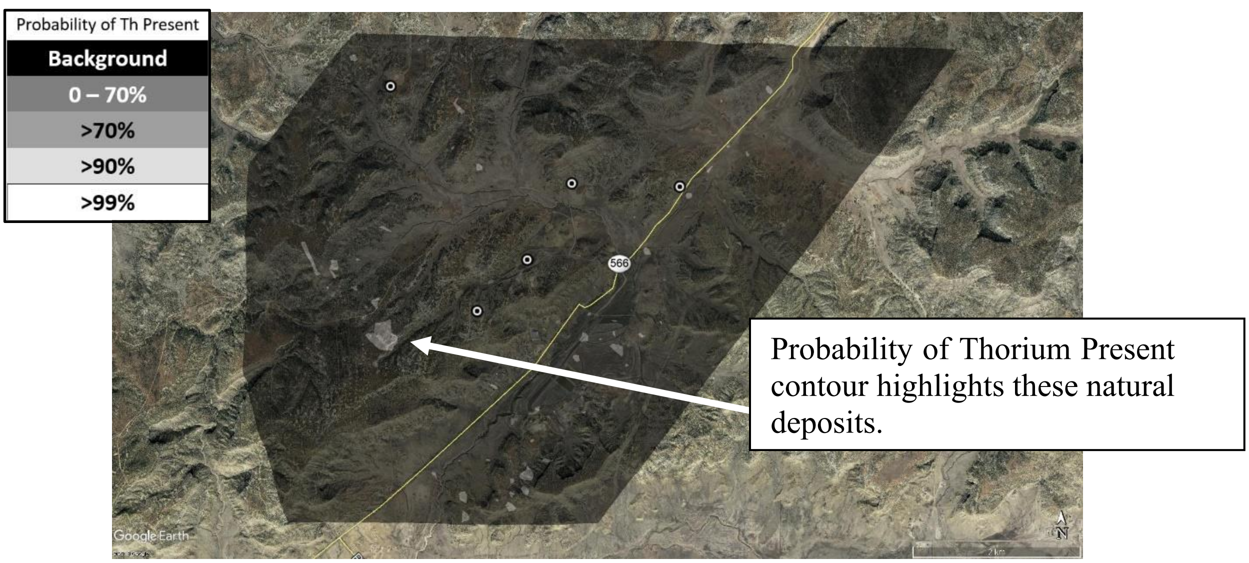


Figure 43: Probability of Thorium Present (PThP) contour of the NECR and Quivira mines. It appears that the geologic formation to the south west and east of these mines contain natural deposits of higher concentrations of Thorium than the surrounding area. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.2.8 Old Church Rock Mine

The Old Church Rock Mine (OCRM) site is located at the west of State Highway 566 approximately 15 miles northeast of Gallup, NM in the Church Rock Chapter of the Navajo Nation. The OCRM was mined by Phillips Petroleum CO. from 1960 to 1962 and the same mine was reopened by United Nuclear Corporation in two different periods from 1976 to 1977 and 1979 to 1981. Underground mining occurred at the site at depths up to 900 feet below grade. Approximately 78,000 tons of ore was extracted during the mining operations. Phase I and II site characterizations were performed at OCRM by INTERA Incorporated in 2008 and 2013 respectively, which were overseen by Navajo Nation Environmental Protection Agency.

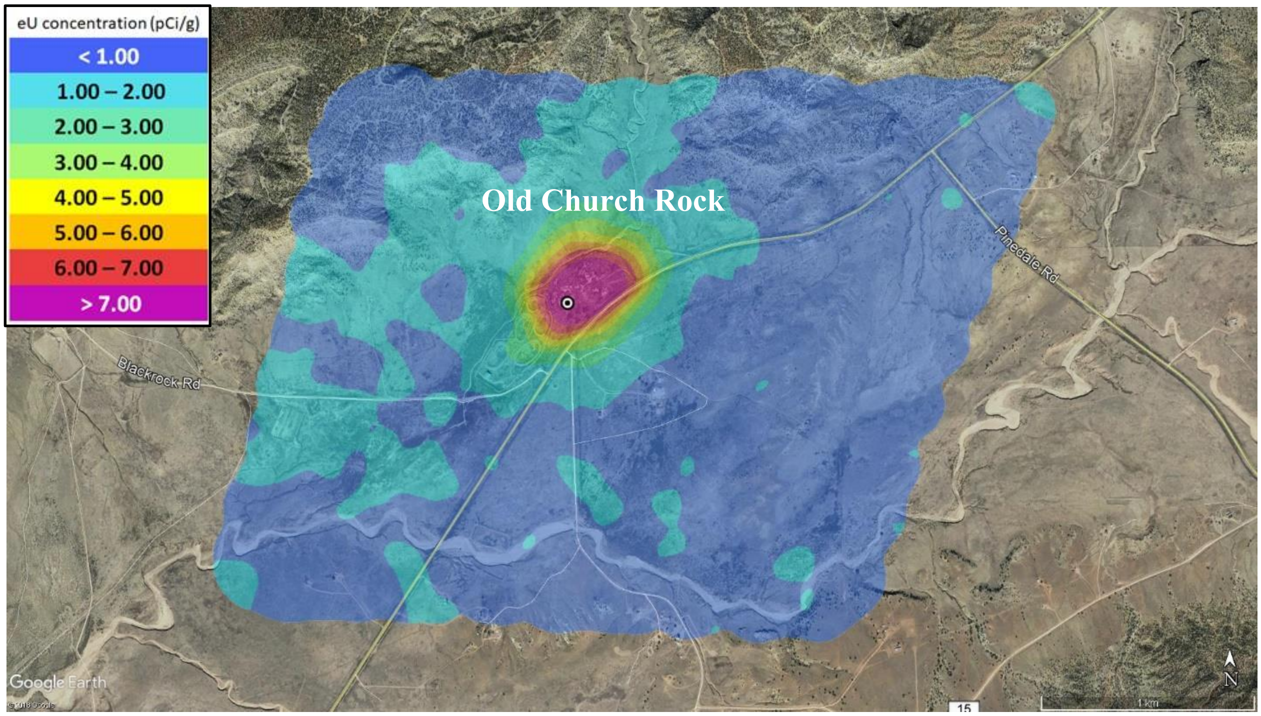


Figure 44: eU concentration (pCi/g) contour of the Old Church Rock mine. This product was derived from 1215 data points covering 3.0 square miles. The dot represents the mine location. The results show surface concentrations exceeding 7 pCi/g at the mine site surrounded by background concentrations ranging between <1 pCi/g to 2 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

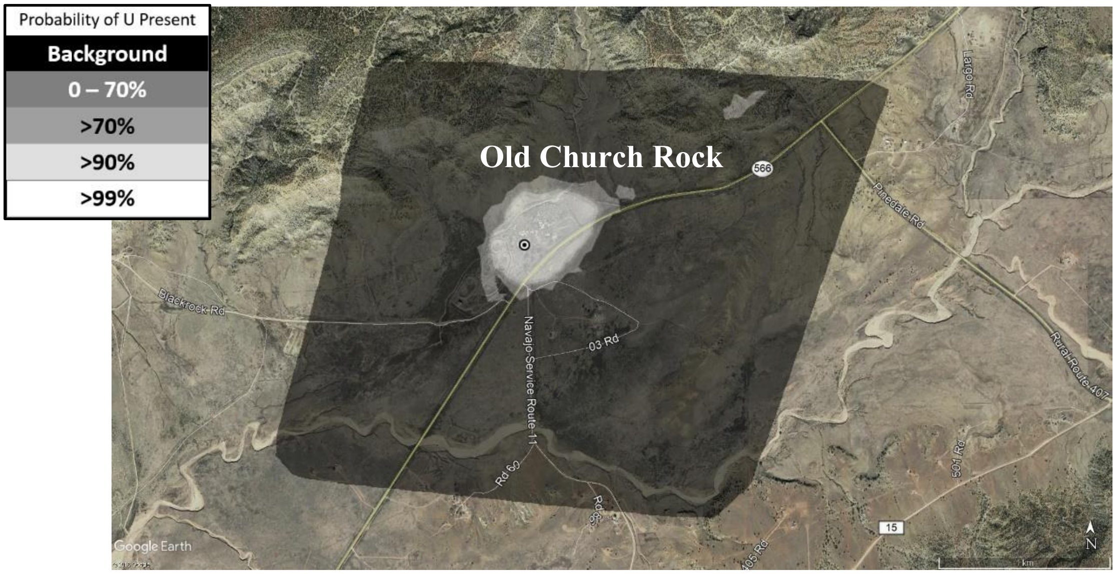


Figure 45: Old Church Rock mine with the Probability of Uranium Present (PUP) contour The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The areas northeast of the mine are natural deposits mostly consisting of thorium. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

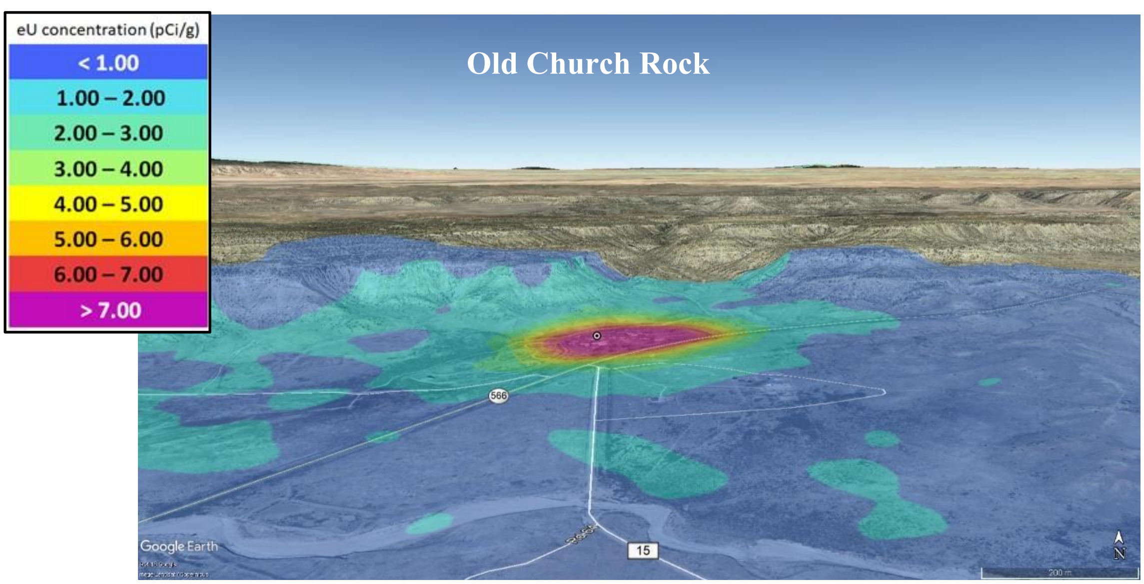


Figure 46: This figure provides a 3D view of the Old Church Rock mine with the eU concentration (pCi/g) contour overlay.

4.2.9 Section 32-33 Mine

Section 32 -33 mine site area is located on both privately held land in New Mexico (Section 33) and Indian Allotment Land (Section 32). State records show at least one decline to a depth of 850 feet and operated from 1960 to 1982. A removal action was conducted in 2012 on the Section 32 mine and consisted of stockpiling approximately 45,000 cubic yards of contaminated soil and installing a fence to control access. The number of residents living within one mile of the mine has increased since the removal action in 2012.

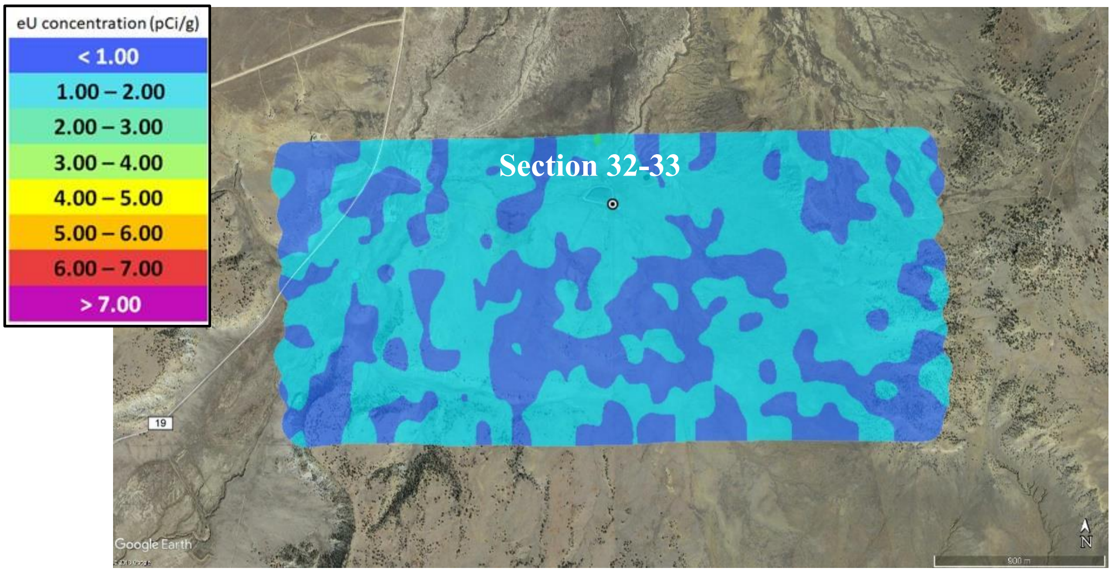


Figure 47: eU concentration (pCi/g) contour of the Section 32-33 mine. This product was derived from 806 data points covering 2.1 square miles. The dot represents the mine location. There are no discernable surface eU concentrations as the surrounding background concentrations range between <1 pCi/g and 2 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

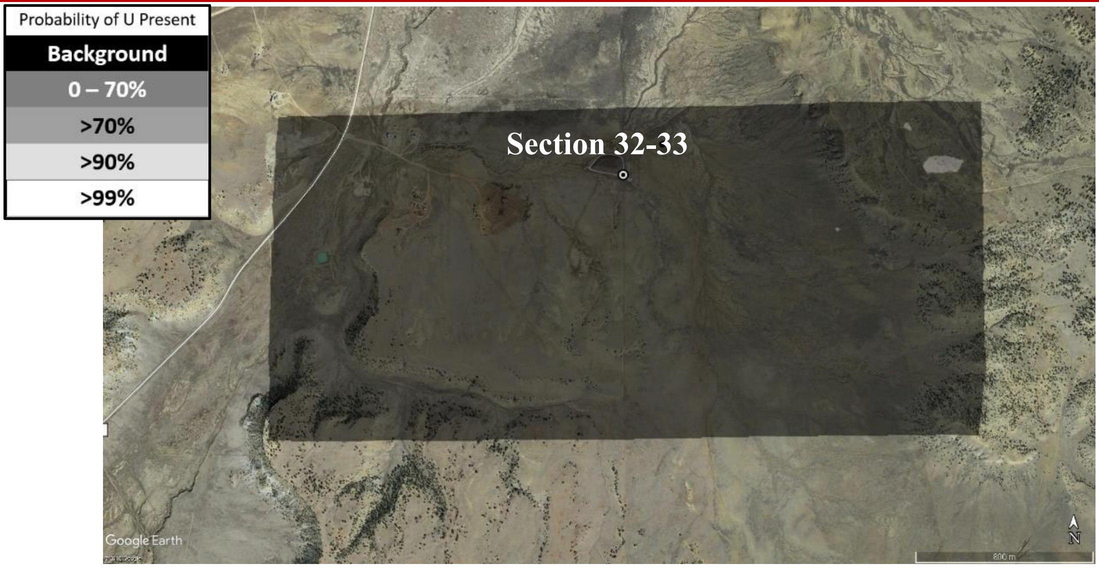


Figure 48: Probability of Uranium Present (PUP) contour shows very limited detection east of the mine, most likely to due to natural deposits. Since a natural deposit of uranium may have been detected, an additional analysis for thorium was performed. Those results are provided in the figures below. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

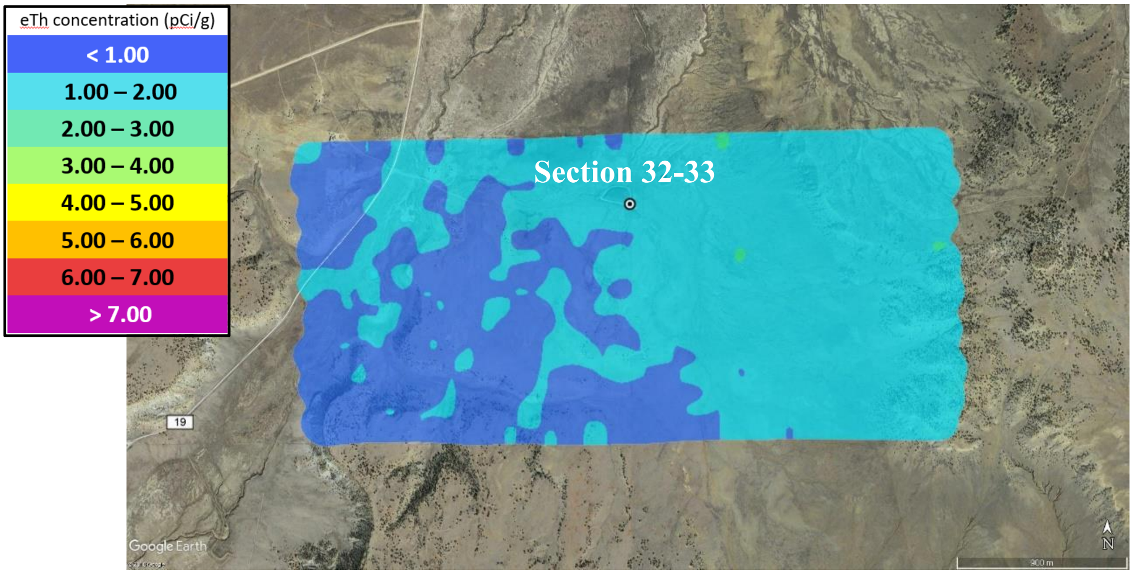


Figure 49: eTh concentration (pCi/g) contour of the Section 32-33 mine shows a natural outcrop of Thorium averaging up to 3 pCi/g east of the site. Please note that ground-based in-situ measurements may be orders of magnitude greater due to a smaller field-of-view. ASPECT altitude target was 500 ft above ground level for this survey. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

Figure 50: Probability of Thorium Present (PThP) contour of the Section 32-33 mine. It appears that the geologic formation east of this site contains natural deposits of higher concentrations of Thorium than the surrounding area. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.2.10 Standing Rock

According to Atomic Energy Commission records, no uranium production occurred at the site. The only reported mining was for road gravel (referred to as road metal on page 396 of McLemore, 1983)[7]. The site is located in a region of beach-placer sandstone deposits that are radioactive due to zircon, monazite, and columbium minerals. High concentrations of titanium, iron, scandium, niobium, thorium, uranium, and rare earth elements are characteristic of beach-placer deposits (McLemore, 1983). The Site was discovered by the US Geological Survey and identified as a deposit for radioactive titaniferous heavy-materials prior to 1957 (Chenoweth, 1957).[9] In 1957, USDOI Bureau of Mines investigated the Site and determined the mining of the titaniferous sandstone deposits would not be economically viable until the more extensive deposits of titanium and zircon in the US are mined out.[10]

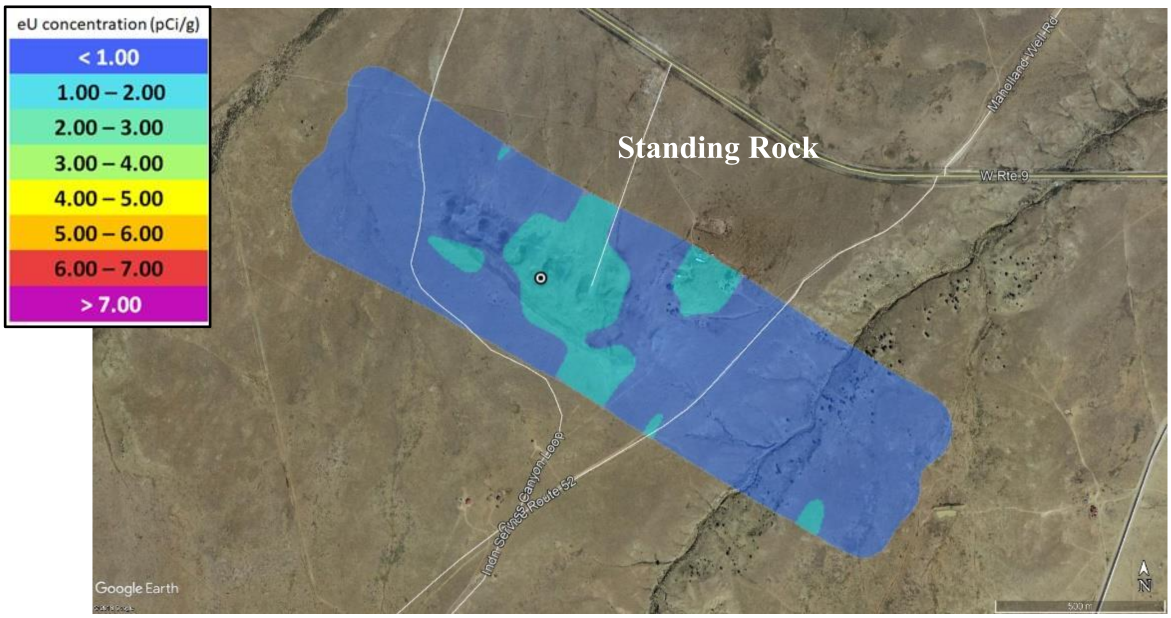


Figure 51: eU concentration (pCi/g) contour of the Standing Rock site. This product was derived from 140 data points covering 0.4 square miles. The dot represents the mine location. There are no discernable surface eU concentrations as the surrounding background concentrations range between <1 pCi/g and 2 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

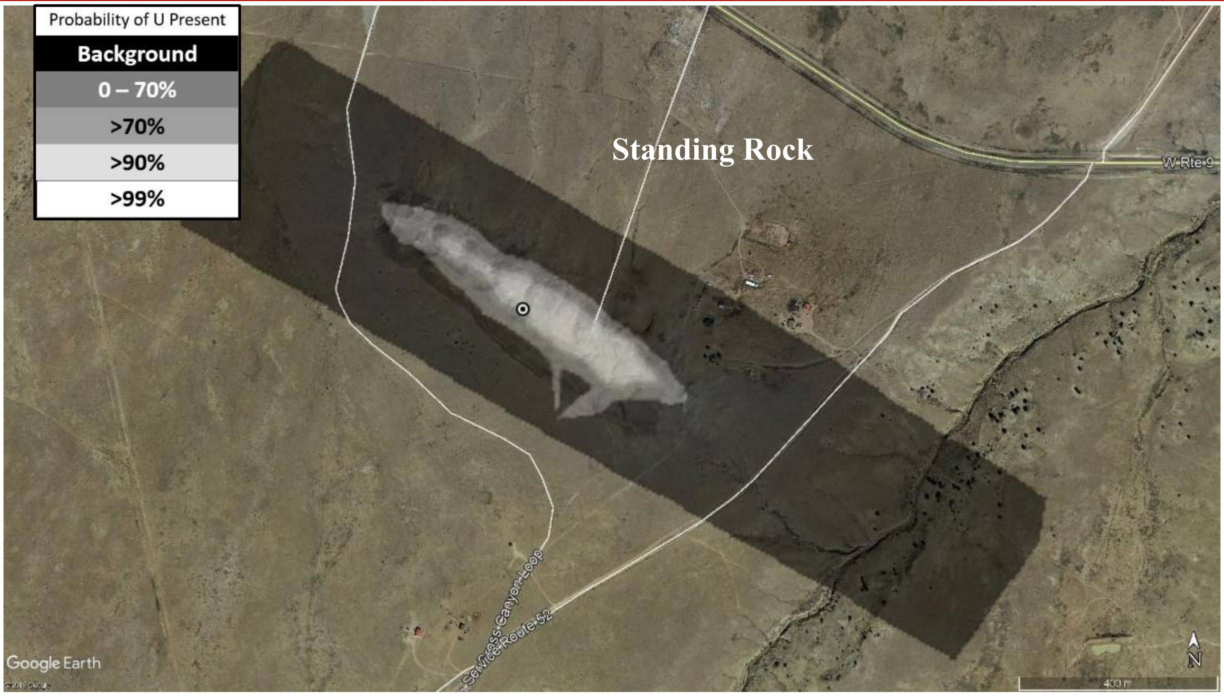


Figure 52: Probability of Uranium Present (PUP) contour indicates a high probability of uranium present in this geologic formation. Since there was no mining activity at the site, this represents a natural deposit. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

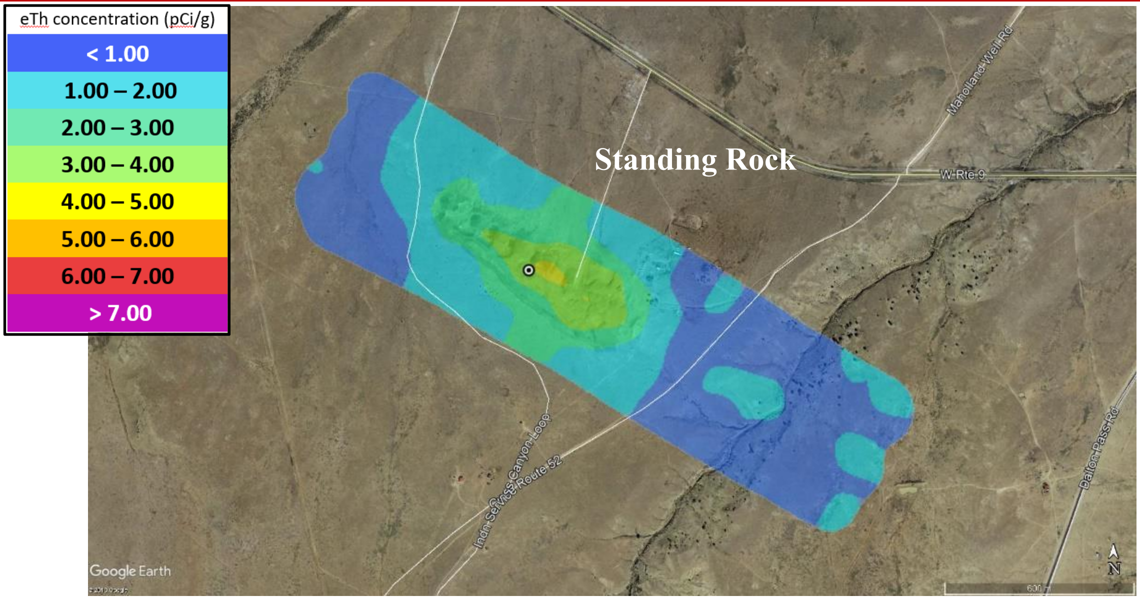


Figure 53:eTh concentration (pCi/g) contour of the Standing Rock site shows a natural outcrop of Thorium averaging up to 5 pCi/g. Please note that ground-based in-situ measurements may be orders of magnitude greater due to a smaller field-of-view. ASPECT altitude target was 500 ft above ground level for this survey

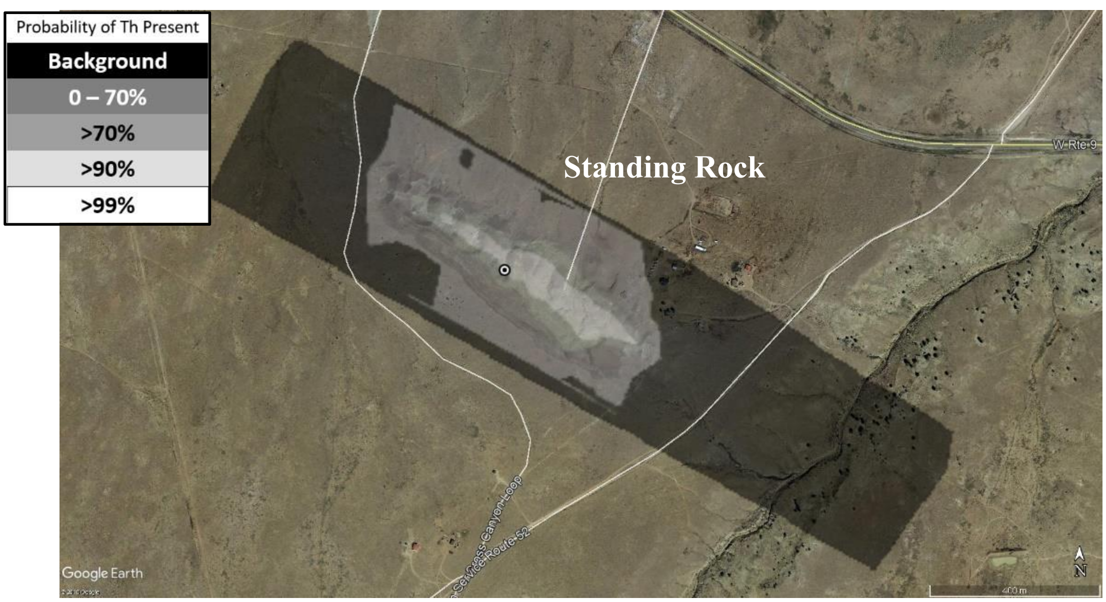


Figure 54: Probability of Thorium Present (PThP) contour of the Standing Rock site. It appears that the geologic formation of this site contains natural deposits of higher concentrations of Thorium than the surrounding area. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

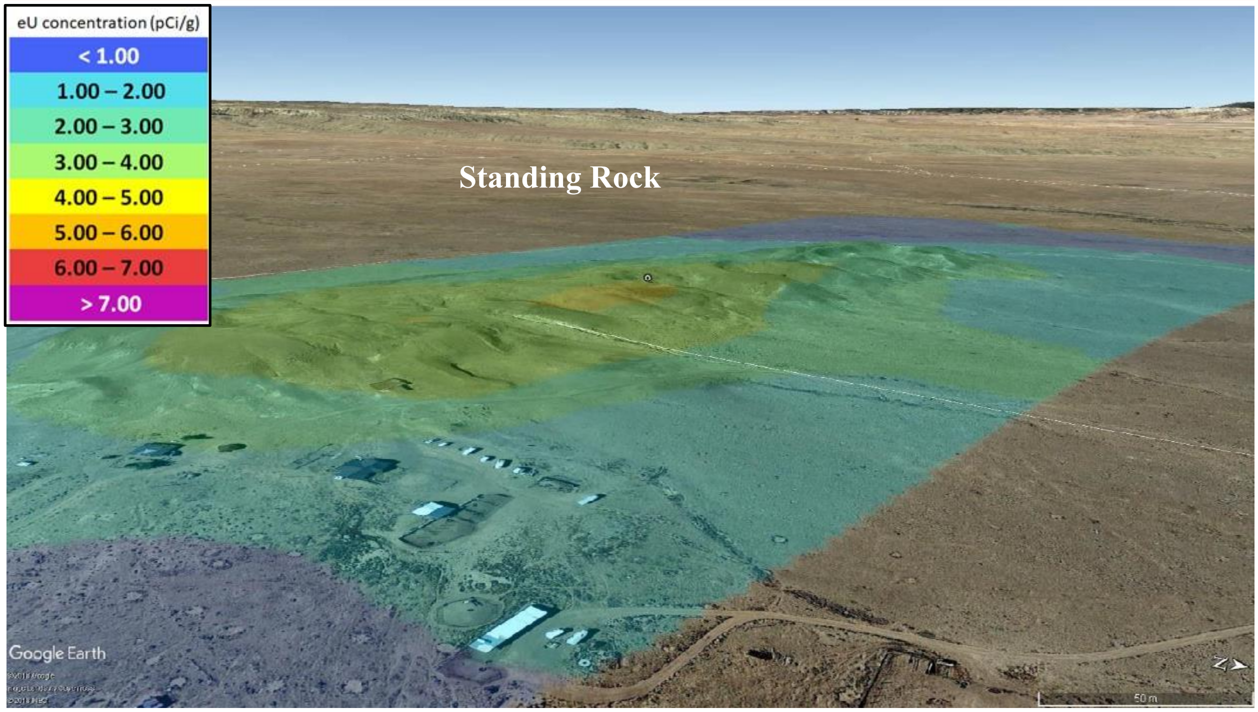


Figure 55: This figure provides a 3D view of the Standing Rock site with the eTh concentration (pCi/g) contour overlay. The name reflects the fact that this formation protrudes from the surface.

4.3 Western Agency Results

The Western Agency of the Navajo Nation contains more than 100 AUMs and includes mines in the checkerboard area of Arizona which are all found within 1 mile of the Navajo Nation's southern border. Aerial radiological surveys were categorized in Zones to (1) focus on where the most AUMs were located, (2) account for costs, and (3) accommodate flight parameters. The Highway from Tuba City, AZ to Bluff, UT was also surveyed. Uranium milling operations took place in Bluff, UT.

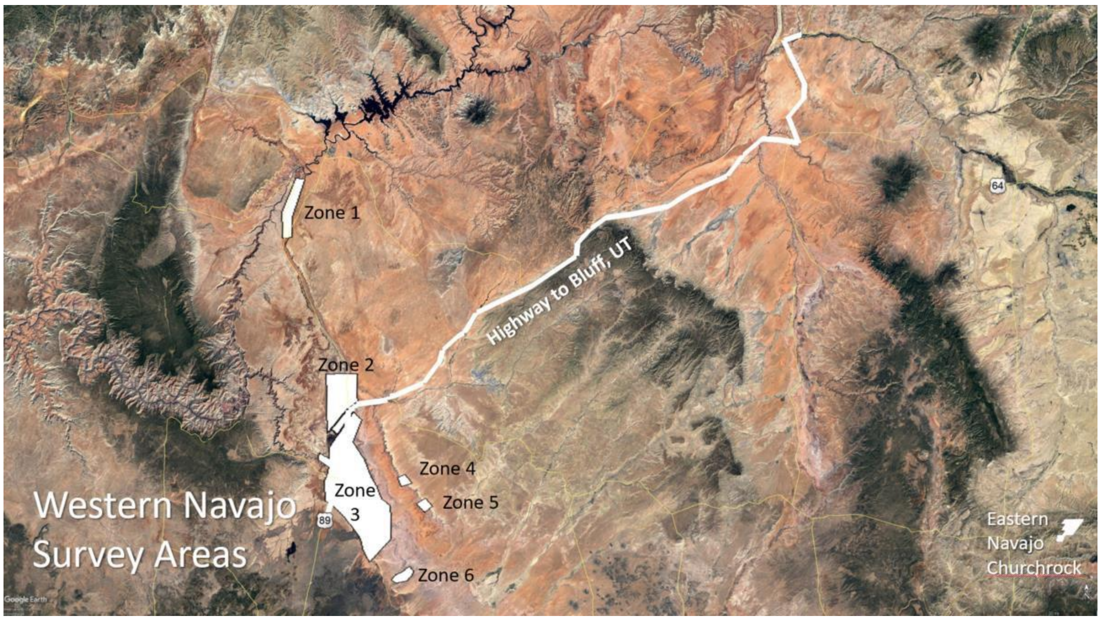


Figure 56: Overview of the Western Agency AUM survey areas in the Navajo Nation.

4.3.1 Zone 1

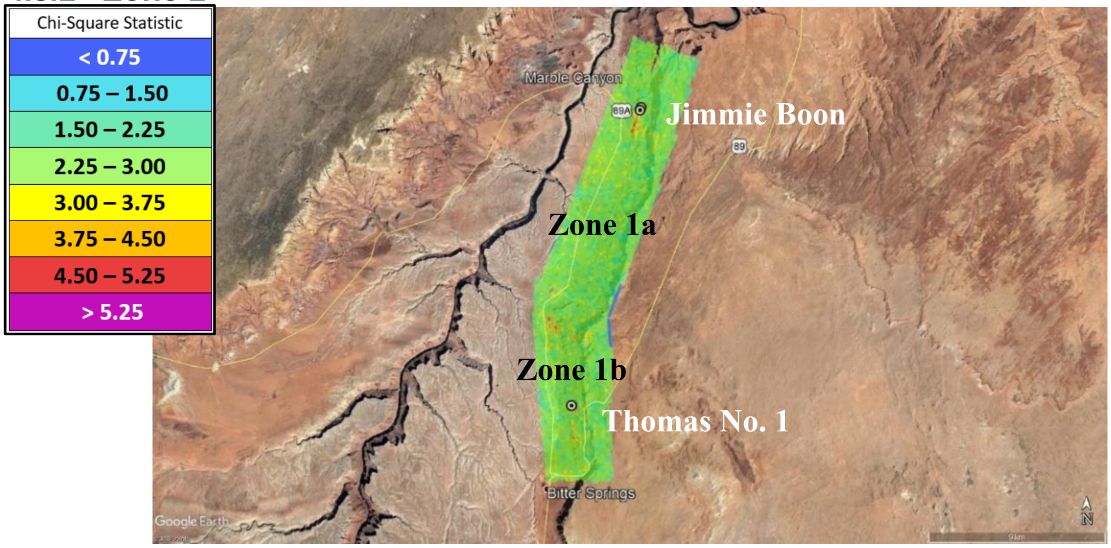


Figure 57: Anomaly contour map for Zone 1a and Zone 1b containing Jimmie Boone and Thomas No. 1 mines respectively. Zone 1a was derived from 4291data points covering 21 square miles. Zone 1b was derived from 2828 data points covering 13.2 square miles. The dots represent mine locations. The legend represents the chi-square statistic indicating deviations from an expected background spectral pattern and is associated with an arbitrary selection of colors. The anomaly function was used due to the mountainous terrain. The average survey altitude for Zone 1a was 833 ± 320 ft and 643± 320ft for Zone 1b.

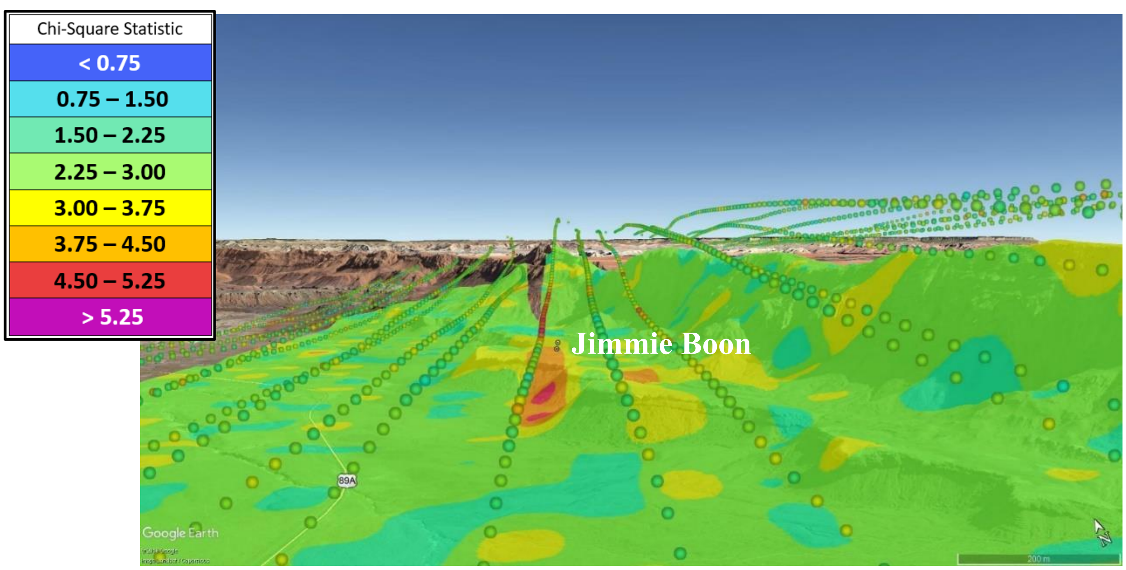


Figure 58: ASPECT 3D flight path in Zone 1a. The direction of flight lines were based on the most efficient survey parameters given the local topography. Each flight line altitude was adjusted to maintain height consistency as much as possible. This image shows the rough terrain which adversely affects height correction. As a result, the anonmaly algorithm was used to identify locations with spectral results that deviate from background.

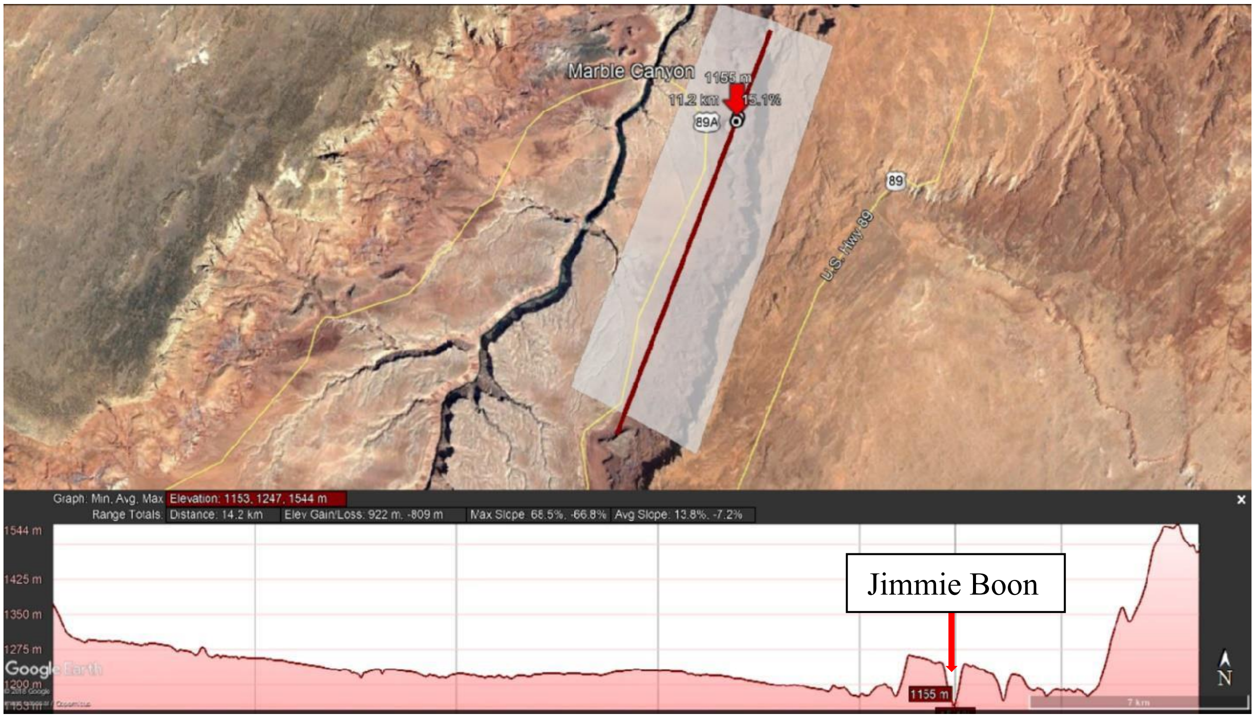


Figure 59: This image shows the severe changes in terrain along flight line 11 in Zone 1. Due to these topography challenges, only the anomaly result was used to identify areas of where the spectral signature indicated an anomaly relative to background.

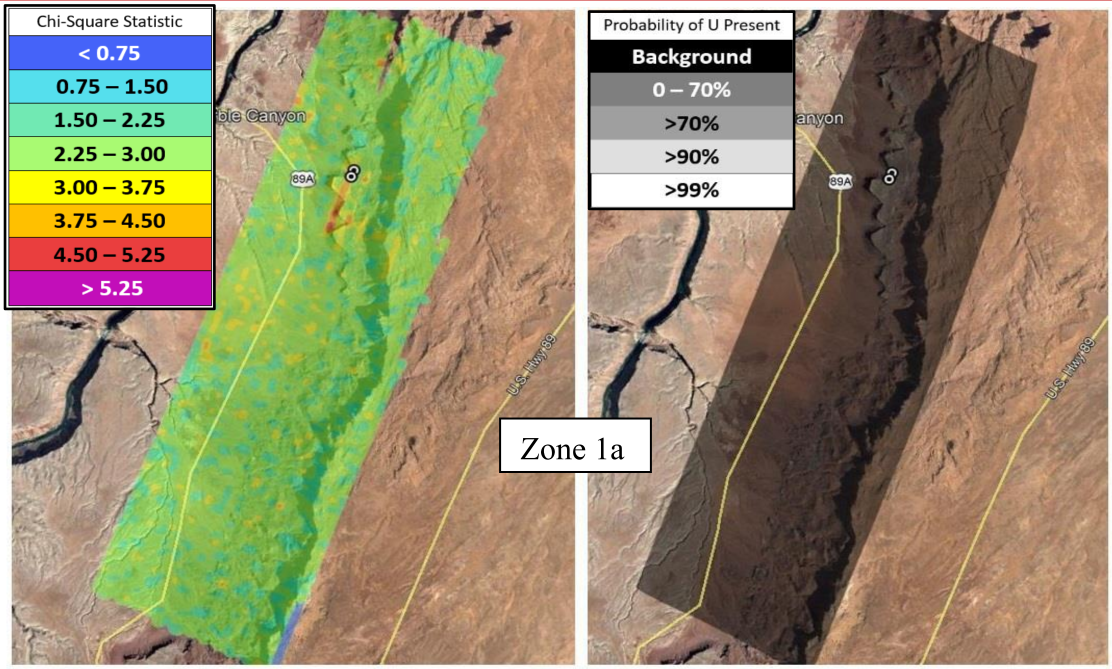


Figure 60:Zone 1a anomaly (left) and PUP (right) products. The PUP product did not identify any locations with statistically significant uranium detection, however, the anomaly product suggests there are differences from background just south of the Jimmie Boon mine locations. A close-up view of the Jimmie Boon mines is provided in the following figure.

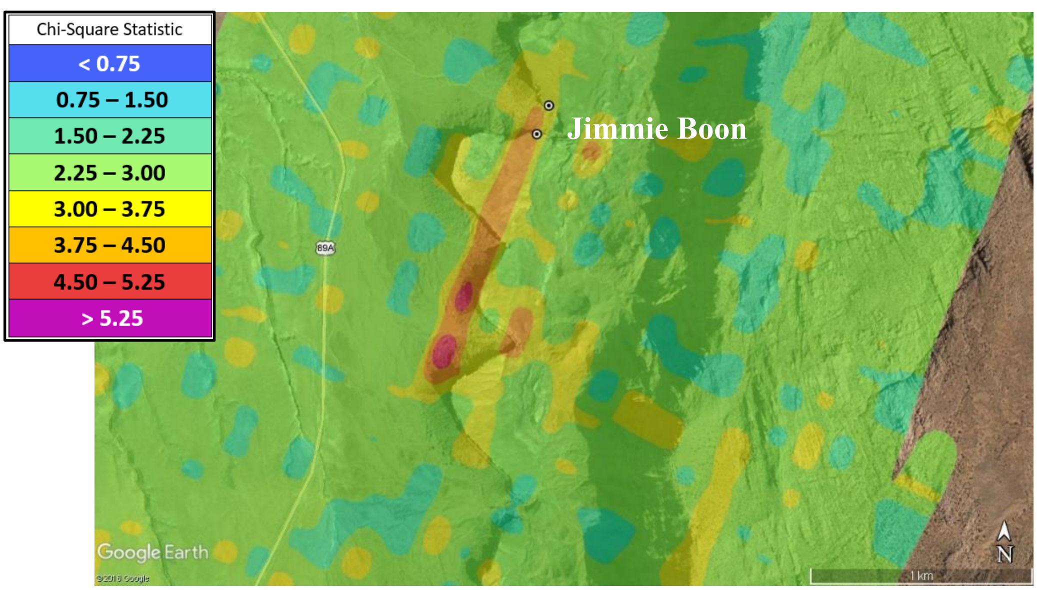


Figure 61:Zone 1a anomaly product with a closer view of the Jimmie Boone mine locations. There are anomalies detected south these locations which suggest the actual mine locations may be incorrect or there are areas with elevated activity substantially different from background that may warrant further ground-based activities.

4.3.2 Zone 2

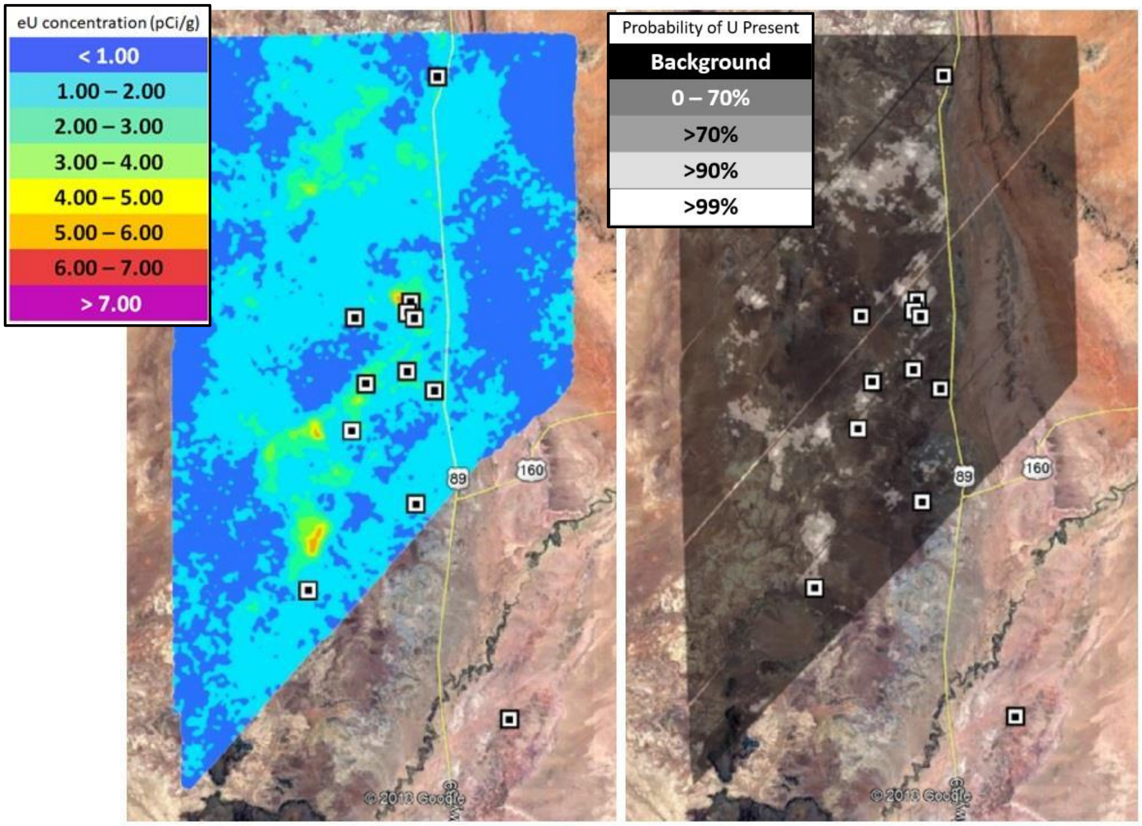


Figure 62: (Left image) eU concentration (pCi/g) contour of Zone 2 within the Western Agency of the Navajo Nation. It took four flights to complete this area. This product was derived from 28,009 data points covering 67.7 square miles. The dots represent mine locations. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.*** *(Right image) Probability of Uranium Present (PUP) contour shows several areas most likely to due to natural outcrops of uranium deposits.* ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.*** *Close-up views of these mining areas are provided in the following figures.*

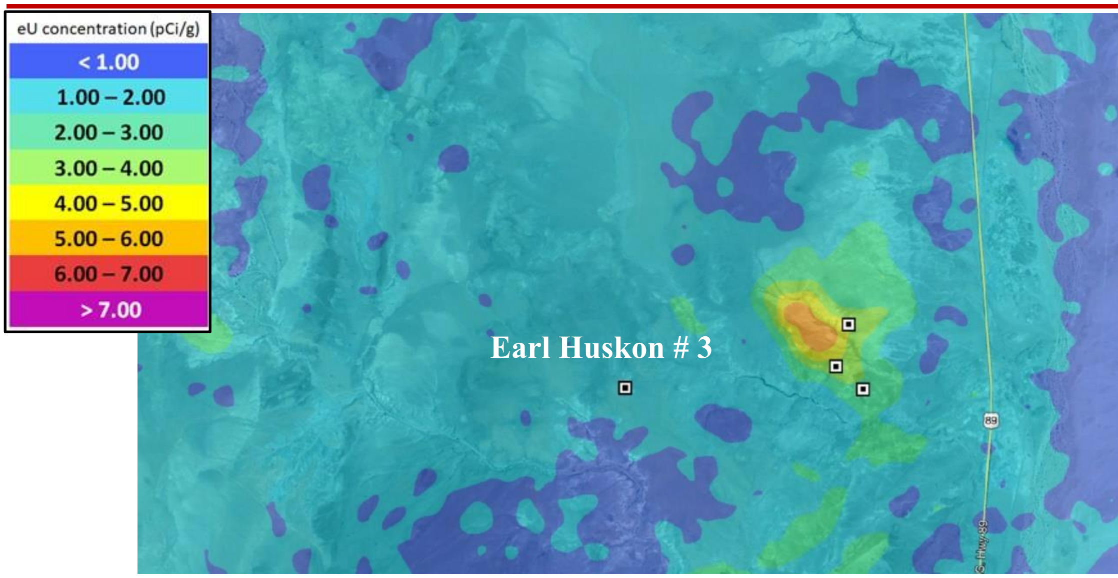


Figure 63: Close-up view of the mines in Zone 2 of the Western Agency. These locations show eU concentrations ranging between 1 pCi/g to 6 pCi/g. The legend represents surface uranium concentrations in picoCuries per gram (pCi/g) and is associated with an arbitrary selection of colors. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

Figure 64 Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal line is the flight path of the aircraft and is caused by separate flights. The eastern portion represents Zone 2b and the western portion is Zone 2c. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

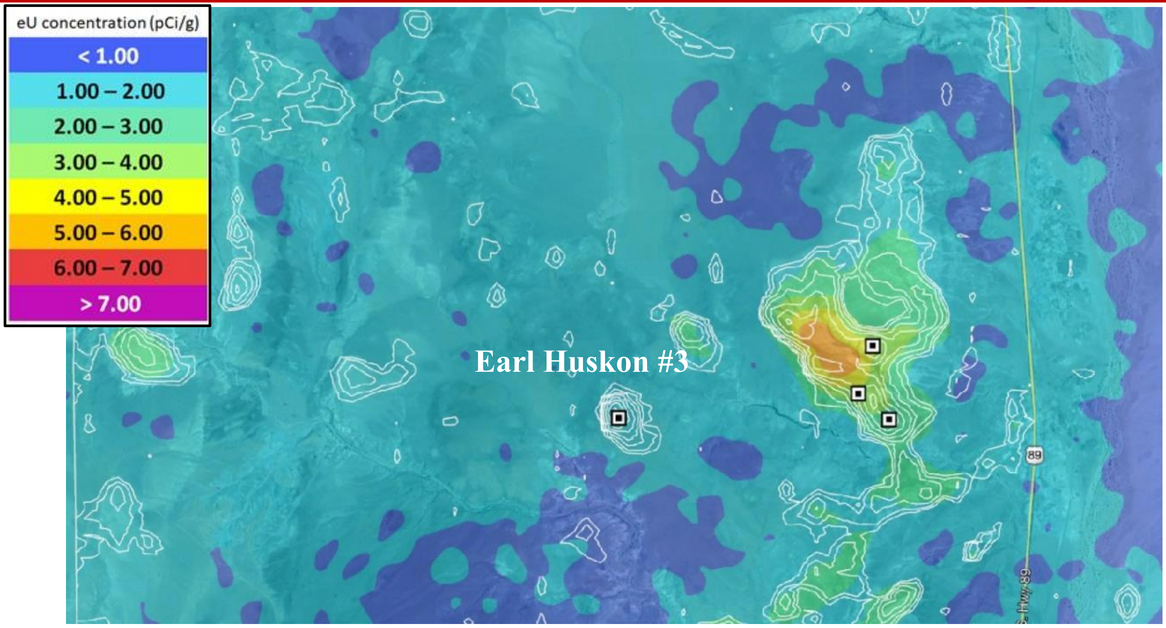


Figure 65: Close-up view of mines in Zone 2 of the Western Agency with the results from the DOE aerial surveys conducted in the 1990s. There appears to be good correlations between these surveys. Better detail can be seen in the PUP product below. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

Figure 66: Close-up view of the mines in Zone 2 of the Western Agency with the results from the DOE aerial surveys conducted in the 1990s.

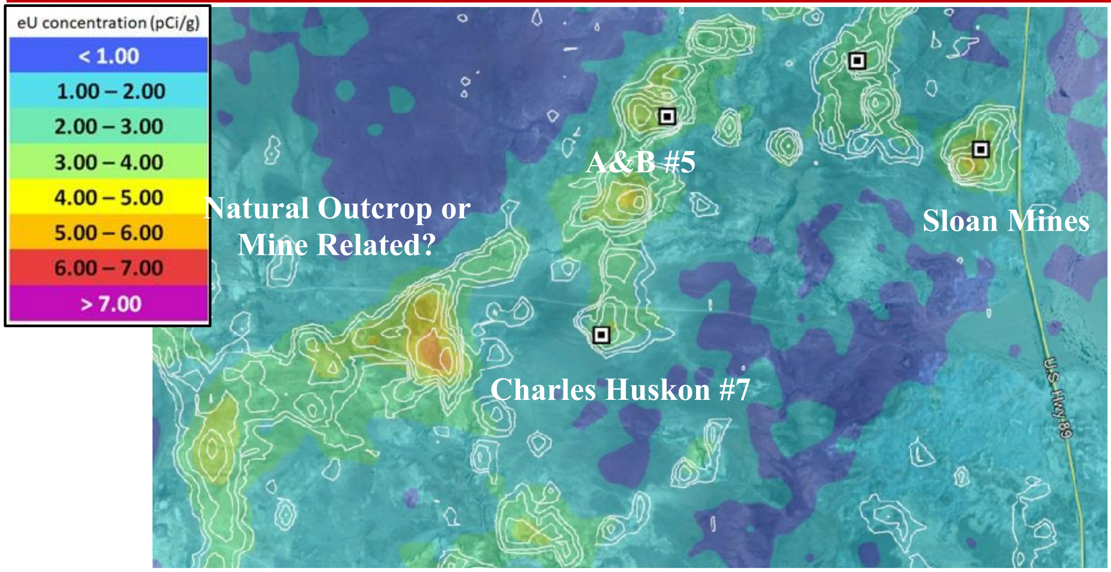


Figure 67: Close-up view of the A&B #5, and Charles Huskon #7 mines in Zone 2 of the Western Agency. There appears to be large natural outcrop of uranium near the surface just west of Charles Huskon #7 or an area with surface contamination due to mining activities. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

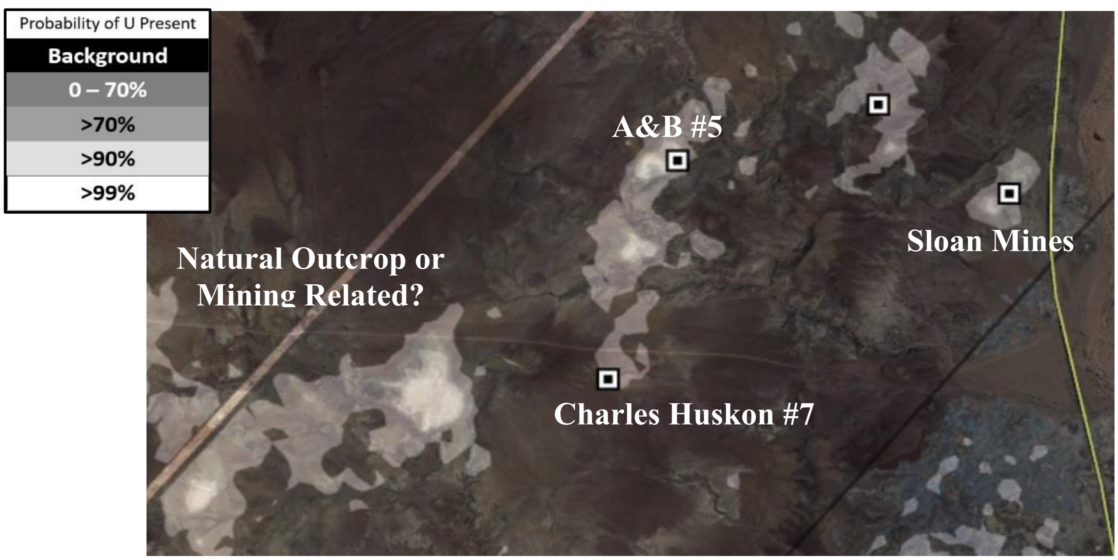


Figure 68: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal line is the flight path of the aircraft and is caused by separate flights. The eastern portion represents Zone 2b and the western portion is Zone 2c and 2d. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

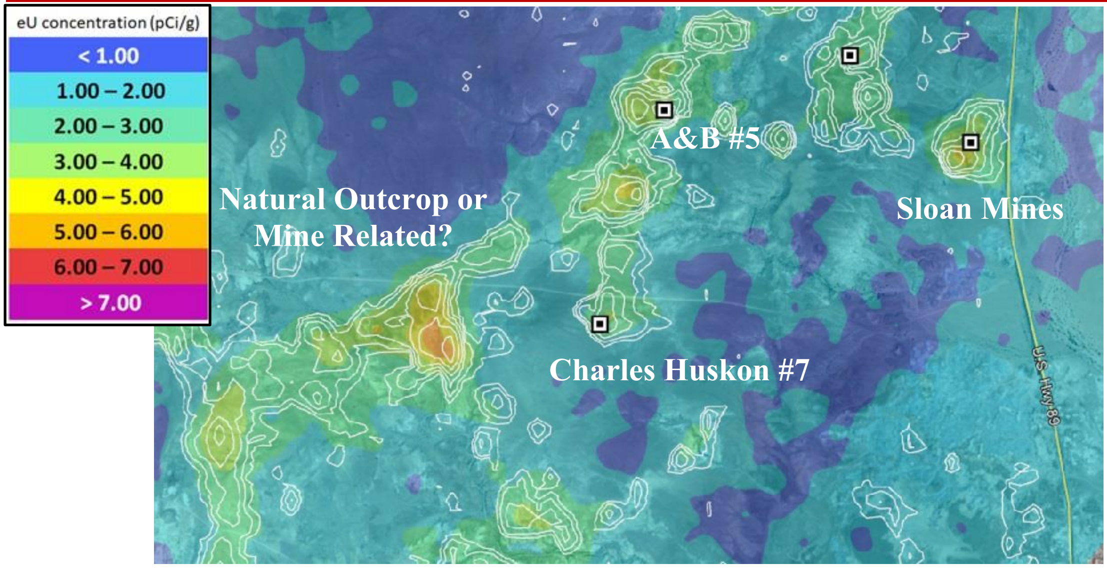


Figure 69: Close-up view of the Sloan mines, A&B #5, and Huskon #7 mines in Zone 2 of the Western Agency with the results from the DOE aerial surveys conducted in the 1990s. There appears to be good correlations between these surveys. Better detail can be seen in the PUP product below. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

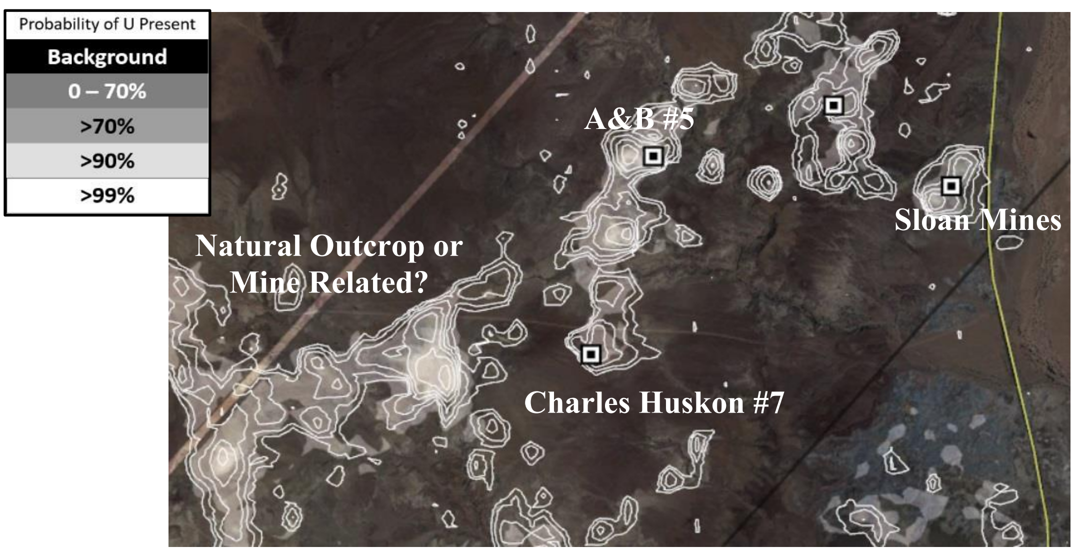


Figure 70: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (dark grey to white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal line is the flight path of the aircraft and is caused by separate flights. The eastern portion represents Zone 2b and the western portion is Zone 2c and 2d. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

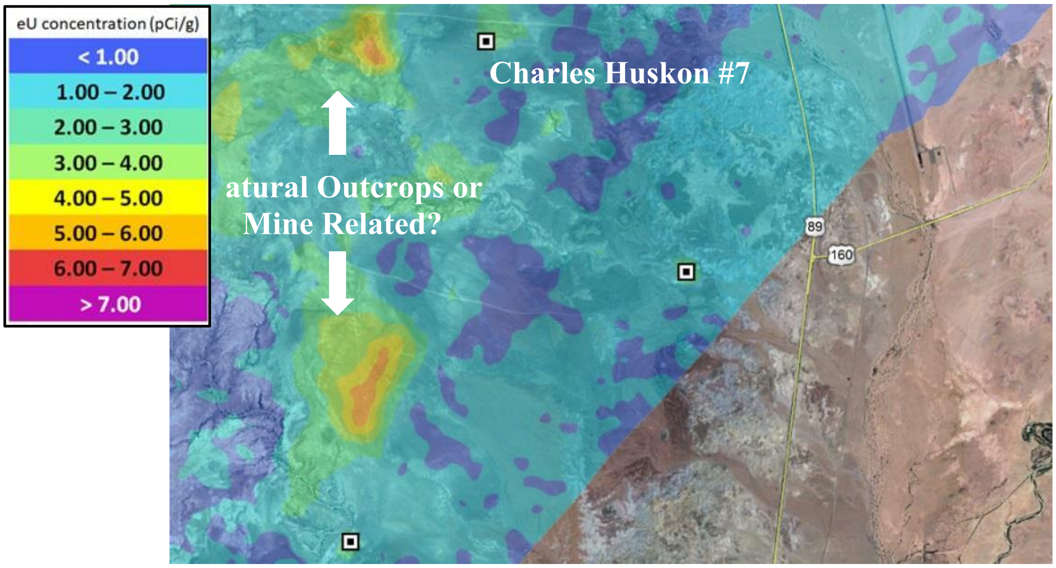


Figure 71: Close-up view of the Charles Huskon #7 mine in Zone 2 of the Western Agency. There appears to be two large natural outcrops of uranium near the surface just west and south of Huskon #7 or these are areas with surface contamination due to mining activities. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

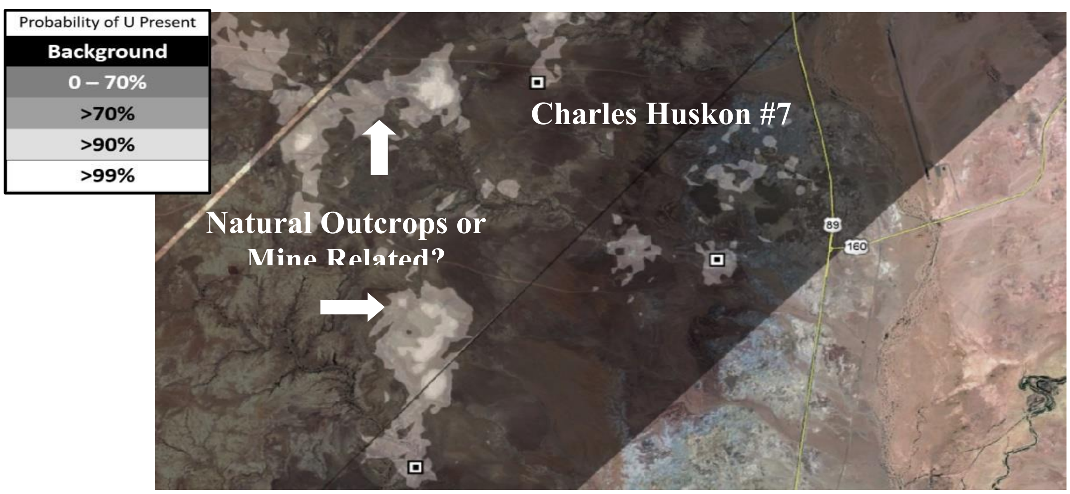


Figure 72: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal line is the flight path of the aircraft and is caused by separate flights. The eastern portion represents Zone 2b and the western portion is Zone 2c and 2d. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

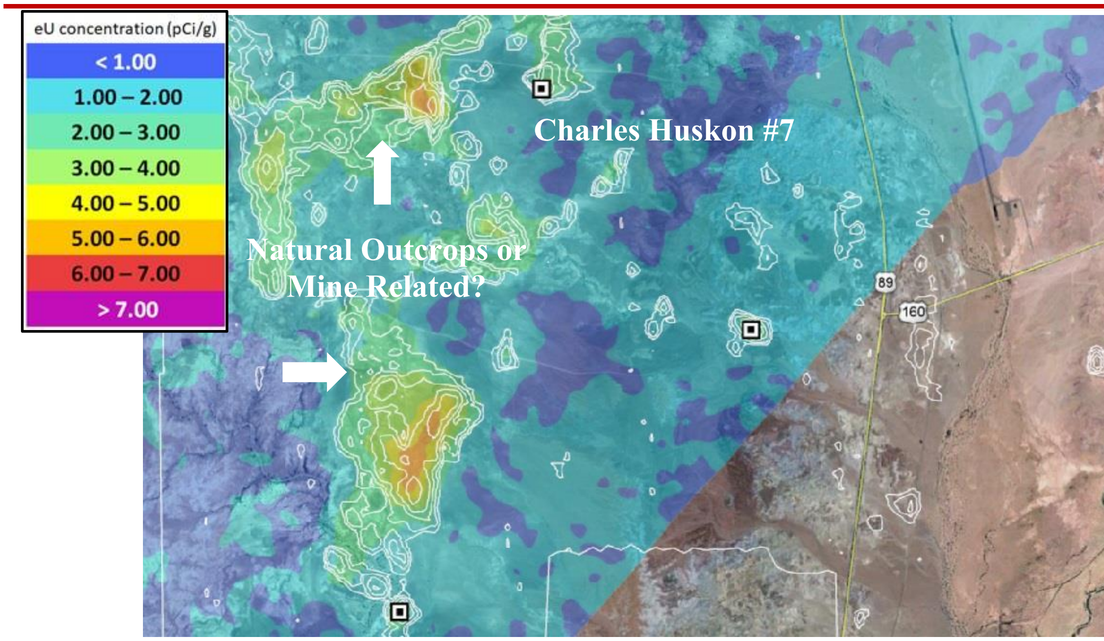


Figure 73: Close-up view of the Charles Huskon #7 mine in Zone 2 of the Western Agency with the results from the DOE aerial surveys conducted in the 1990s. There appears to be good correlations between these surveys. Better detail can be seen in the PUP product below. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

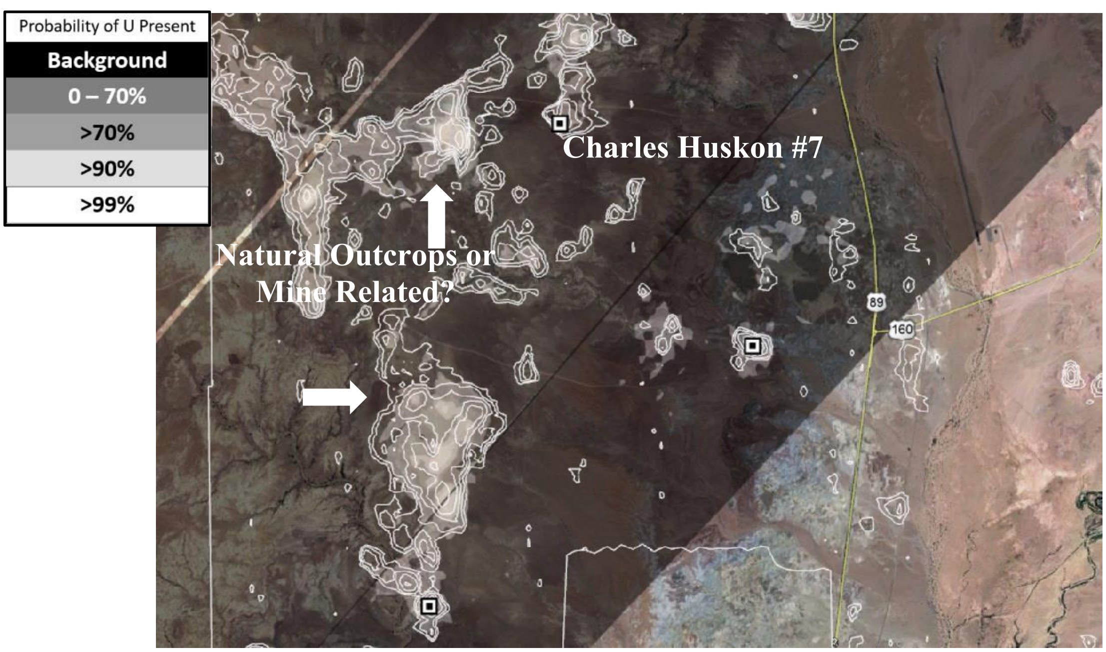


Figure 74: Close-up view of the Charles Huskon #7 mine in Zone 2 of the Western Agency with the results from the DOE aerial surveys conducted in the 1990s.

4.3.3 Zone 3

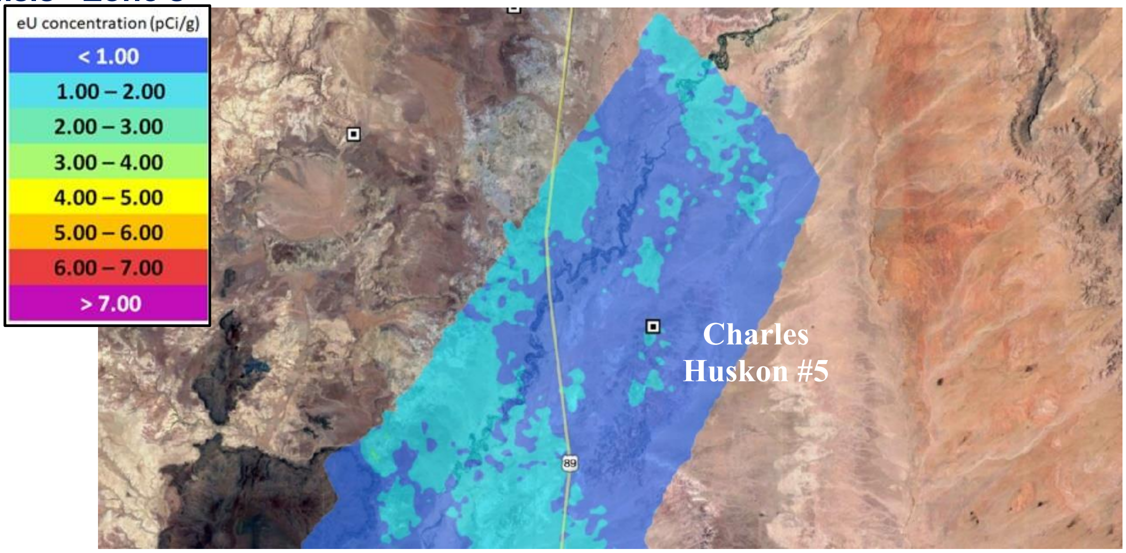


Figure 75: Close-up view of the northern most section of Zone 3. There does not appear to be any large natural outcrops of uranium or AUMs that exists in this area exceeding 2 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

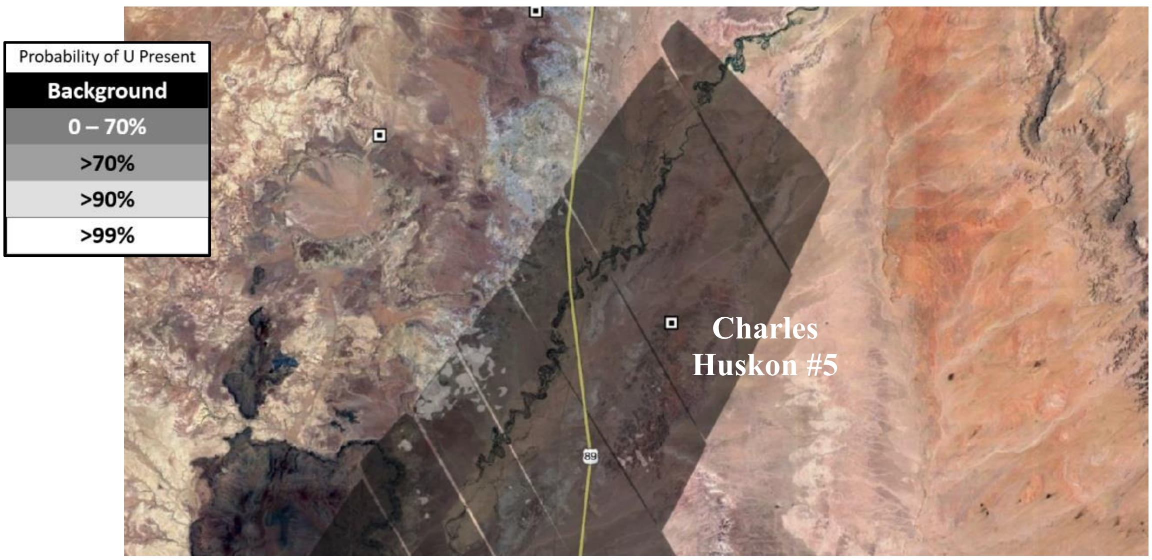


Figure 76: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. The eastern portion in this image shows an area with potential natural outcrop of uranium. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

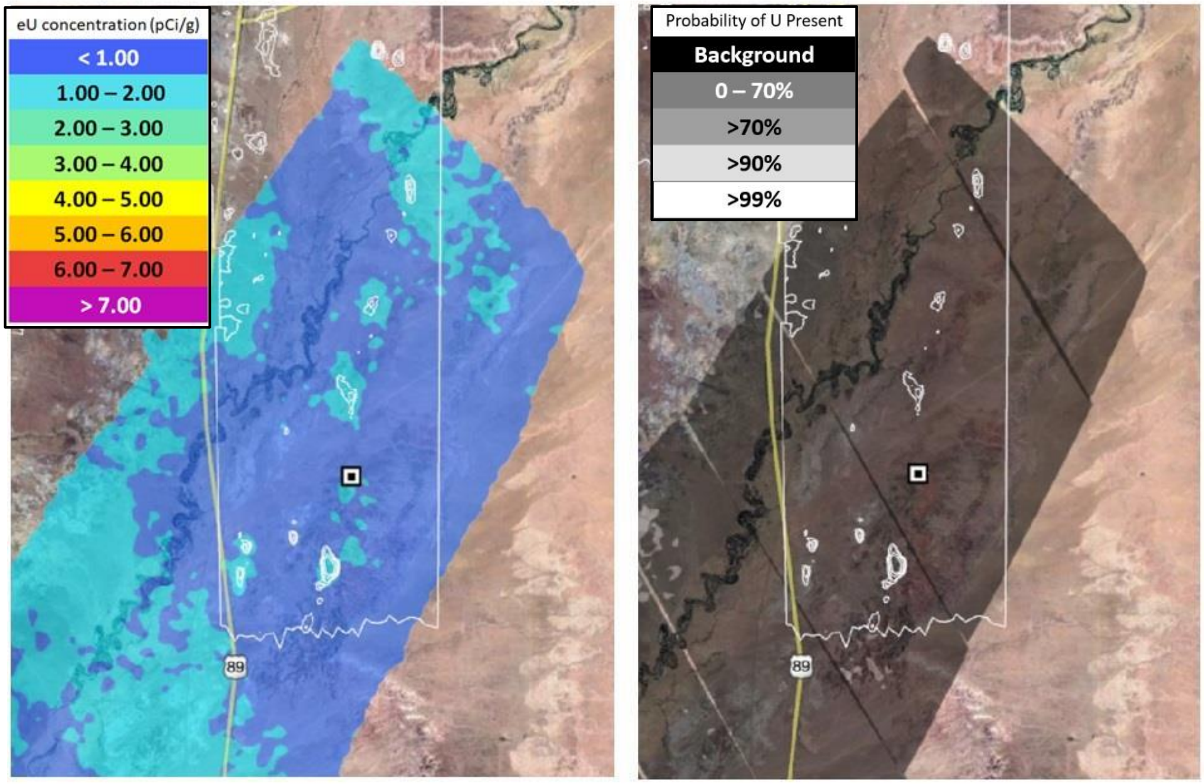


Figure 77: eU concentration contour map (left) and PUP contour map (right) with the results from the DOE aerial surveys conducted in the 1990s. There is reasonable correlation between the eU concentration contour map with the DOE results, however the PUP product does not show significant deviations from background.

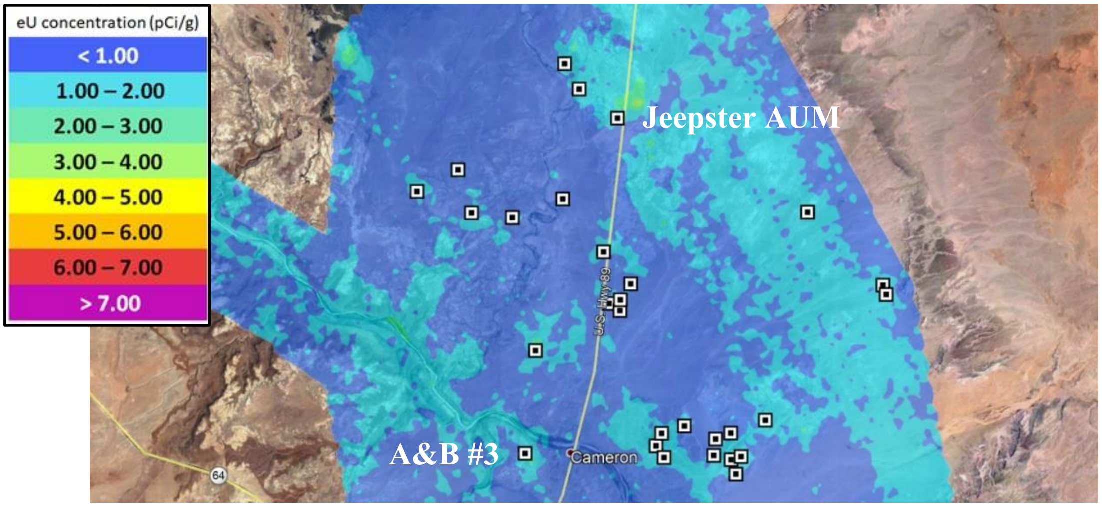


Figure 78: Close-up view of the northern section of Zone 3. There appears to be an area east of the Jeepster AUM with surface eU concentration that exists in this area up to 4 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

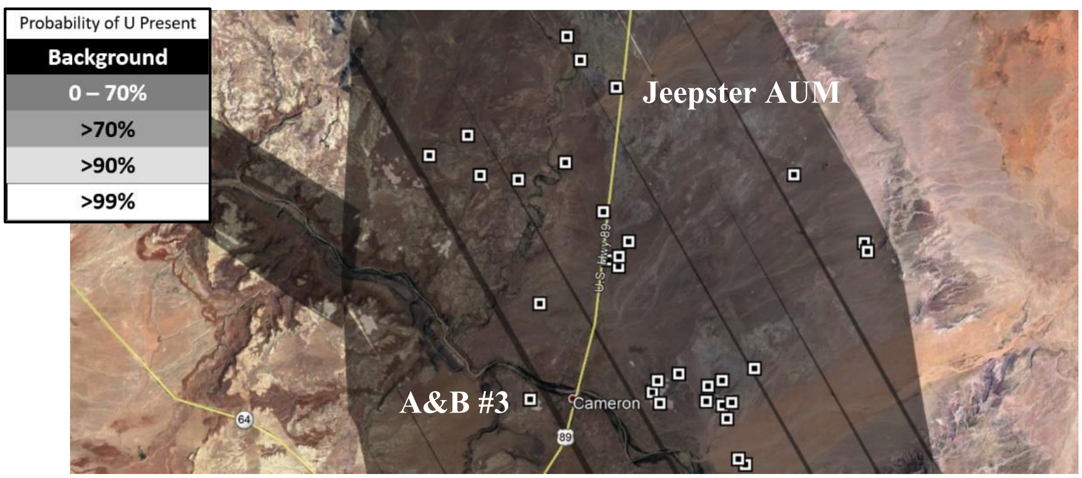


Figure 79: Probability of Uranium Present (PUP) product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. Most of the AUMs within this image do not appear to contain elevated uranium signature that deviate from natural background. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

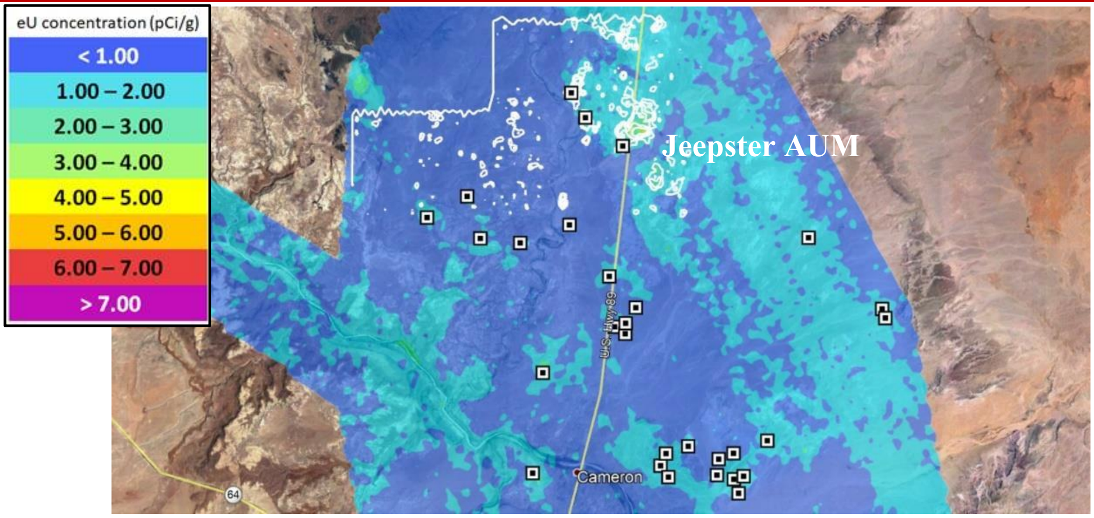


Figure 80: Close-up view of the northern section of Zone 3 with the results from the DOE aerial surveys conducted in the 1990s. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

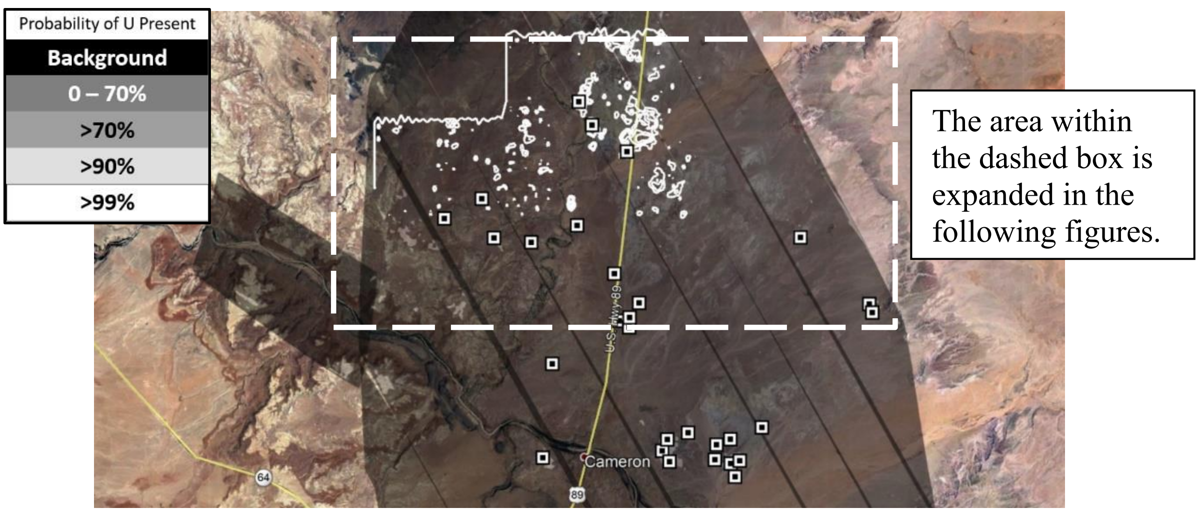


Figure 81: Close-up view of the northern section of Zone 3 with the results from the DOE aerial surveys conducted in the 1990s. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. Most of the AUMs within this image do not appear to contain elevated uranium signature that deviate from natural background. Additional views are provided in the following figures. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

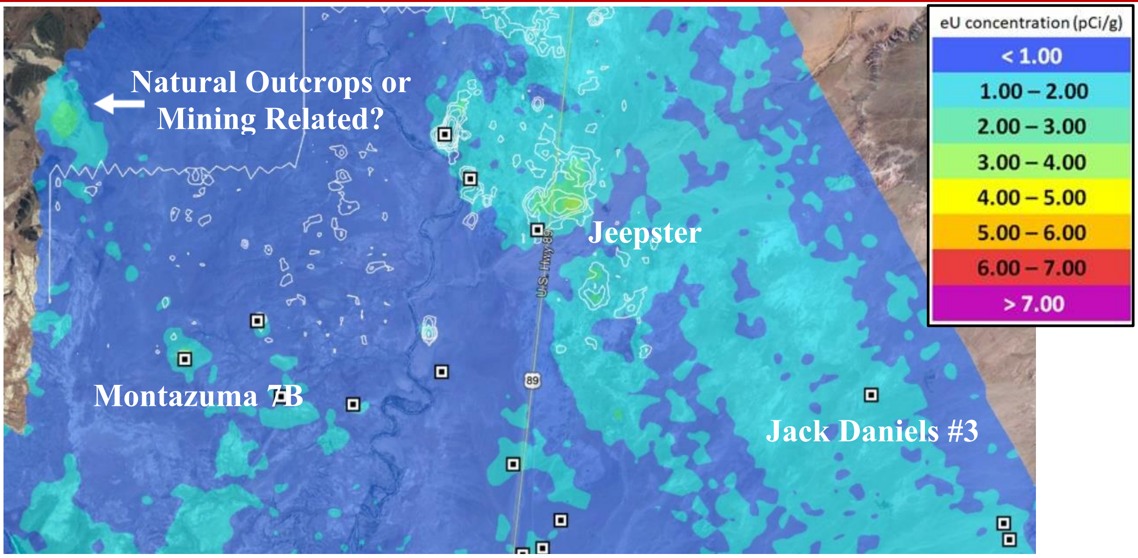


Figure 82: Closer view of the northern section of Zone 3 with the results from the DOE aerial surveys conducted in the 1990s. Many of the areas identified by the DOE with elevated activity do not appear in the ASPECT surveys. It is possible that remedial actions taken since the 1990s were successful in reducing the surface eU concentrations to natural levels. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

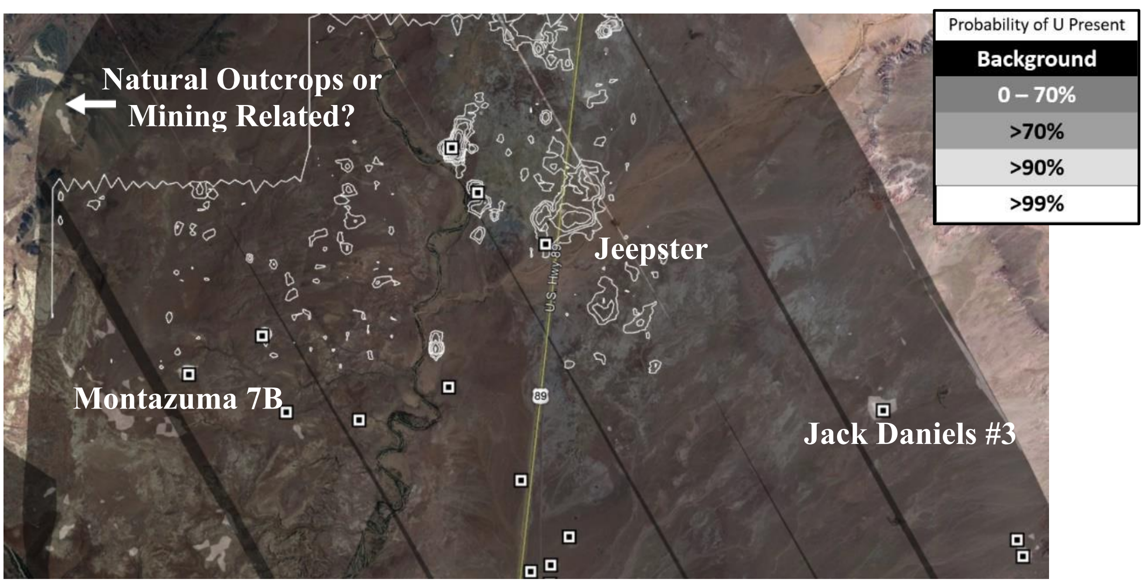


Figure 83: Closer view of the northern section of Zone 3 with the results from the DOE aerial surveys conducted in the 1990s. The PUP product shows little to no detectable eU activity outside natural background (black) variability. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

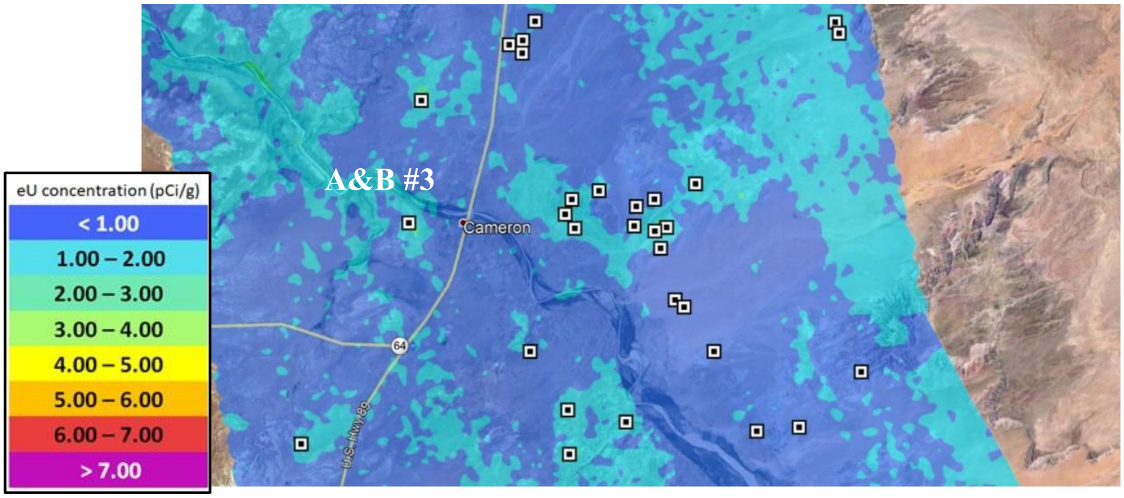


Figure 84: Close-up view of Zone 3 near Cameron. Numerous AUMs are located within this section. A few show surface concentrations up to 3 pCi/g. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions***

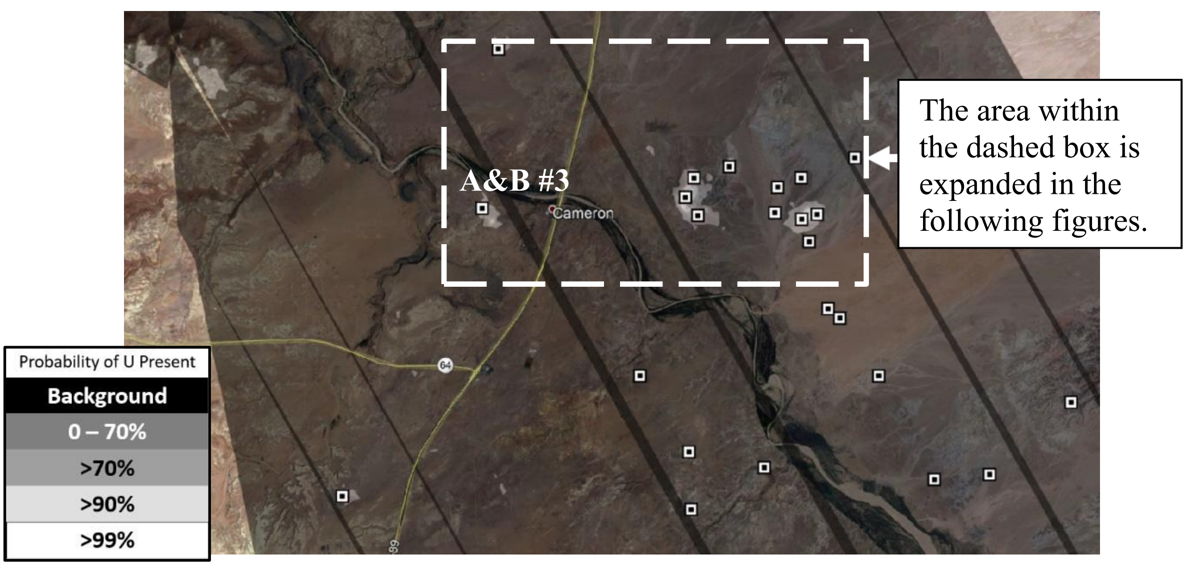


Figure 85: Close-up view of Zone 3 near Cameron. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. Most of the AUMs within this image do not appear to contain elevated uranium signature that deviate from natural background. Additional views are provided in the following figures. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

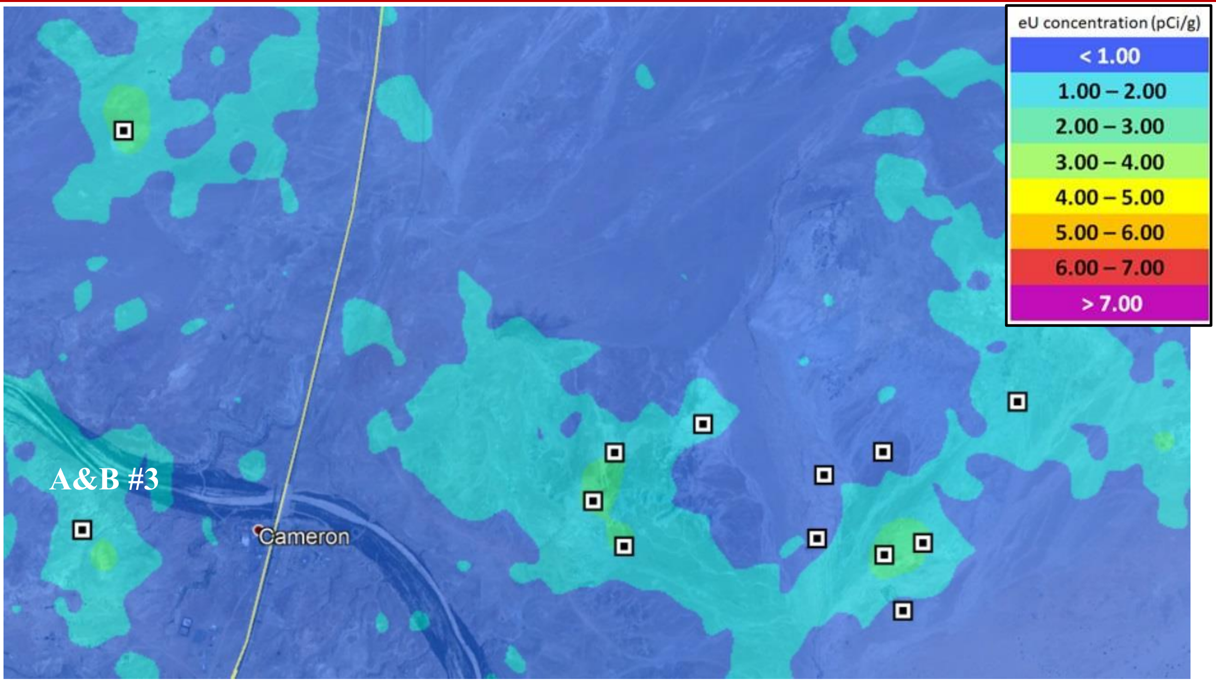


Figure 86: Closer view of the Cameron area within Zone 3 ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

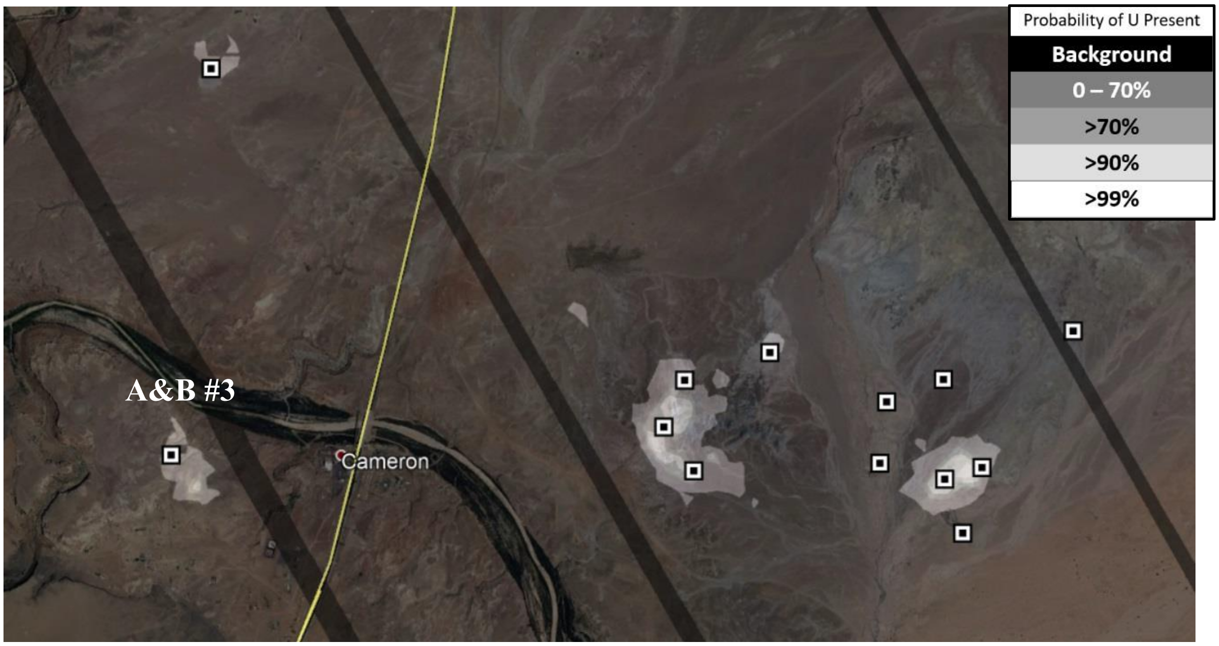


Figure 87: Closer view of the Cameron area within Zone 3. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

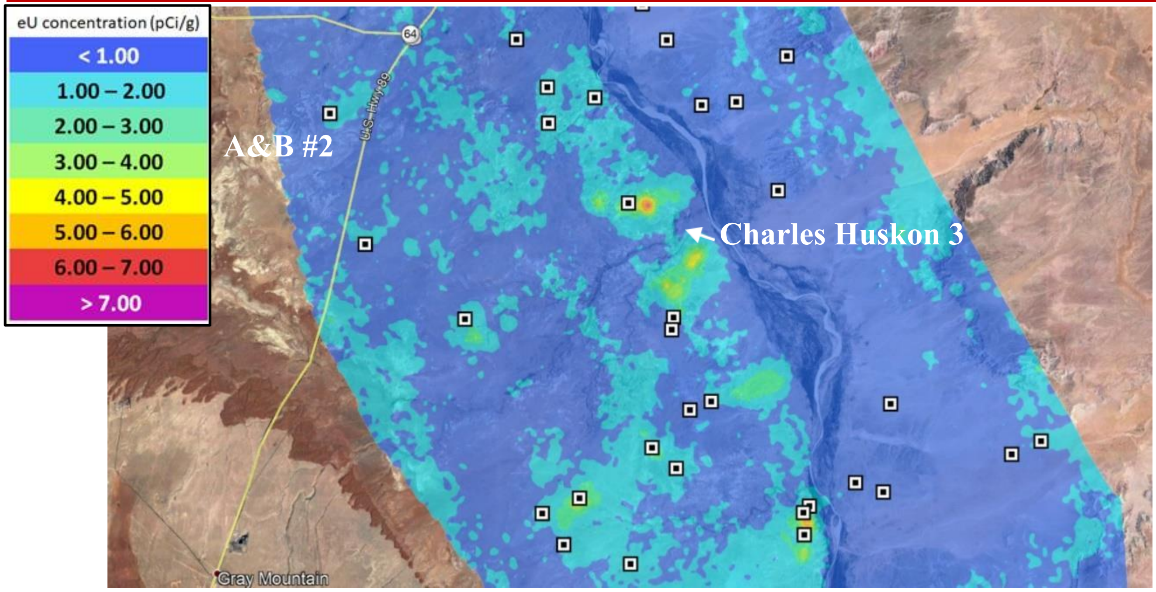


Figure 88: Close-up view of the middle section of Zone 3. There are several AUMs with surface eU concentrations up to 7 pCi/g (e.g., Charles Huskon No. 3). ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

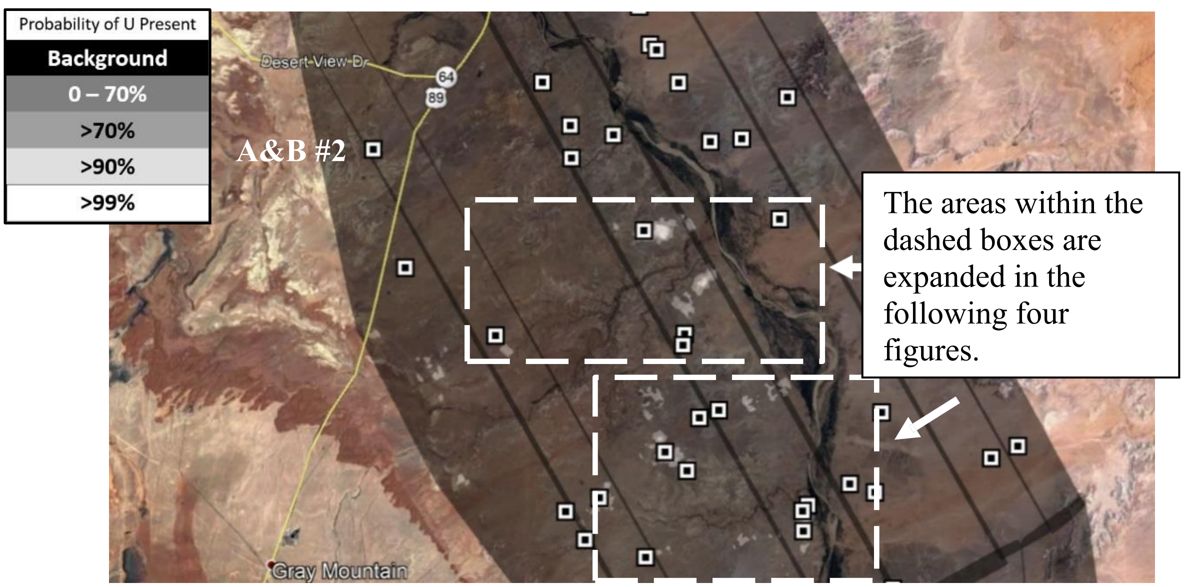


Figure 89: Close-up view of the middle section of Zone 3. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. Additional views are provided in the following figures. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

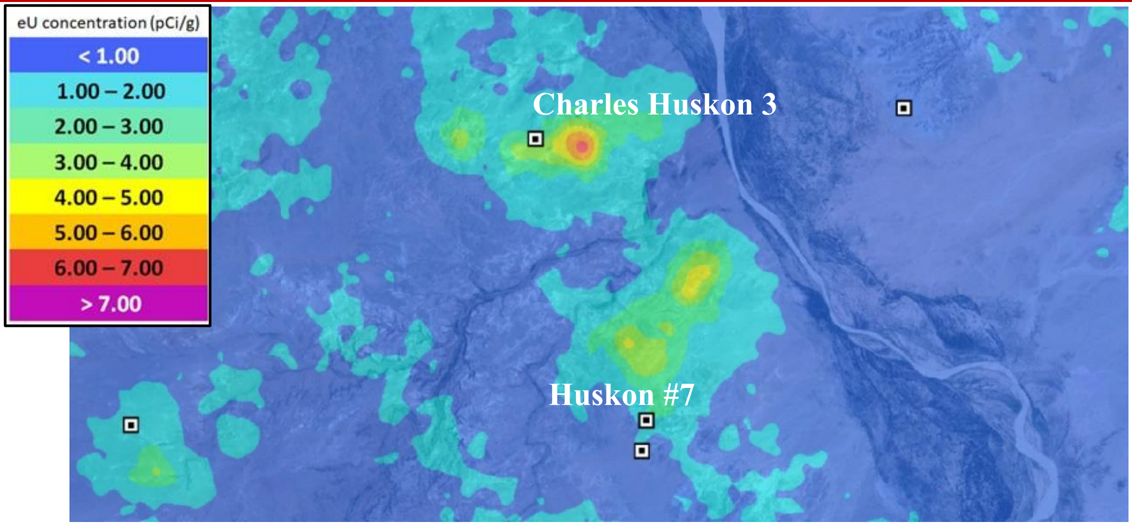


Figure 90: Closer view of the mining area within Zone 3. There are many other mines not associated with this mine in this view but it was selected to title this image. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

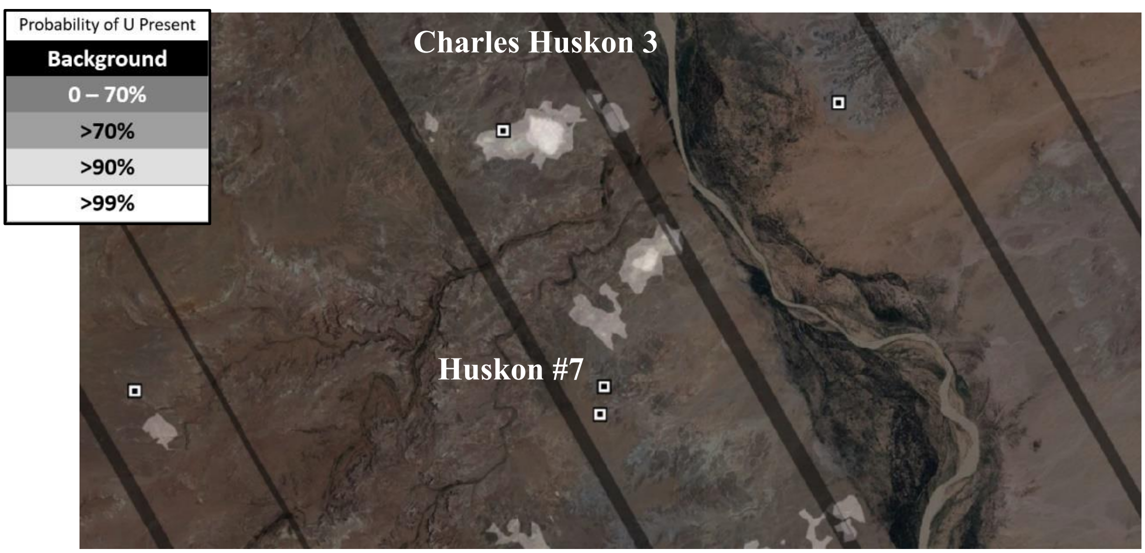


Figure 91:Closer view of the mining area within Zone 3. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

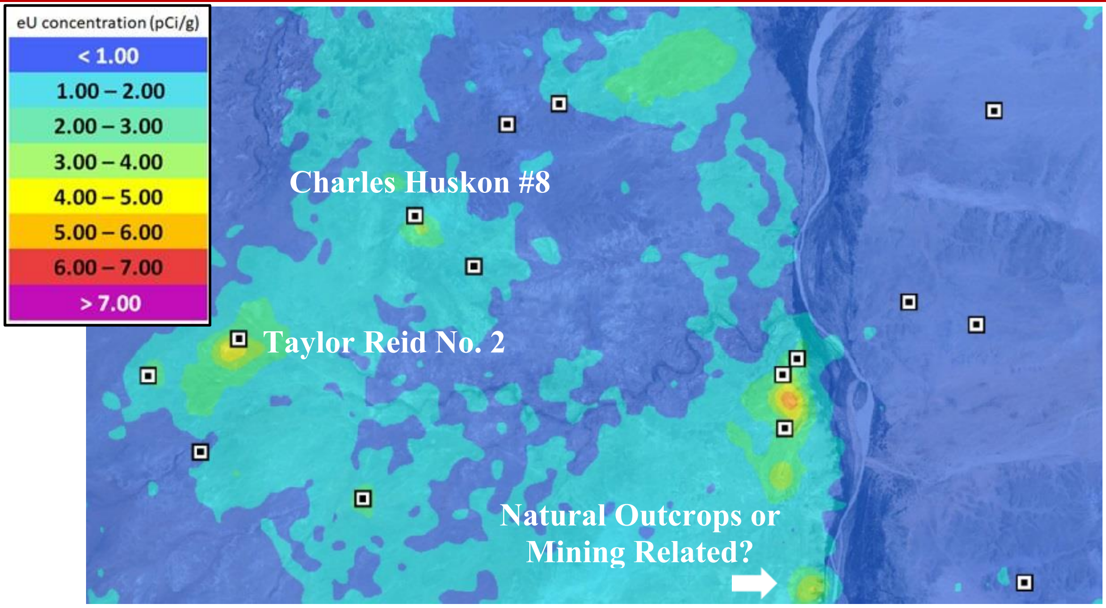


Figure 92: Closer view of the Taylor Reid No. 2 mining area within Zone 3. There are many other mines not associated with this mine in this view but it was selected to title this image. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

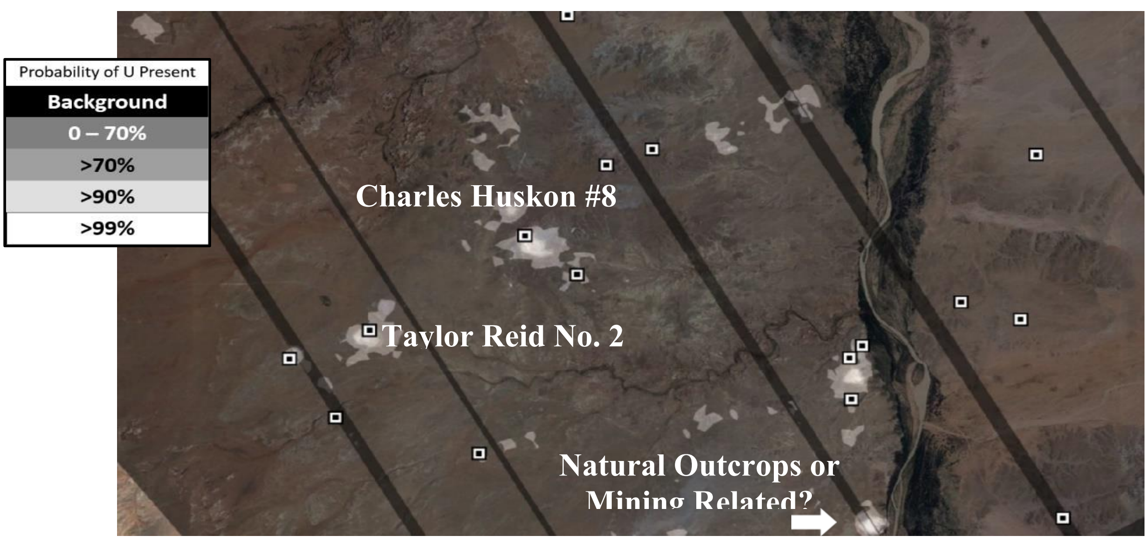


Figure 93: Closer view of the Taylor Reid No. 2 mining area within Zone 3. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

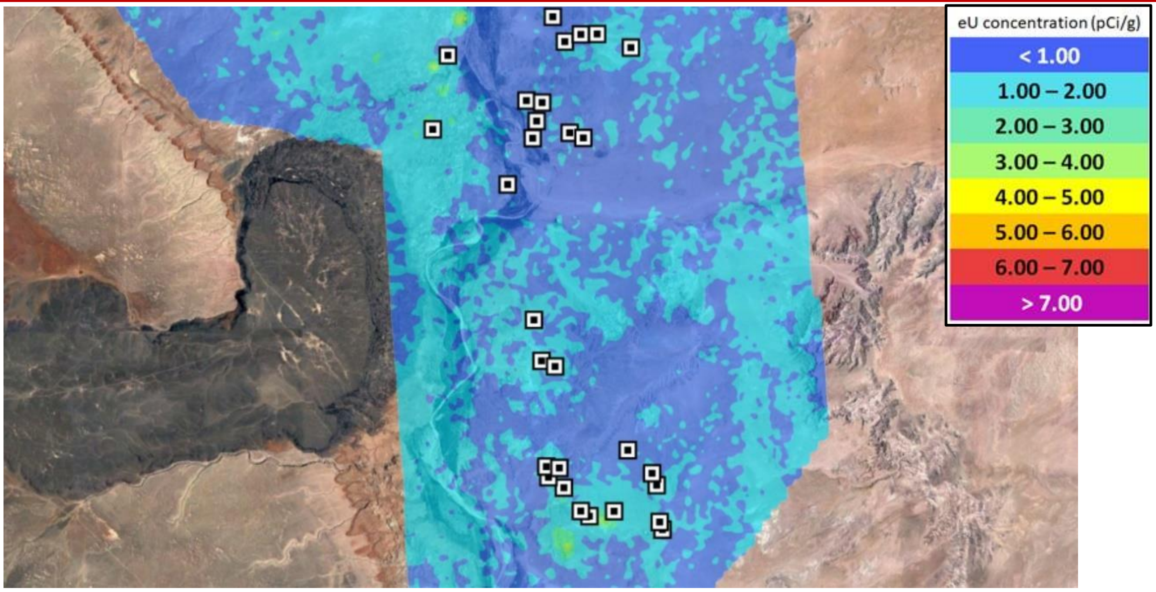


Figure 94: Close-up view of the southern section of Zone 3. There are several AUMs with minimal to no surface contamination distinguishable from the surrounding background. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

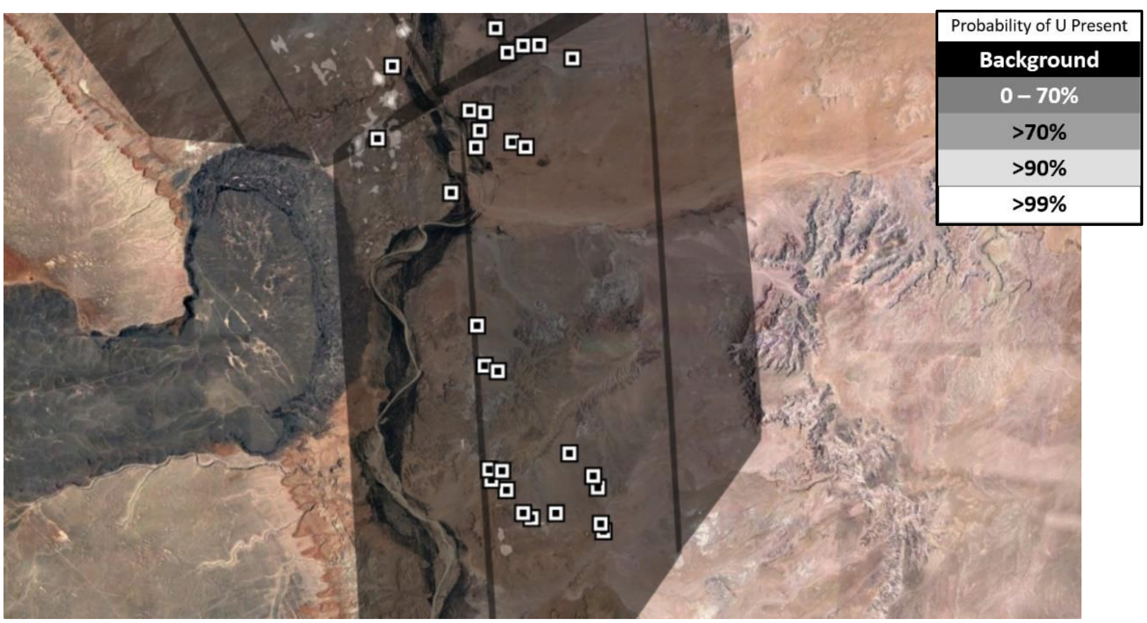


Figure 95: Close-up view of the southern section of Zone 3. The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal lines are caused by separate flights. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.3.4 Zone 4

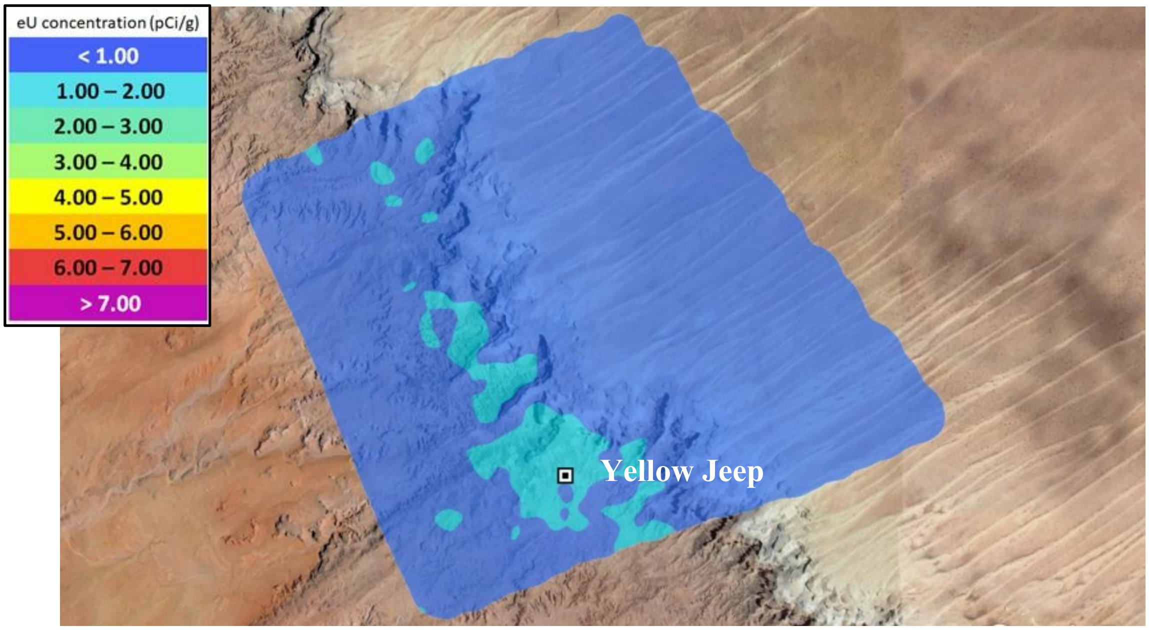


Figure 96: eU concentration contour map of the Yellow Jeep mining area in Zone 4. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

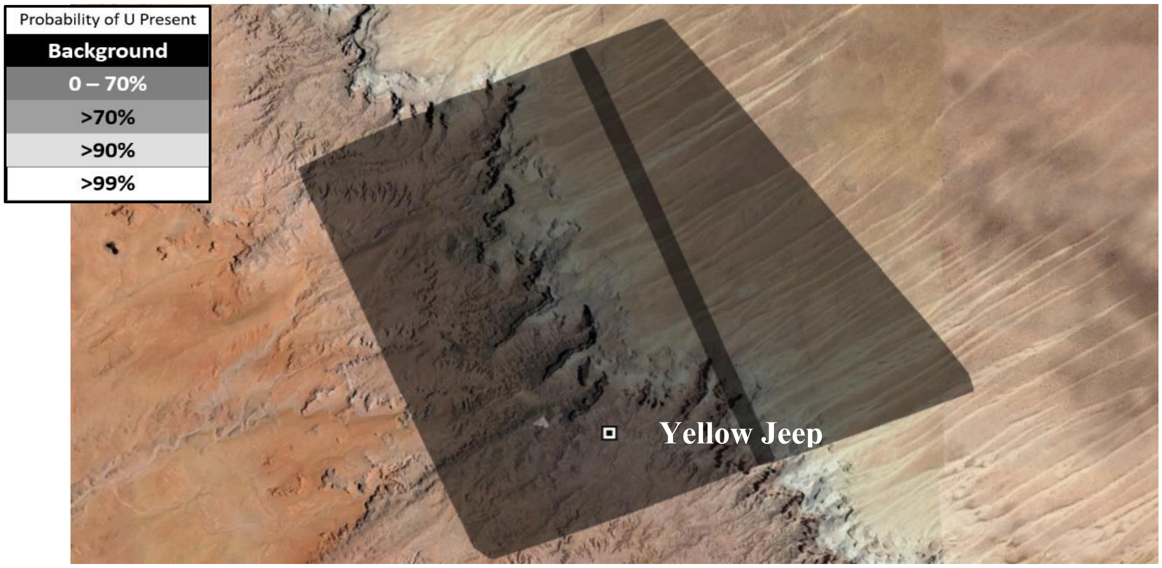


Figure 97: The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. The diagonal line is caused by separate flights. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.3.5 Zone 5

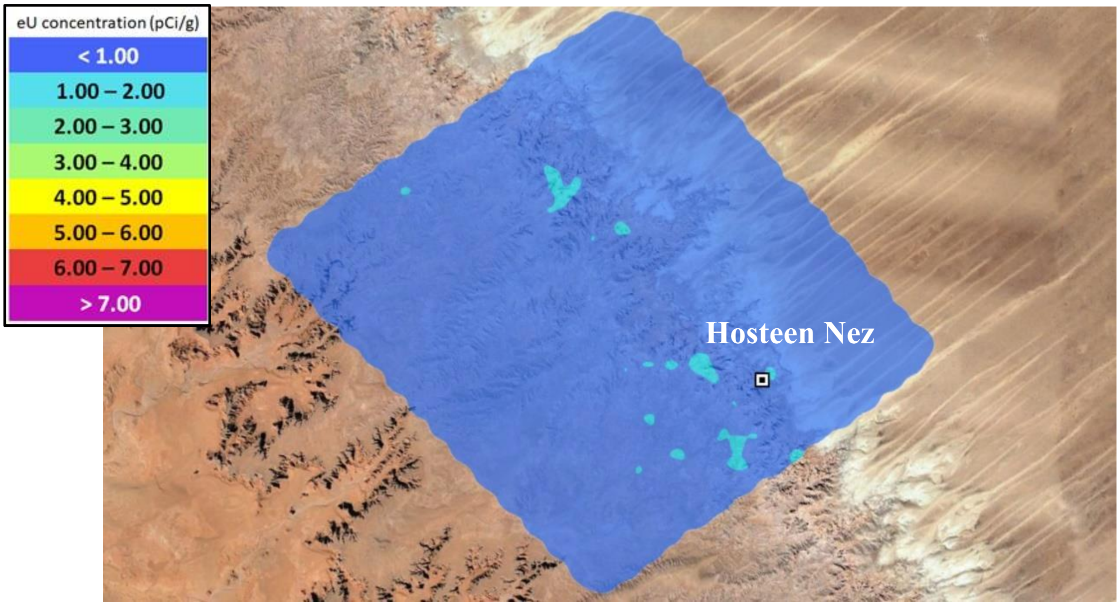


Figure 98: eU concentration contour map of the Hosteen Nez mining area in Zone 5. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

Figure 99: The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.3.6 Zone 6

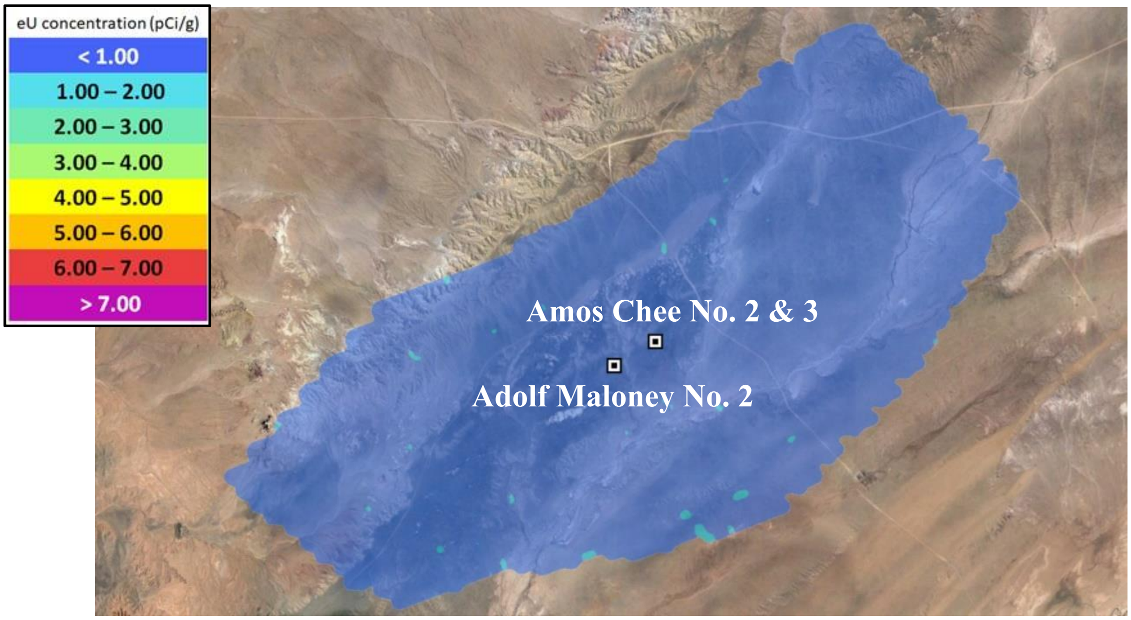


Figure 100: eU concentration contour map of the Amos Chee No. 2 &3 and the Adolf Maloney No. 2 mining area in Zone 6. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean- up decisions.***

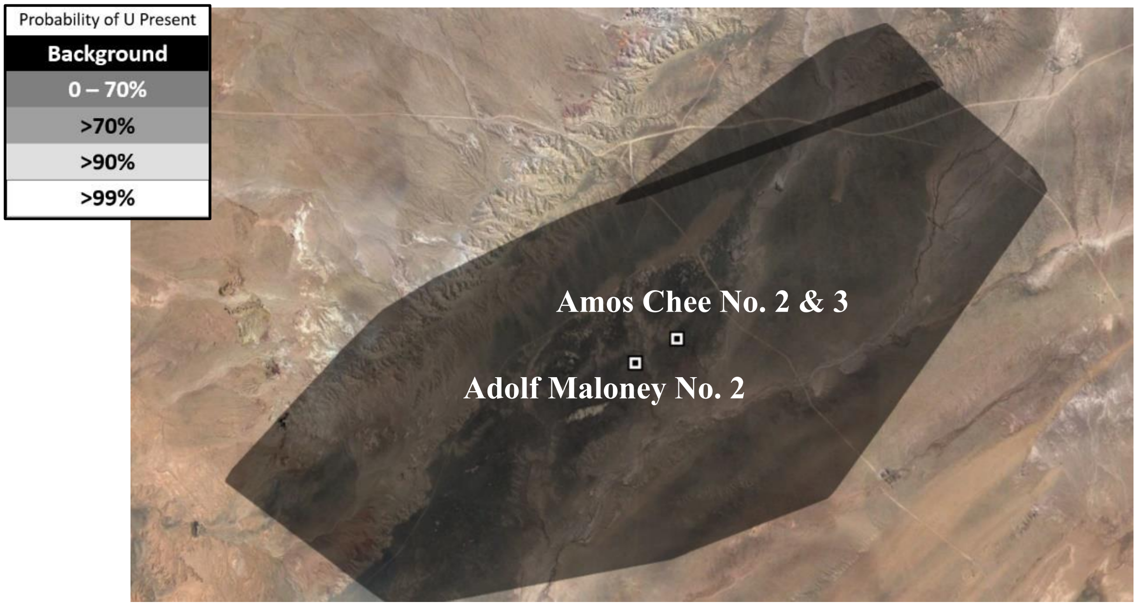


Figure 101: The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.3.7 Bridge Zone

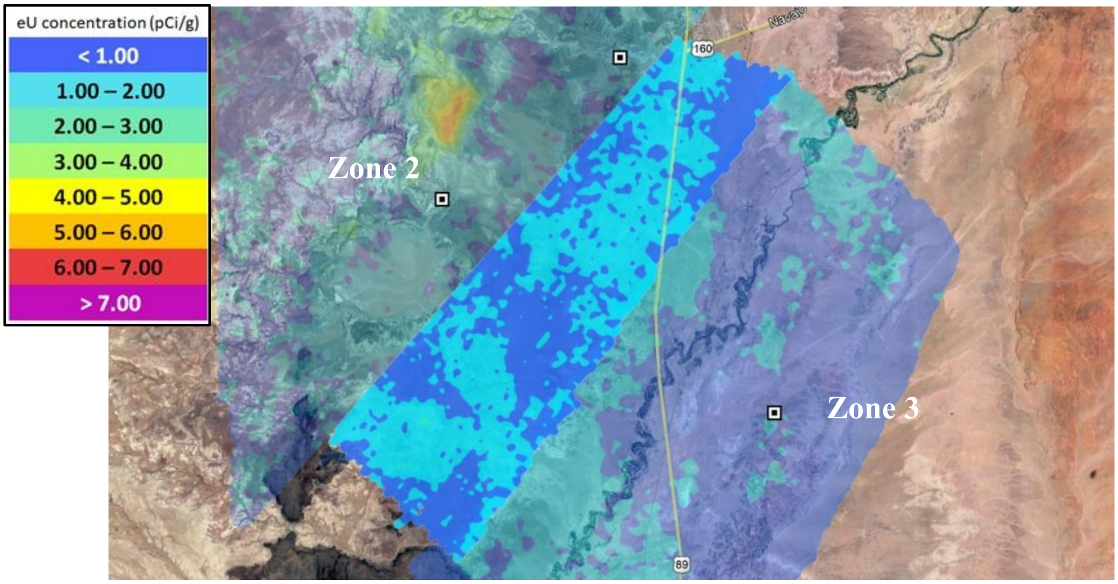


Figure 102: eU concentration contour map of Bridge area between Zones 2 and 3. ***This image should not be used independently to assess potential health risks. Additional information is necessary to make appropriate health-related or clean-up decisions.***

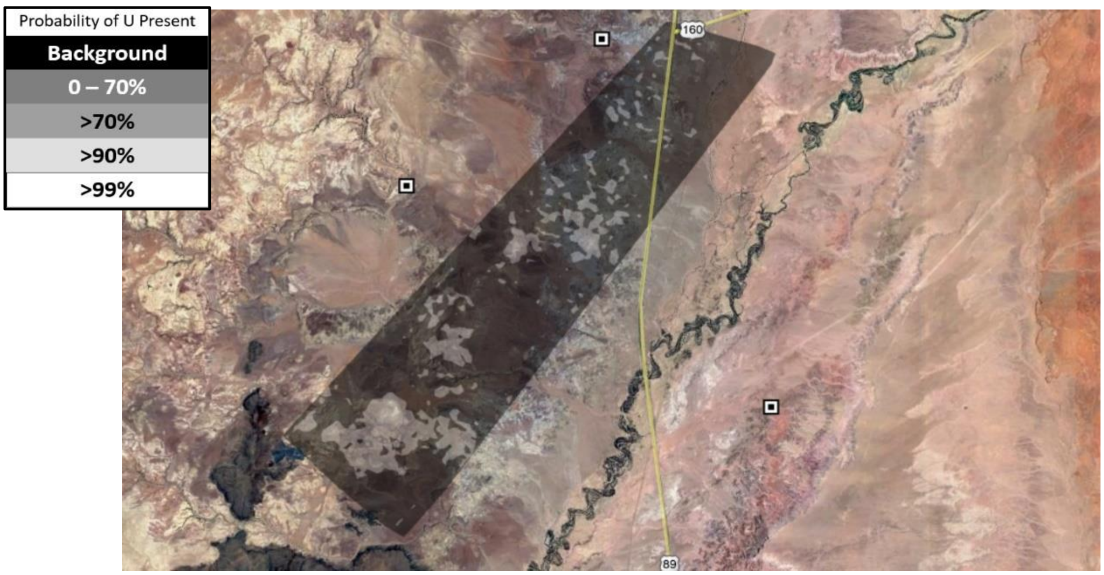


Figure 103: The PUP product shows areas where natural uranium is out of balance (white) with the natural background (black). White areas indicate where uranium spectral signatures are statistically significantly present for uranium and its decay products. There appears to be several areas with natural uranium outcropping. ***This product is not correlated to concentration and should be used to identify areas where further ground-based characterization efforts may be warranted.***

4.3.8 Highway

Figure 104: eU concentration data collected along the highway from Route 89 south of Tuba City, AZ to Route 160 to Route 161 to Bluff,UT. Milling operations of uranium ore occur in Bluff, UT. No significant deviations from background was detected along the roadway.

5 Photographic Results

Approximately 2,000 high resolution digital aerial photographs were taken over the survey areas. 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. These can all be viewed in the Google Earth software.

6 Appendices

6.1 ASPECT Survey Instrumentation

The U.S. Environmental Protection Agency, CBRN Consequence Management Advisory Team fields a fixed-wing aircraft known as the Airborne Spectral Photometric Environmental Collection Technology (ASPECT). ASPECT is a 24/7/365 response-ready asset that can be airborne within an hour and collecting chemical, radiological and photographic data anywhere in the continental United States within nine hours of notification from its home base near Dallas, TX. A primary goal of the program is to provide actionable intelligence to decision makers within minutes of data collection while the aircraft is still flying via the aircraft satellite communication system. More information is available at http://www2.epa.gov/emergency-response/aspect.

ASPECT Aircraft

The ASPECT sensor suite is operated from a single engine Cessna 208B Cargo Master aircraft (Figure 2). The aircraft and crew are certified for full instrument flight rules (IFR) flight operations. This aircraft is equipped with one 20 X 30 inch belly hole with a retractable bay door. All sensor systems are mounted on vibration isolated base plates positioned over the belly hole. The aircraft can operate from any airport having a 3000 foot runway and can stay aloft for 5 hours.

Figure105: ASPECT Aircraft, Cessna 208B Caravan

ASPECT uses two chemical sensors and three radiological sensors to detect and map chemical plumes and radiological deposition patterns and point sources. The chemical sensors were not used for this survey and will not be described in this report. Information about these sensors is available at http://www2.epa.gov/emergency-response/aspect.

ASPECT Radiological Detection Capabilities

The radiological detection technology consists of three detectors systems: (1) thallium-activated sodium iodide (NaI[Tl]) gamma detectors, (2) lanthanum bromide gamma detectors, and (3) boron tri-flouride neutron detectors. The NaI[Tl] gamma detectors were used to produce the products for this survey. These consisted of one RSX-5 and two RSX-4 units (Radiation Solutions, Inc., 386 Watline Avenue, Mississauga, Ontario, Canada) (Figure 3). Each RSX-4 unit was equipped with four 2"x4"x16" NaI[Tl] scintillation crystals and the RSX-5 was equipped with five crystals where one "upward looking" crystal is positioned on top of the four "downward looking" crystals for a total of 15 NaI[Tl] detectors or 25 liters of crystal volume.

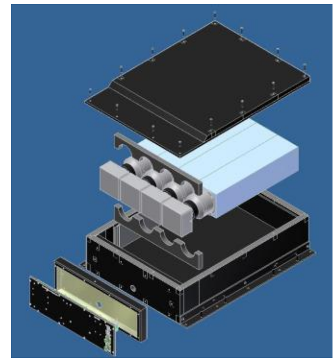
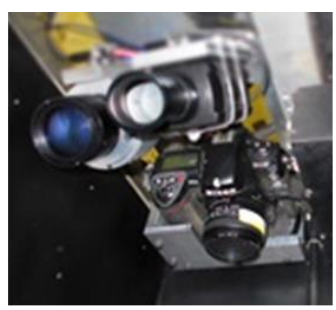


Figure106: RSX-4 unit showing four detector locations. The ASPECT was equipped with 13 NaI[Tl] and 3 LaBr3:Ce scintillating detectors.

The Radiation Solutions RSX units were 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.

All data are geo-referenced with embedded geographical coordinates and can be used in a variety of GIS systems. Collected data are processed using onboard algorithms while the aircraft is in flight and preliminary data results are sent using a satellite system to the ASPECT scientific reach back team for QA/QC analysis (Figure 4).

RSX4 Gamma Spectrometer (25 L NaI + 1 upward)



DX2 Aerial Camera; Visible (2) & IR Video (2)

Satellite System

Figure 107: Sensor Suite used for the Navajo Nation Surveys

NOTE: Images of the LaBr detectors (1 liter) and BF3 neutron detectors are not shown

Technical specifications for the RSX gamma ray spectrometers are contained in Table 1.

TABLE 1 - RX4 Technical Specifications

System:	RSI RSX4 Gamma Ray Spectrometer
Detector: Gamma Ray	4 Tl-doped NaI Detectors per pack, 3 Packs, 2x4x16 inch crystals, one pack contains an additional upward-looking detector
Total NaI[Tl] Detector Volume:	25 liters
Energy Coverage:	0 – 3000 keV
Number of Channels:	1024
Energy Resolution:	Approx. 3 keV per Channel
Scan Rate:	1 Hz
Internal Calibration:	Automatic based on Natural K, U, and T (gain stabilization)
Field of View (FOV):	45 Degrees
Cross Field Scan Coverage:	600 feet @ 300 feet collection altitude (AGL)
Altitude Determination:	2.4 GHz Radar Altimeter, 10 Meter DEM Database
Power:	28 vdc @ 4 amps full load (3 Packs)
Weight:	136 Kg (300 lbs.)
Spin-up Time:	Less than 5 minutes
Standard Outputs:	1024 Gamma Ray Spectra, GPS (2 Hz)
Data Processing	1 Step Full Processing of Total Count, Sigma, and Exposure Rate, Approximately 1 minute Processing Time After Data Collection.

ASPECT Camera Systems

ASPECT utilizes a still digital Nikon DX2 camera to collect and provide visible aerial imagery as part of the core data product package (Figure 5). The DX2 consists of a 12.4 mega pixel CMOS camera supporting a 3:5 aspect ratio frame. The system uses a 28 mm wide-angle lens and is slaved to the primary IR sensors and provides concurrent image collection when the other sensors are triggered for operation. All imagery is geo-rectified using both aircraft attitude correction (pitch, yaw, and roll) and GPS positional information. Imagery can be processed while the aircraft is in flight status or approximately 600 frames per hour can be automatically batch processed once the data is downloaded from the aircraft. Technical specification for the DX2 camera is provided in Table 2.

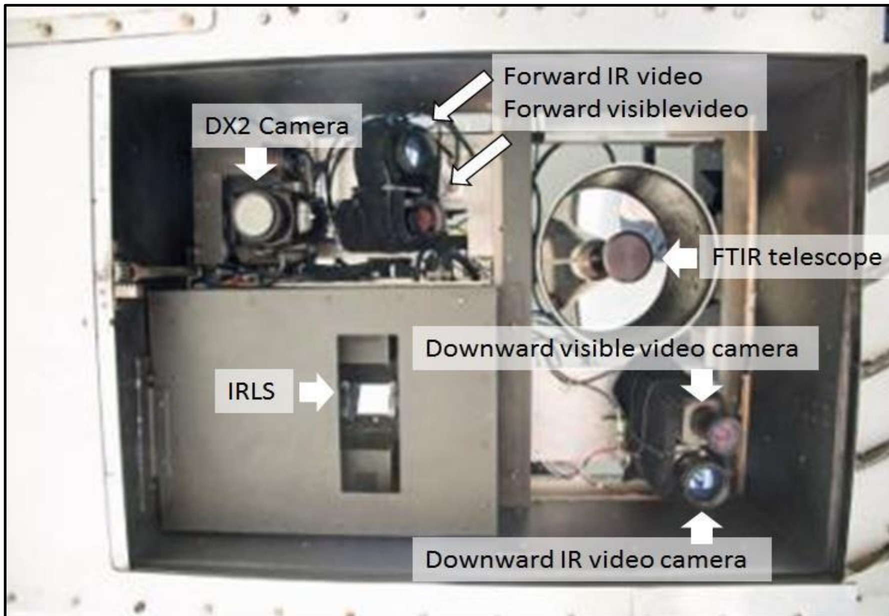


Figure 108: ASPECT Camera Suite

TABLE 2 - DX2 Aerial Digital Camera Technical Specifications

System:	Nikon DX2 Camera Body
Detectors:	12.4-megapixel digital CMOS sensor
Aspect Ratio:	3:5
Lens:	28 mm Digital Compatible
Field of View (FOV):	824 meters Cross flight and 548 meters Direction of Flight @ 850 meter collection altitude (AGL)
Pixel Resolution (IFOV):	19.2 cm @ 850 meter collection altitude (AGL)
Frame Timing and Collection Rate:	Operator Selectable, 3 to 8 seconds, Approximately 600 frames per hour
Trigger Control:	Automatic, Manual, and Slave
Power:	12 vdc @ 1 amp full load
Spin-up Time:	Less than 2 minutes from System Start
Standard Outputs:	JPEG, Tiff
Data Processing:	Full INS/GPS Geospatial Rectification

In order to provide situational information from the perspective of the flight crew, ASPECT also supports an oblique camera system that is operated from the right side of the aircraft. This camera consists of a Canon EOS Rebel digital SLR camera body with a 30 – 120 mm variable zoom lens (Figure 6). Frames are collected at an approximate the 2 o'clock position

Figure 109: EOS Oblique Camera

relative to the aircraft with the target approximately 1000 meters from the aircraft. Figure 7 provides examples of an aerial (downward view) photo and an oblique (side view) photos. The aerial photos are taken at an altitude of about 2,800 feet above the ground (AGL) and the oblique photos are taken at lower altitudes ranging from 500 feet to about 1,200 feet AGL. Table 3 provides technical specification of the oblique camera system.

TABLE 3 - Canon EOS Aerial Oblique Digital Camera Technical Specifications

System:	Canon EOS Camera Body
Detectors:	6.3-megapixel digital CMOS sensor
Aspect Ratio:	3:5
Lens:	30-120 mm zoom, Digital Compatible
Trigger Control:	Manual
Power:	Internal Battery
Standard Outputs:	JPEG, Tiff
Data Processing:	Spatial Geo-reference

Figure 110: (Left) Aerial (downward view) photo taken at 2,800 AGL. (Right) Oblique photo taken about 500 feet AGL.

ASPECT Satellite System

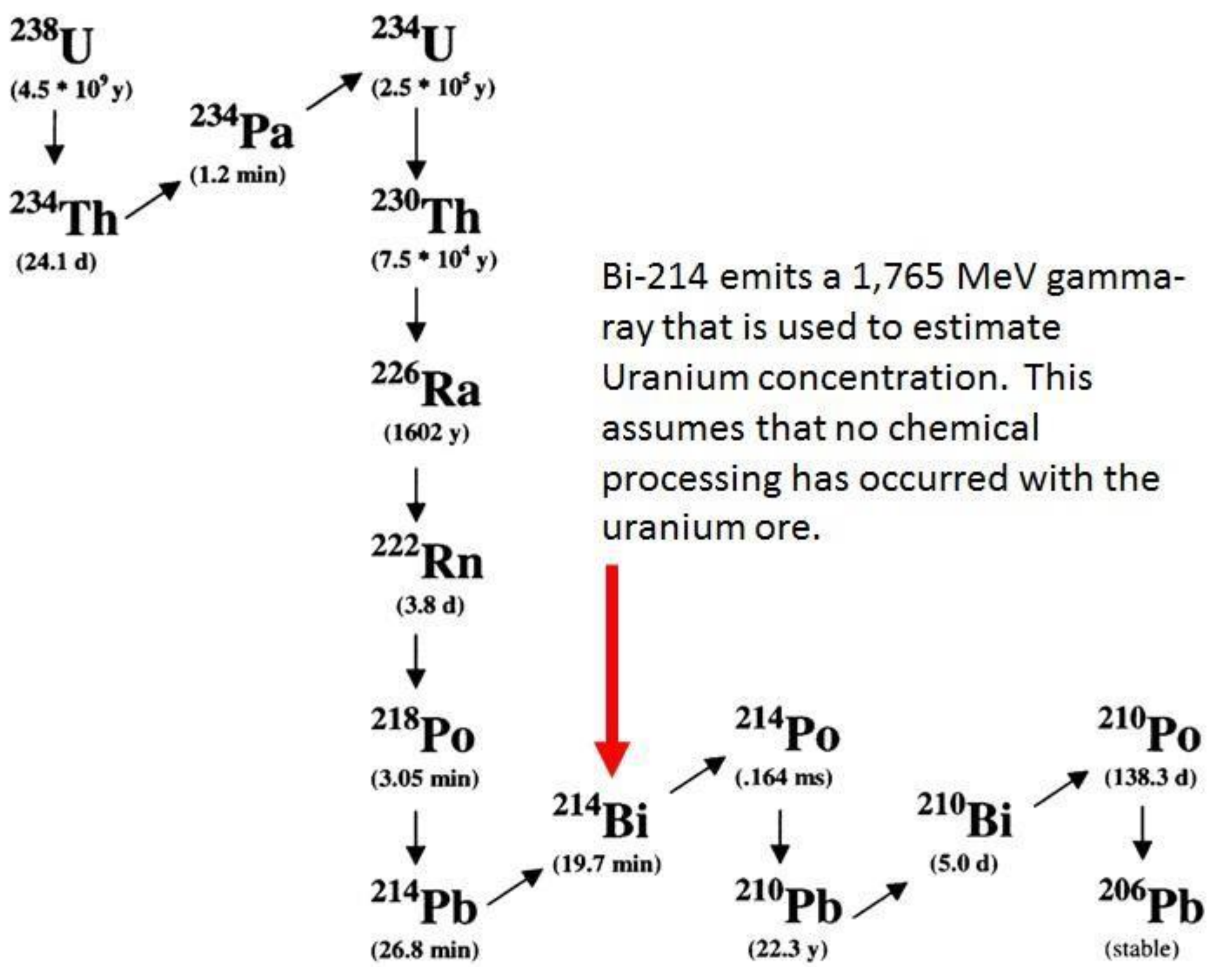
The ability to rapidly transfer data from the ASPECT aircraft to the ultimate end user is mandatory if the system is to support emergency response functions. ASPECT uses a state of the art satellite-based communication system that provides broadband data through put while the aircraft is in flight status (Figure 8). The system consists of an electronically-steered phase-array satellite antenna coupled to a RF power amplifier/receiver supporting a wired onboard computer TCP/IP modem/network. All components of the system have been installed and certified as part of a formal FAA STC procedure. The system utilizes a geosynchronous satellite connection and permits full rate communication throughout the contiguous U.S. Table 4 contains the technical specifications for the satellite communications system.

Figure 111: ASPECT satellite communication system phased array antenna.

TABLE 4 - Satellite Communication Technical Specifications

System:	Chelton Broadband Satellite System
Antenna:	HGA-7000 Electronically Steered Phased Array Antenna.
Modem:	Integrated Airborne Modem/Router, 100 MB/s data rate
Power Amplifier:	HPA-7400 Bi-directional Power Amplifier/Pre-Amplifier Short Coupled to the Phased Array Antenna.
Data Rate:	Up to 332 kbs (Approximately 60 Kbs) Full Duplex
Constellation Type:	Fixed Geo-Synchronous
Coverage:	Continuous Coverage Over the Lower 48 States.
Certification:	FAA STC
Power:	28 vdc @ 10 amp full load
Spin-up Time:	Less than 2 minutes from System Start
Standards:	TCP/IP

6.2 Appendix I: Uranium Decay Chain



6.3 Appendix II: Additional Considerations for Aerial Measurements

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.

6.3.1 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 and subtracting these contributions for the survey data.

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 ninth 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. See Appendix I for the Uranium decay chain.

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.[11] The ninth daughter product, thallium-208 (^{208}Tl), is used to estimate the presence of thorium by its 2.61 MeV gamma-ray emission. Figure 10 illustrates the spectral characteristics of natural background radiation,

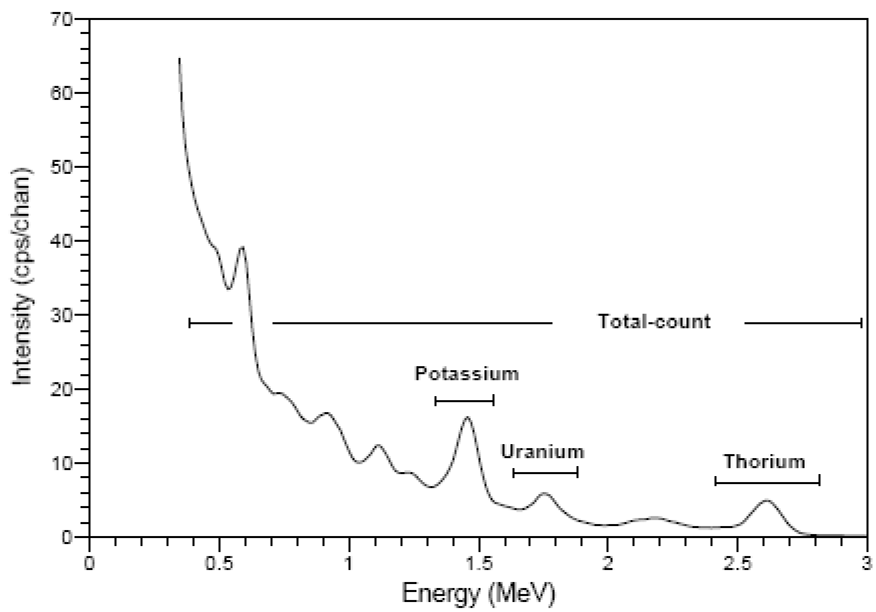


Figure 112: Typical airborne gamma ray spectrum showing positions of the conventional energy windows. Adapted from IAEA-TECDOC-1363

Technologically enhanced naturally occurring radioactive material (TENORM) is naturally occurring radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing. It also may identify areas where NORM materials are significantly elevated from the normal background due to geologic outcroppings that are near or exposed at the surface.

6.3.2 Secular Equilibrium Assumption

Secular equilibrium is assumed in order to estimate uranium 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 migration from causes such as differing water solubility of various radionuclides In addition, human intervention in this natural chain of events may have caused an increased uncertainty in uranium concentration estimates.

6.3.3 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.[1] Temperature and pressure changes contribute little to the overall uncertainties associated with airborne detection systems as compared to other factors.

6.3.4 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. 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.

6.3.5 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.

6.4.6 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

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

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 uranium ore (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.

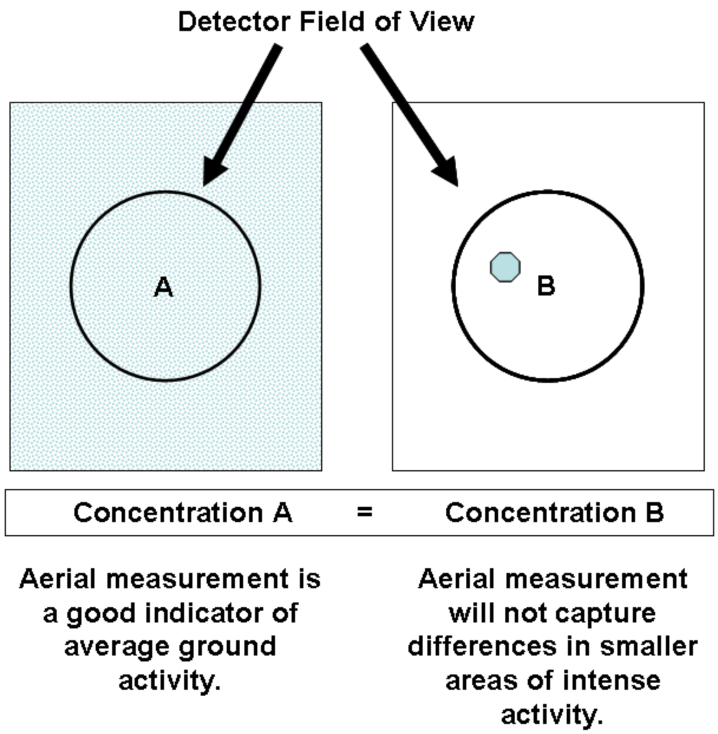


Illustration of aerial measurement capabilities and interpretation of the results

6.3.7 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. Even if a laboratory uses an in-growth period to equilibrate the radon with ^{214}Bi in the soil sample, it does not account for the surrounding sources of radon from nearby soils that were not sampled. In-situ ground-based measurements account for these surrounding factors via a larger surface area than a soil sample. 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.

6.3.8 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[2]. 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.

[2] 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.

6.4 Appendix IV: How to use Google Earth

The following information is presented to describe how the ASPECT Team examined data using the Google Earth software package. The ESRI package provides a similar capability.

The Google Earth software package permits data to be viewed and analyzed in a straight forward fashion with minimal training and/or computer hardware requirements. A free version of Google Earth (downloadable from the internet) is all that is required to use this package.

The ASPECT Program processes all data into a format that can be accessed through Google Earth using an "nlink" script. This small file permits full access to all data associated with a particular mission and/or deployment and greatly aids in near real-time situational awareness. This script can be obtained by contacting Region 9 Superfund and Emergency Management Division. The following instructions detail how to install the script and use the system:

1. Download the provided KML file to your desktop if you received it through email. If provided on a memory stick, simply copy the KML file to your desktop.

2. To open the kml, double click the file located on your desktop. This will automatically bring up your Google Earth Program, and the ASPECT airplane icon will appear and zoom to the geographic area of the mission. The ASPECT airplane icon provides total access to all of the data available for the mission.

3. Double Click the airplane and a balloon will expand listing all of the relevant information for the particular ASPECT mission. The relevant information available may vary from mission to mission. All of the sections depicted in blue are links to data on the ASPECT mission servers. The following is a brief description of each section:

    a. **Brief Mission Description.** This section contains details of the overall mission and specific details of the current mission which will open up in a separate browser window.

    b. **Sensor suite capabilities.** This browser window contains a description of the sensors used on ASPECT aircraft. When finished with this section, close the browser window.

    c. **Color aerial photography.** Clicking the color aerial photography section permits georectified NADAR images to be displayed and/or downloaded using the Google Earth. Once selected, available images from the last mission will be displayed as transparent outlines on the main screen. *Note: By default, only outlines from the last mission are displayed. Additional images collected on prior missions can be selected under the places menu on the left side of the Google Earth tool.*

To load the actual imagery into Google Earth, click on a camera icon in one of the polygons. A photo balloon will open and a thumb nail of the non-georectified photograph will be displayed. Two options are given at the bottom of the image:

Download Image Overlay into Google Earth

Download High Resolution Image into Web Browser

By clicking on the "Download Image Overlay into Google Earth" the image will be imported into the Google Earth imagery database and the georegistered image will be shown on the screen. Repeat this process for as many images as you are interested in. *Note: each time you execute this procedure the referenced aerial photograph frame will appear in blue in you temporary places pane on the left hand side of the Google Earth window. Should you want to view a full resolution image of this frame, click on the option "Download High Resolution Image into Web Browser". The full resolution image will be displayed in a separate browser window.*

d. **Mosaic Aerial Photography (By Date).** Selection of a color mosaic will load a georectified color mosaic into Google Earth. Selected of the appropriate image is referenced to the date of collection. Due to the large size of these files, several minutes may be required to fully download the file.

e. **Oblique Photography.** Viewing of oblique color aerial photography is accomplished by selecting the oblique photography item. Once selected, available oblique images for the last flight will be displayed as a collection of arrows. These arrows represent the location that the aircraft was positioned and the direction the camera was pointed when the frame was collected (about 2 o'clock of the heading looking about 45 degrees down). As the cursor is moved over the respective arrows, the frame number will be highlighted. If an arrow is double clicked a thumb nail of the image will be displayed. The user has the option of downloading the image in a browser.

f. **Infrared Color Imagery.** Multi-channel color infrared imagery is selected using this option. Once selected, transparent outlines of available images from the last flight will be displayed. Operation and manipulation of IR imagery is identical to procedures used to view color aerial photography.

g. **FTS Confirmed Detection.** This section contains the locations of confirmed remote sensed chemical detections for the last mission. Detections will be displayed as an icon. Each detected compound will be displayed as a unique icon. As with other data, data from prior missions can be selected under the places menu.

h. **Chemical Report Retrieval.** Chemical data associated with FTS confirmed detections is contained in this section. Each report shows a listing of compounds which are automatically scanned by ASPECT. The number of detections, maximum concentration, and the coordinates of the collection line are given in the report.

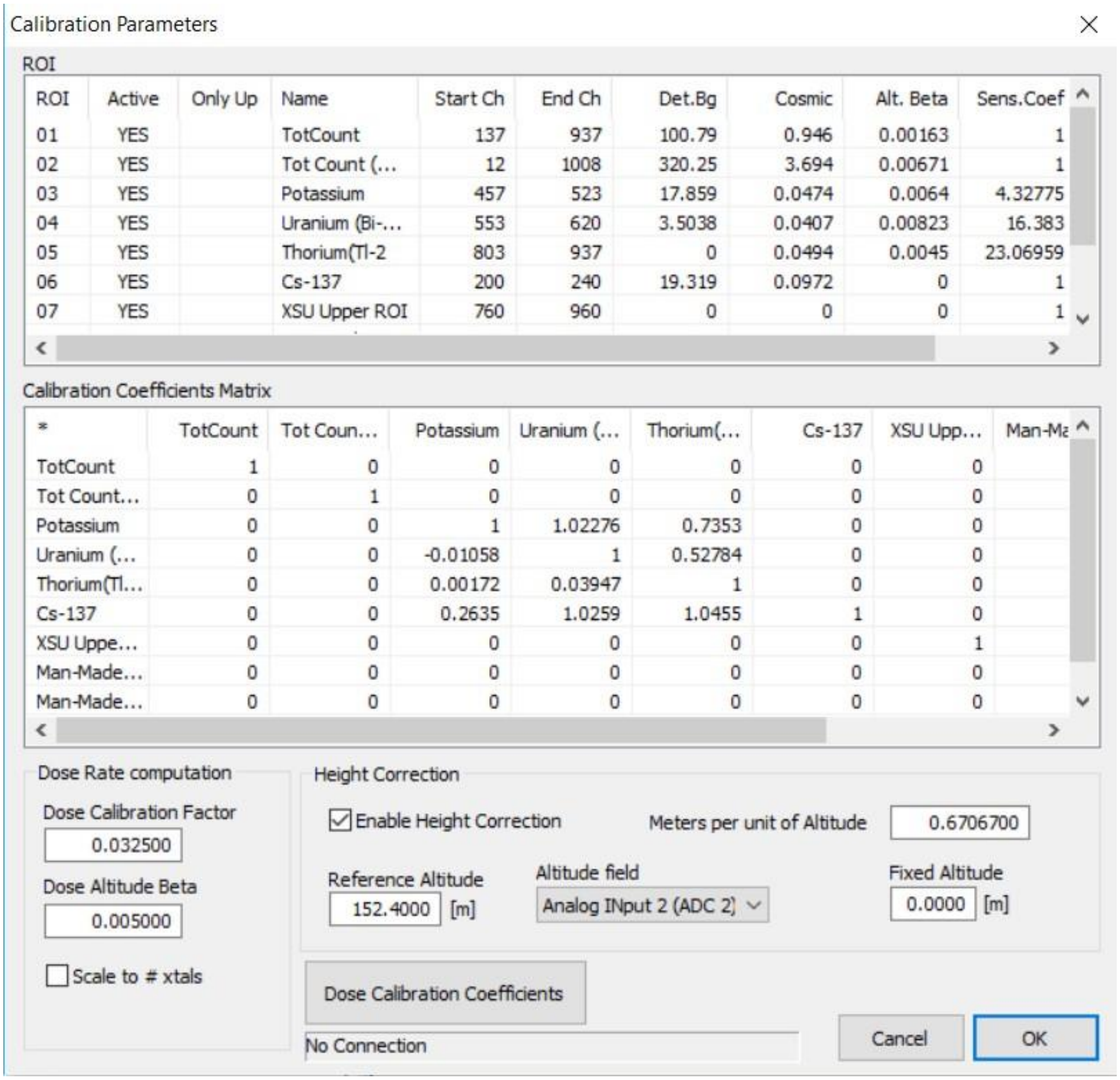
i. **Aircraft Flight Tracks (By Date).** Flight track information for the last mission is available using this selection. Once selected, a color flight path will be displayed. Multiple tracks can be displayed by selecting additional paths from other missions.

j. **New Data Additions.** As new data are added to the mission website the provided Google Earth link will permit full access to the new data. You must periodically close the Google Earth program and re-open it again using the Google Earth icon on your desktop. When you exit the program, Google Earth will prompt whether to save your "temporary places". Select discard. Depending on the amount of data being collected and uploaded to the mission server, reloading the Google Earth program once each hour will permit access to the new data.

k. **Troubleshooting.** If you are having problems with multiple ASPECT airplane icons appearing on the screen do the following:

1. Locate the Places Box on the upper left hand side of Google Earth.
2. Locate the line labeled as My Places.
3. Right click on My Places and select Delete Contents
4. Close Google Earth and reopen using the Google Earth Icon on your desktop

6.5 Appendix V: ASPECT RadAssist Calibration Parameters



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

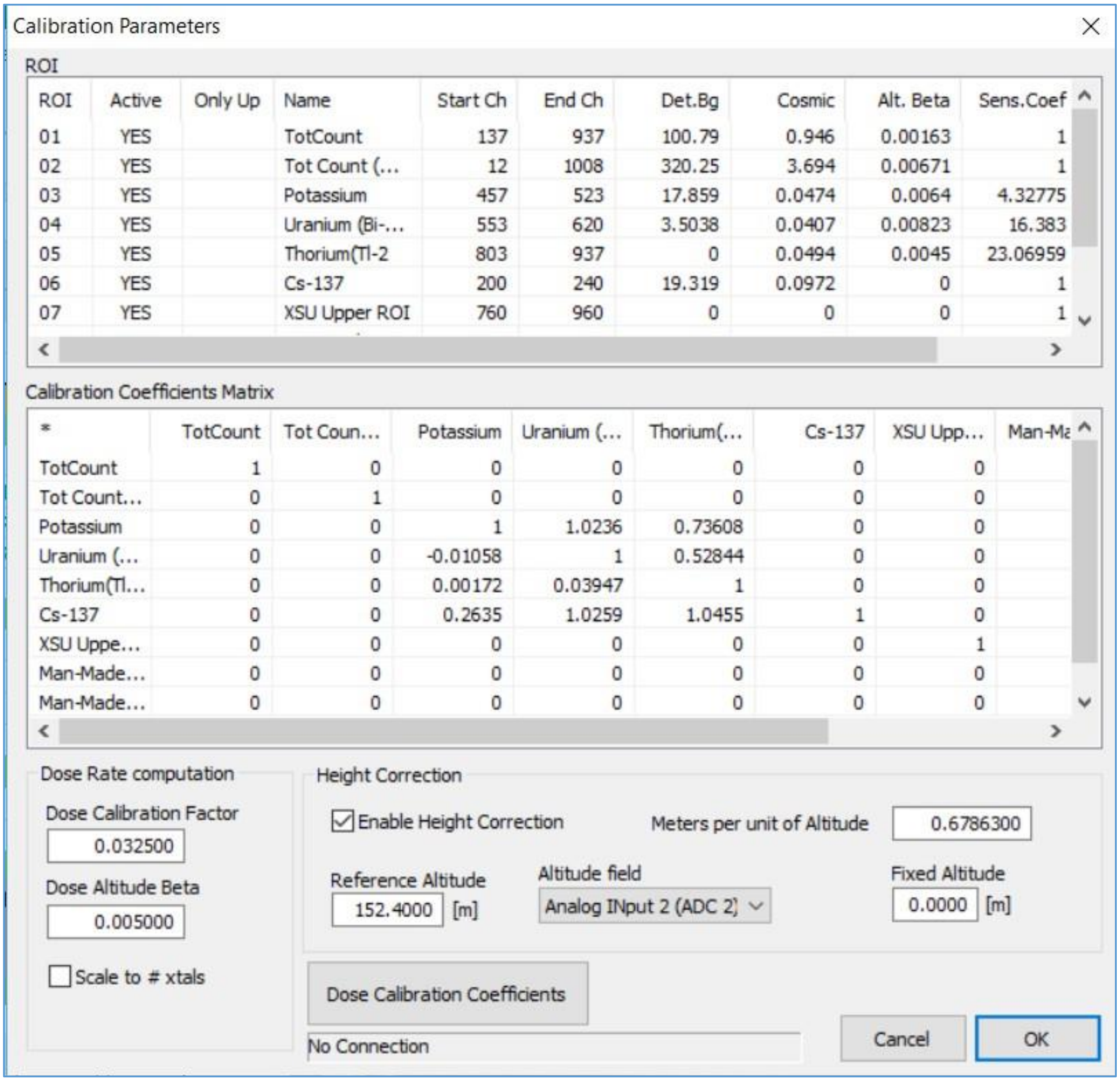
*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.02276	0.7353	0	0	
Uranium (...	0	0	-0.01058	1	0.52784	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation
Dose Calibration Factor: 0.032500
Dose Altitude Beta: 0.005000
Scale to # xtals

Height Correction
Enable Height Correction
Meters per unit of Altitude: 0.6706700
Reference Altitude: 152.4000 [m]
Altitude field: Analog INput 2 (ADC 2)
Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients
No Connection
Cancel
OK

Figure 113: RadAssist calibration parameters for Eastern Agency Navajo Nation Black Jack 1, June 20, 2018.



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.0236	0.73608	0	0	
Uranium (...	0	0	-0.01058	1	0.52844	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 114: RadAssist calibration parameters for Eastern Agency Navajo Nation Eunice Becenti, June 20, 2018.

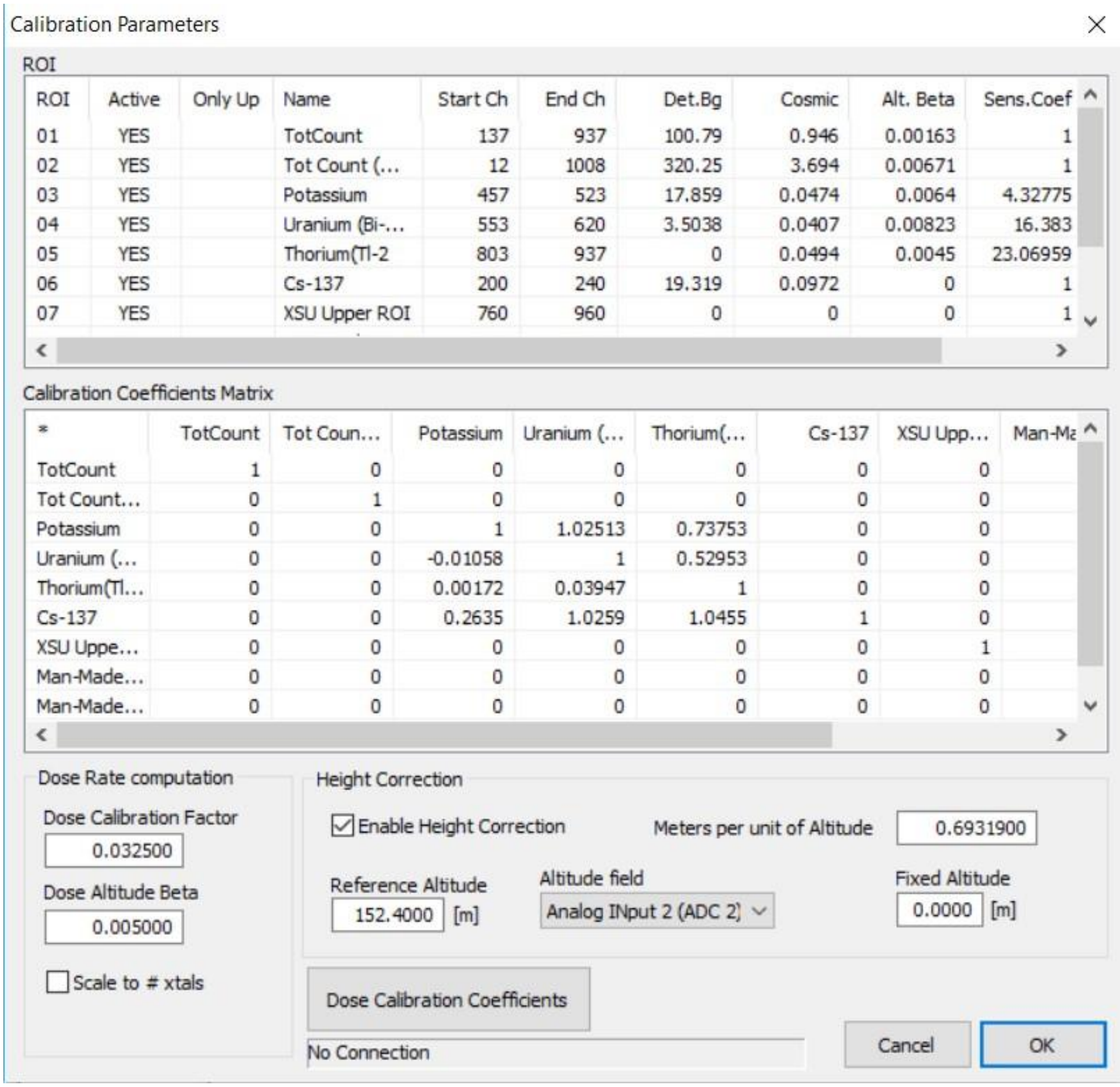


Figure 115: RadAssist calibration parameters for Eastern Agency Navajo Nation Evelyn, June 20, 2018

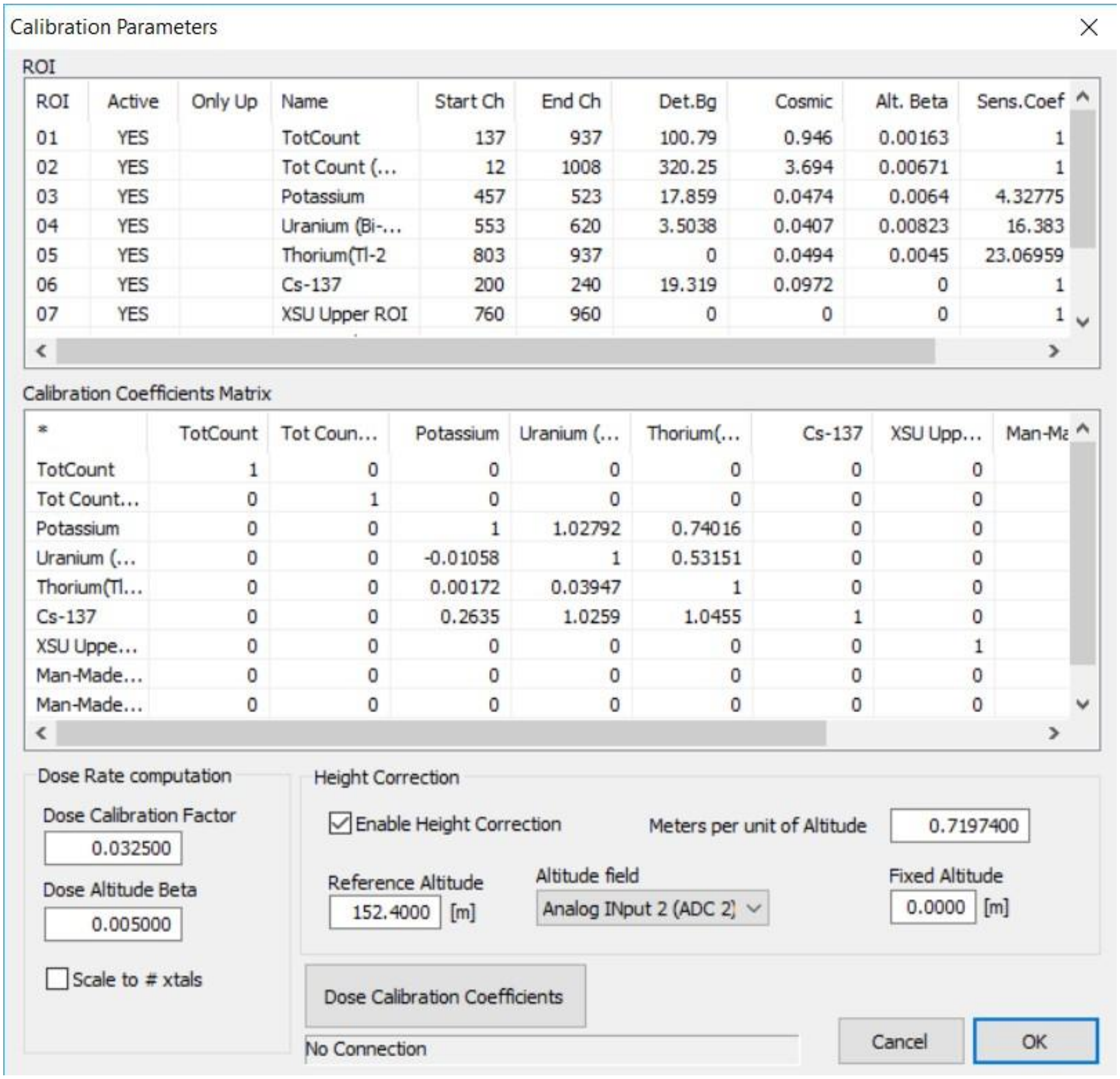
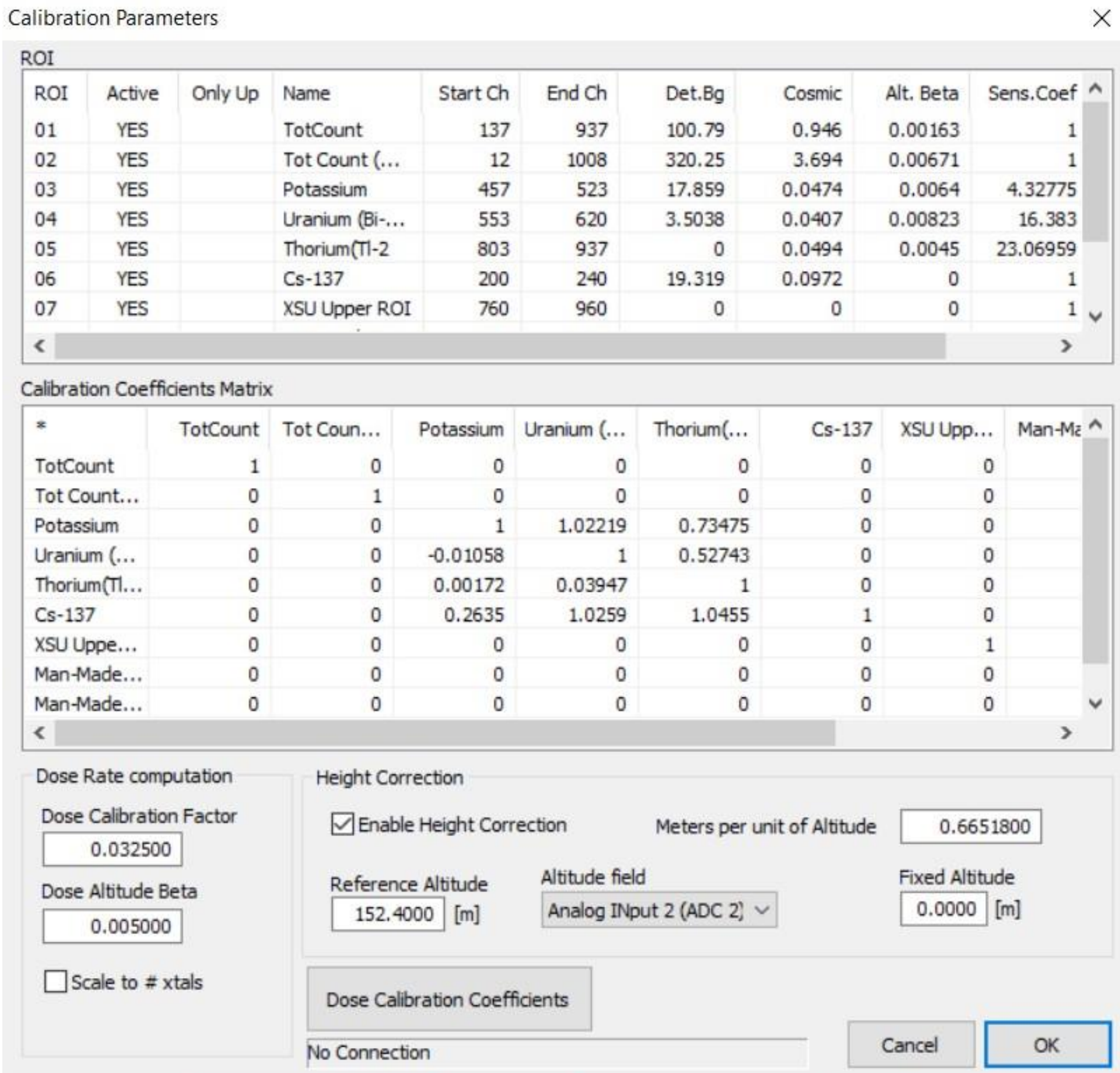


Figure 116: RadAssist calibration parameters for Eastern Agency Navajo Nation Haystack, June 20, 2018.



Calibration Parameters

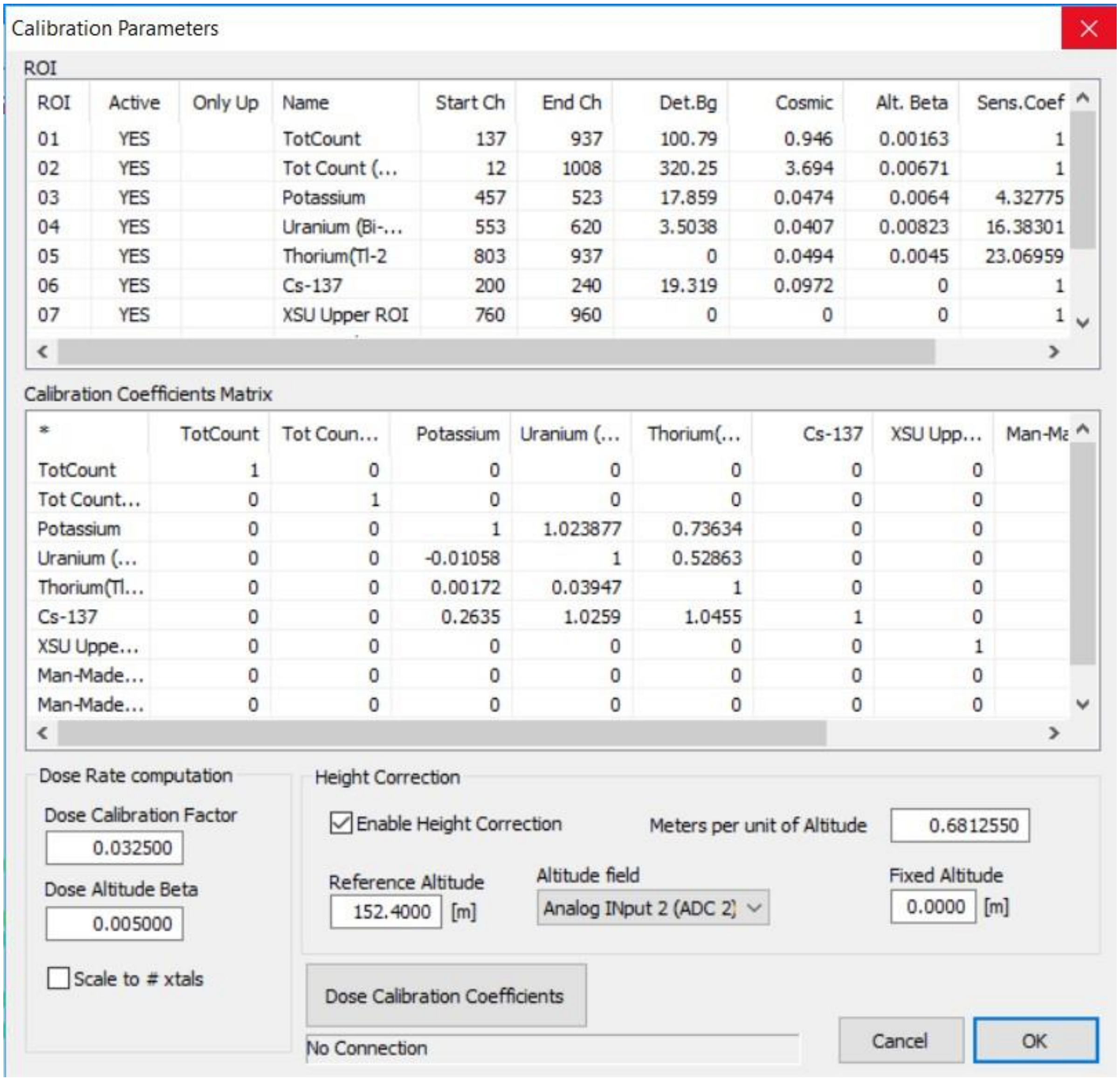
ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (…	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-…	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun…	Potassium	Uranium (…	Thorium(…	Cs-137	XSU Upp…	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count…	0	1	0	0	0	0	0	
Potassium	0	0	1	1.02219	0.73475	0	0	
Uranium (…	0	0	-0.01058	1	0.52743	0	0	
Thorium(Tl…	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe…	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	

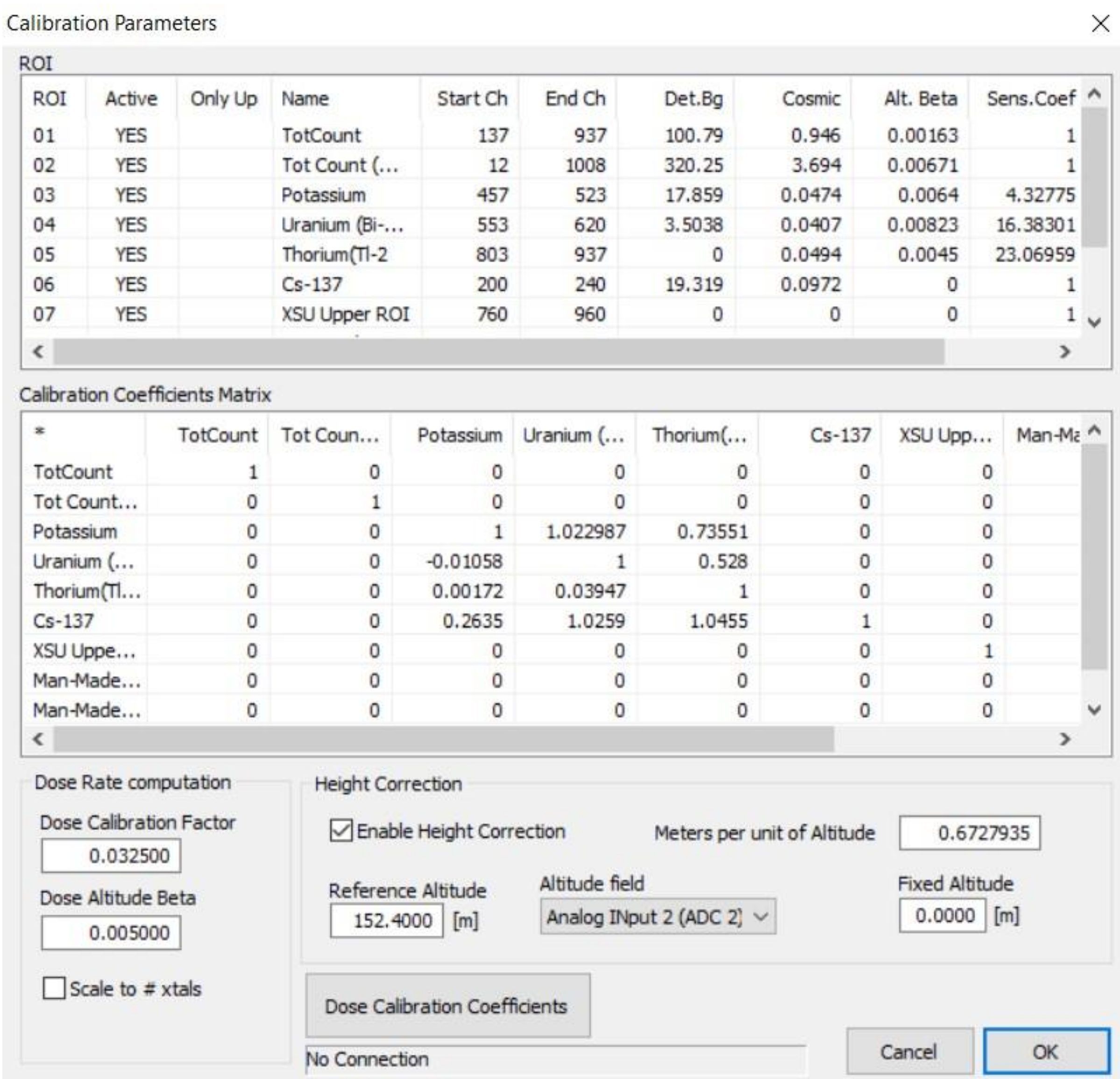
Figure 117: RadAssist calibration parameters for Eastern Agency Navajo Nation Mariano Lake, Mac1&2, Black Jack 2, Ruby 1, & Ruby 3; June 20, 2018



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.38301
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.023877	0.73634	0	0	
Uranium (...	0	0	-0.01058	1	0.52863	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 118: RadAssist calibration parameters for Eastern Agency Navajo Nation NE Church Rock, June 19, 2018



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.38301
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.022987	0.73551	0	0	
Uranium (...	0	0	-0.01058	1	0.528	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor 0.032500

Dose Altitude Beta 0.005000

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude 0.6727935

Reference Altitude 152.4000 [m]

Altitude field Analog INput 2 (ADC 2)

Fixed Altitude 0.0000 [m]

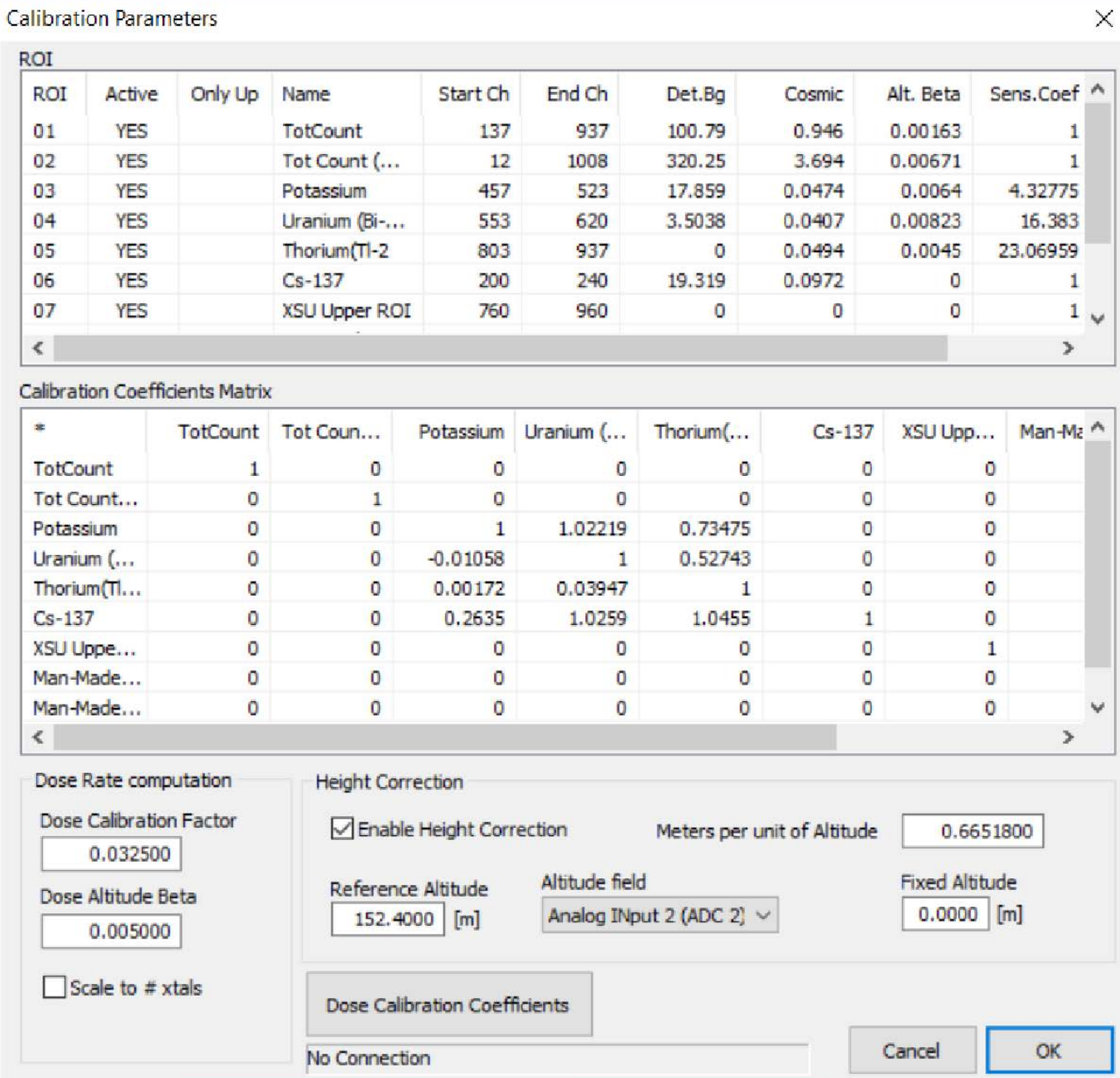
Dose Calibration Coefficients

No Connection

Cancel

OK

Figure 119: RadAssist calibration parameters for Eastern Agency Navajo Nation Old Church Rock, June 23, 2018



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.02219	0.73475	0	0	
Uranium (...	0	0	-0.01058	1	0.52743	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 120: RadAssist calibration parameters for Eastern Agency Navajo Nation Ruby 3; June 20, 2018

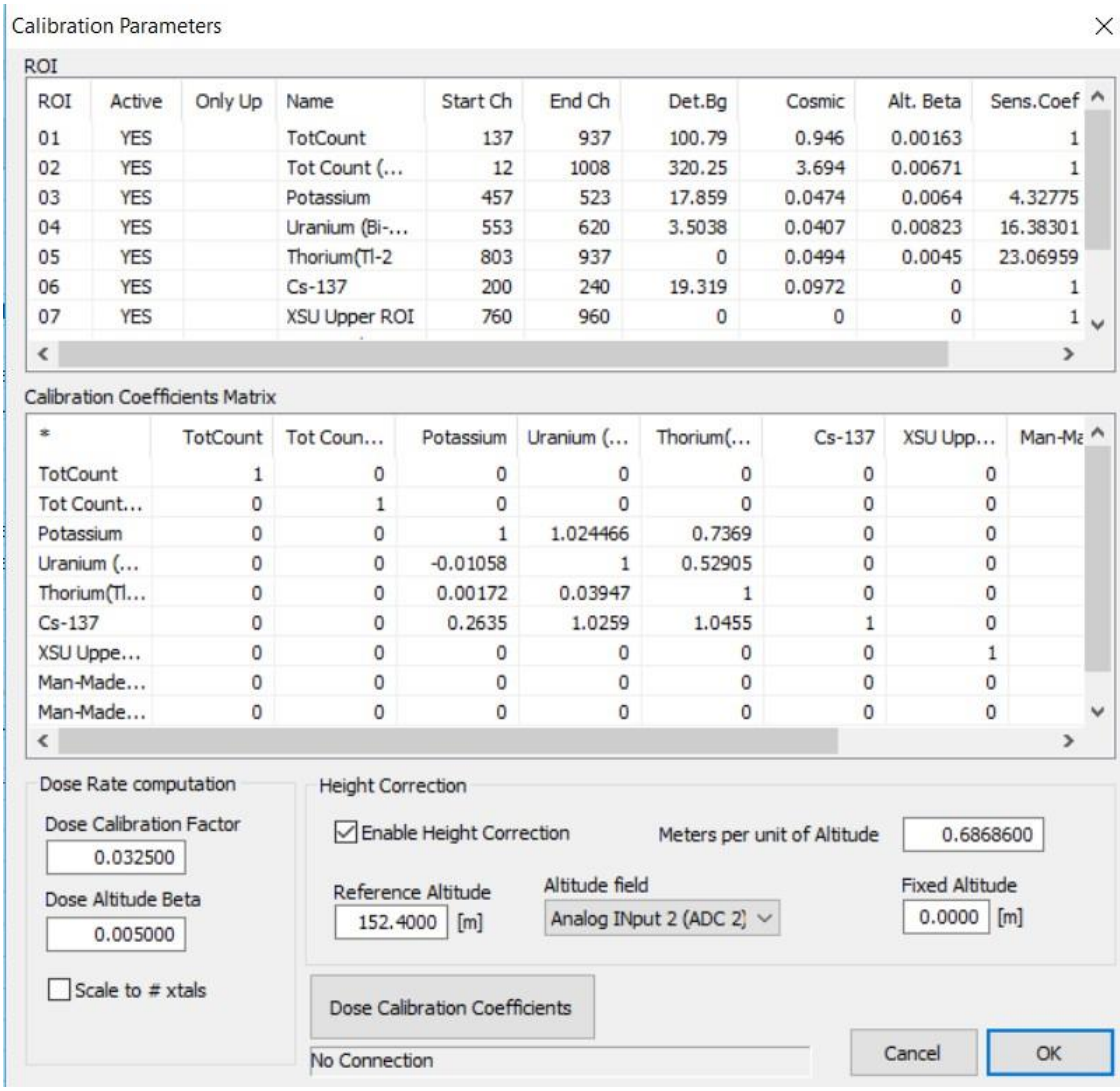
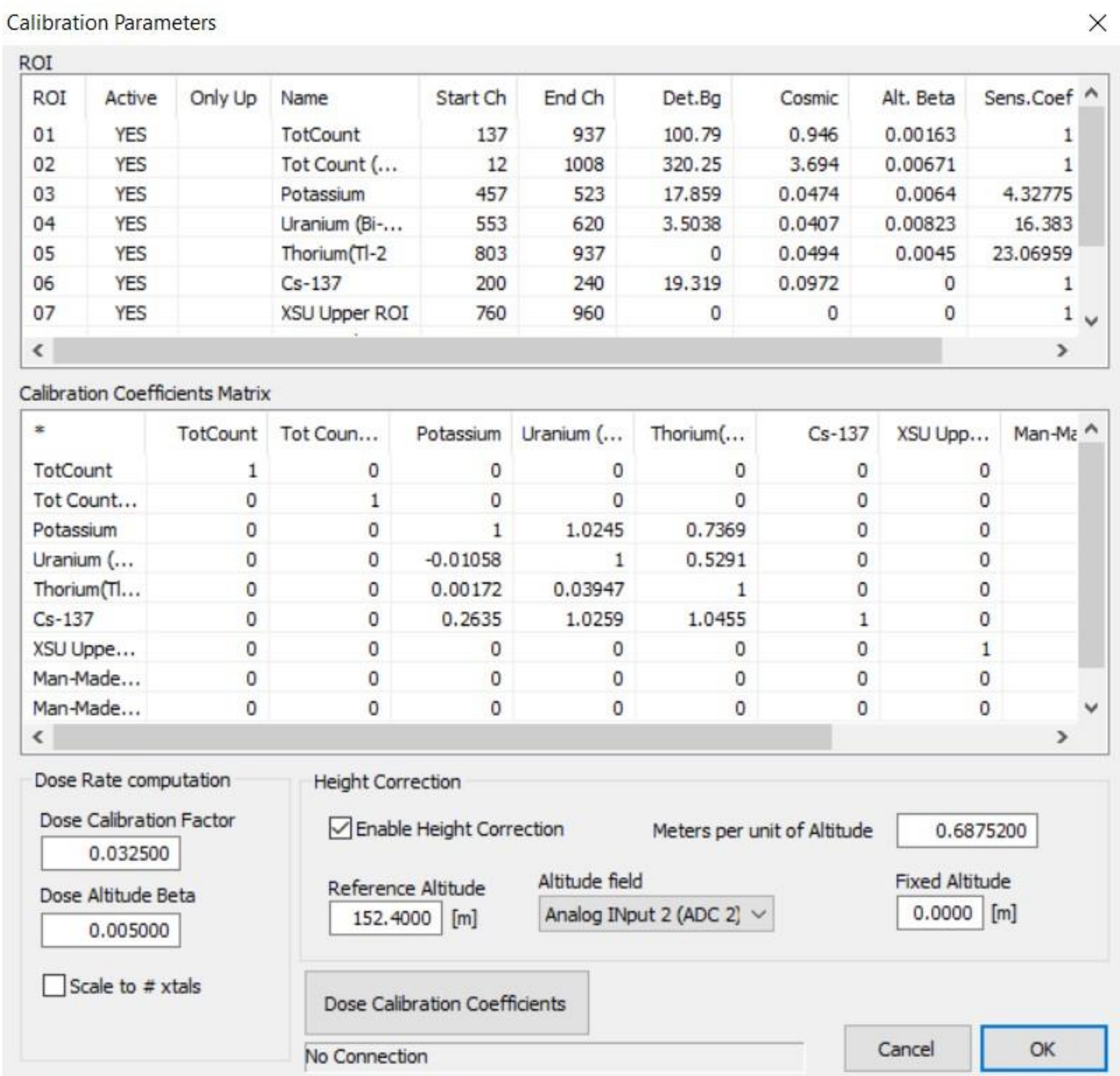


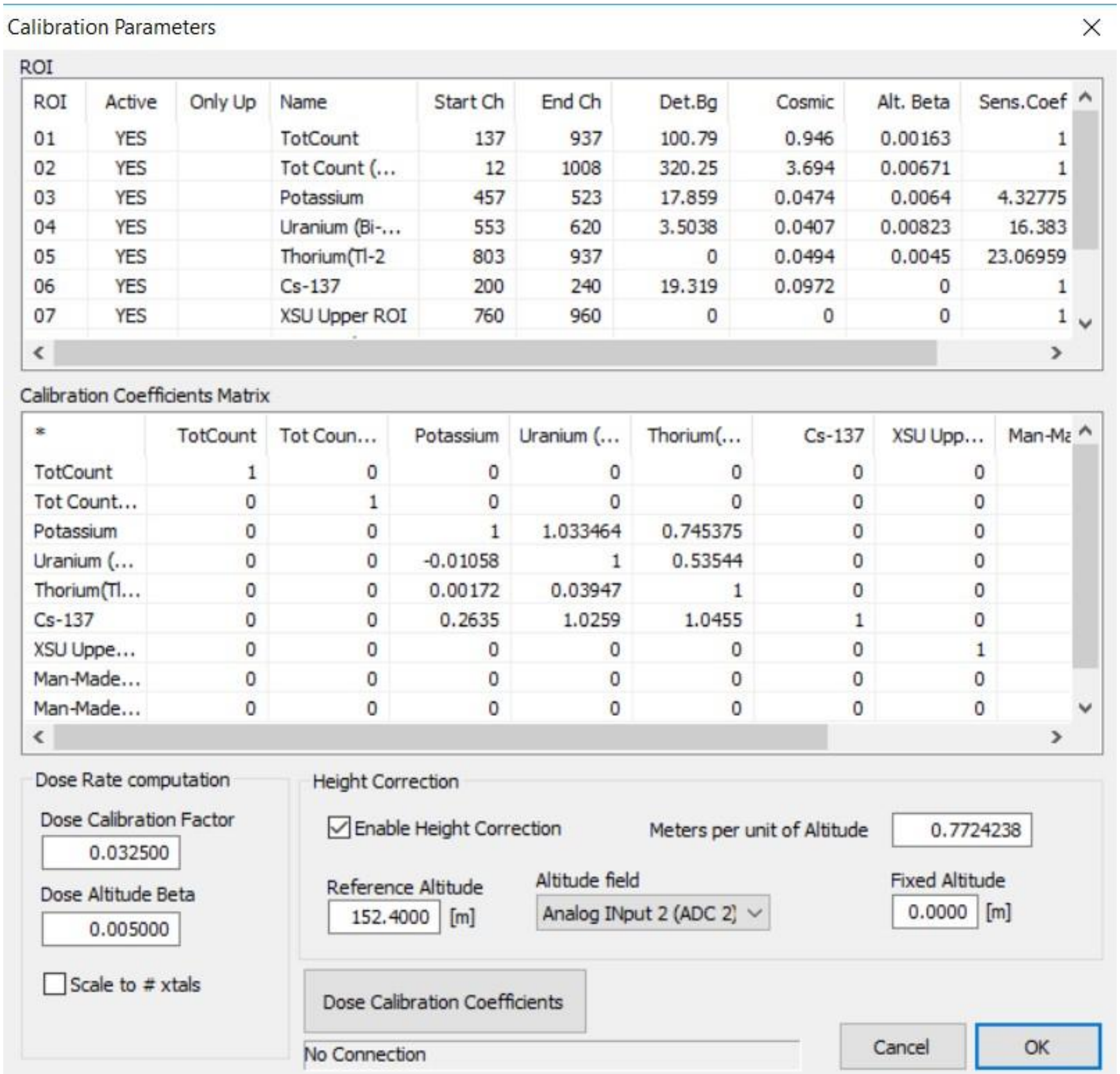
Figure 121: RadAssist calibration parameters for Eastern Agency Navajo Nation Section 32-33, June 20, 2018



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.0245	0.7369	0	0	
Uranium (...	0	0	-0.01058	1	0.5291	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 122 RadAssist calibration parameters for Eastern Agency Navajo Nation Standing Rock, June 19, 2015



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Mε
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.033464	0.745375	0	0	
Uranium (...	0	0	-0.01058	1	0.53544	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude: 0.7724238

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

Fixed Altitude: 0.0000 [m]

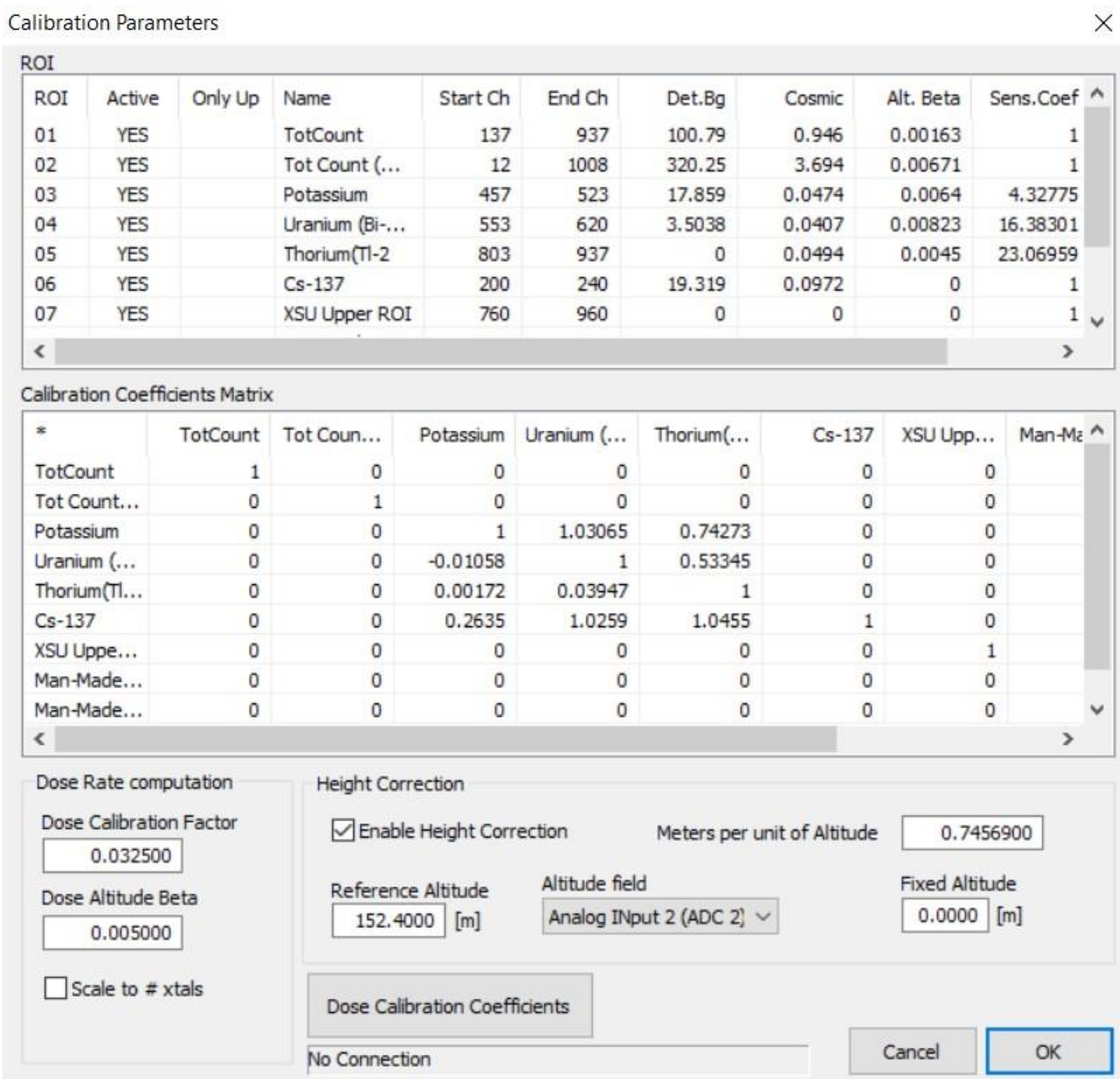
Dose Calibration Coefficients

No Connection

Cancel

OK

Figure 123: RadAssist calibration parameters for Western Agency Navajo Nation Zone 1a and 1b, Flight 21, July 6, 2018


Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.38301
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

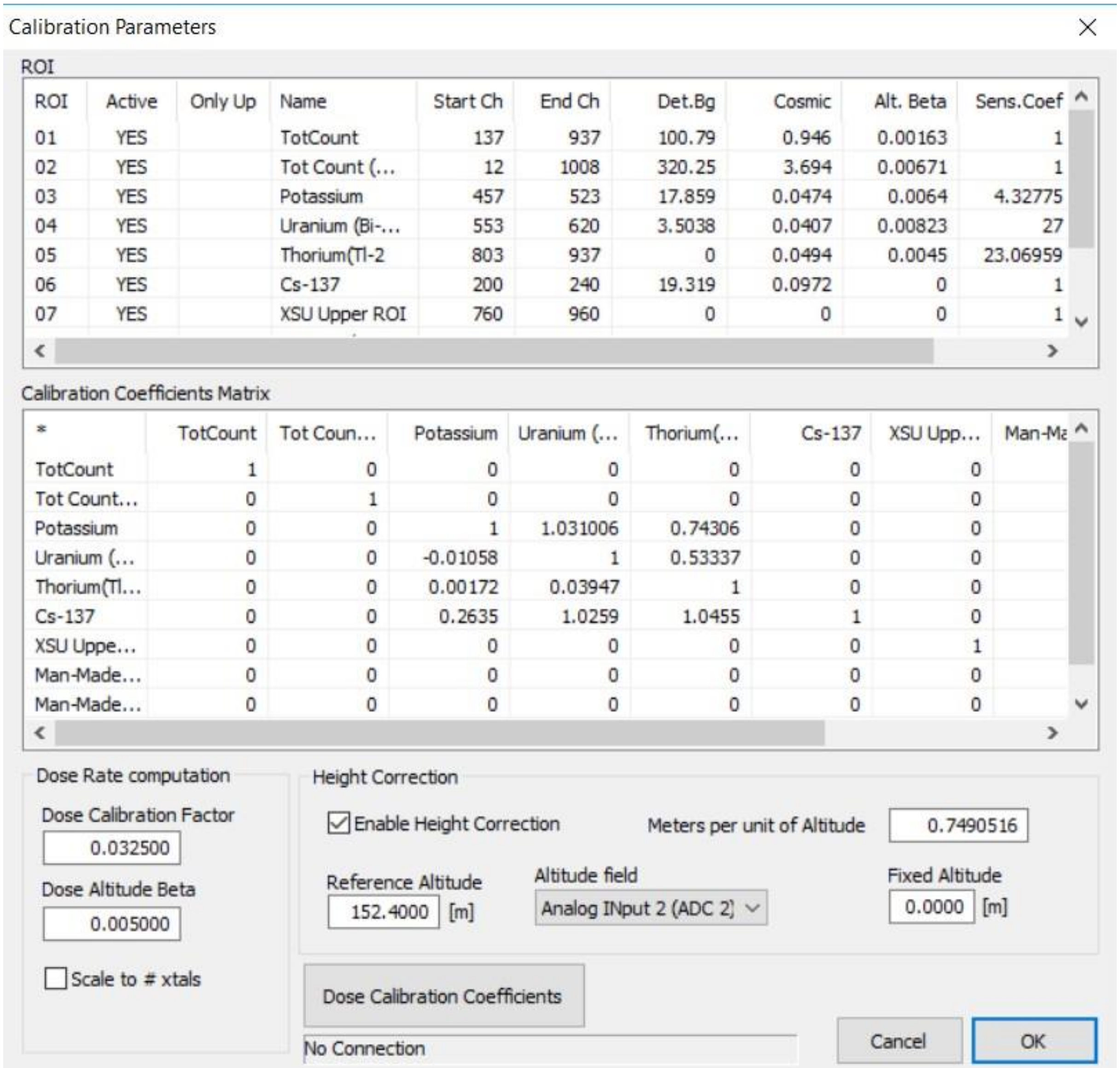
*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03065	0.74273	0	0	
Uranium (...	0	0	-0.01058	1	0.53345	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation
Dose Calibration Factor 0.032500
Dose Altitude Beta 0.005000
Scale to # xtals

Height Correction
Enable Height Correction
Meters per unit of Altitude 0.7456900
Reference Altitude 152.4000 [m]
Altitude field Analog INput 2 (ADC 2)
Fixed Altitude 0.0000 [m]

Dose Calibration Coefficients
No Connection
Cancel
OK

Figure 124: RadAssist calibration parameters for Western Agency Navajo Nation Zone 2a, Flight 1, June 25, 2018


Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	27
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.031006	0.74306	0	0	
Uranium (...	0	0	-0.01058	1	0.53337	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude: 0.7490516

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients

No Connection

Cancel

OK

Figure 125: RadAssist calibration parameters for Western Agency Navajo Nation Zone 2b, Flight 2, June 26, 2018

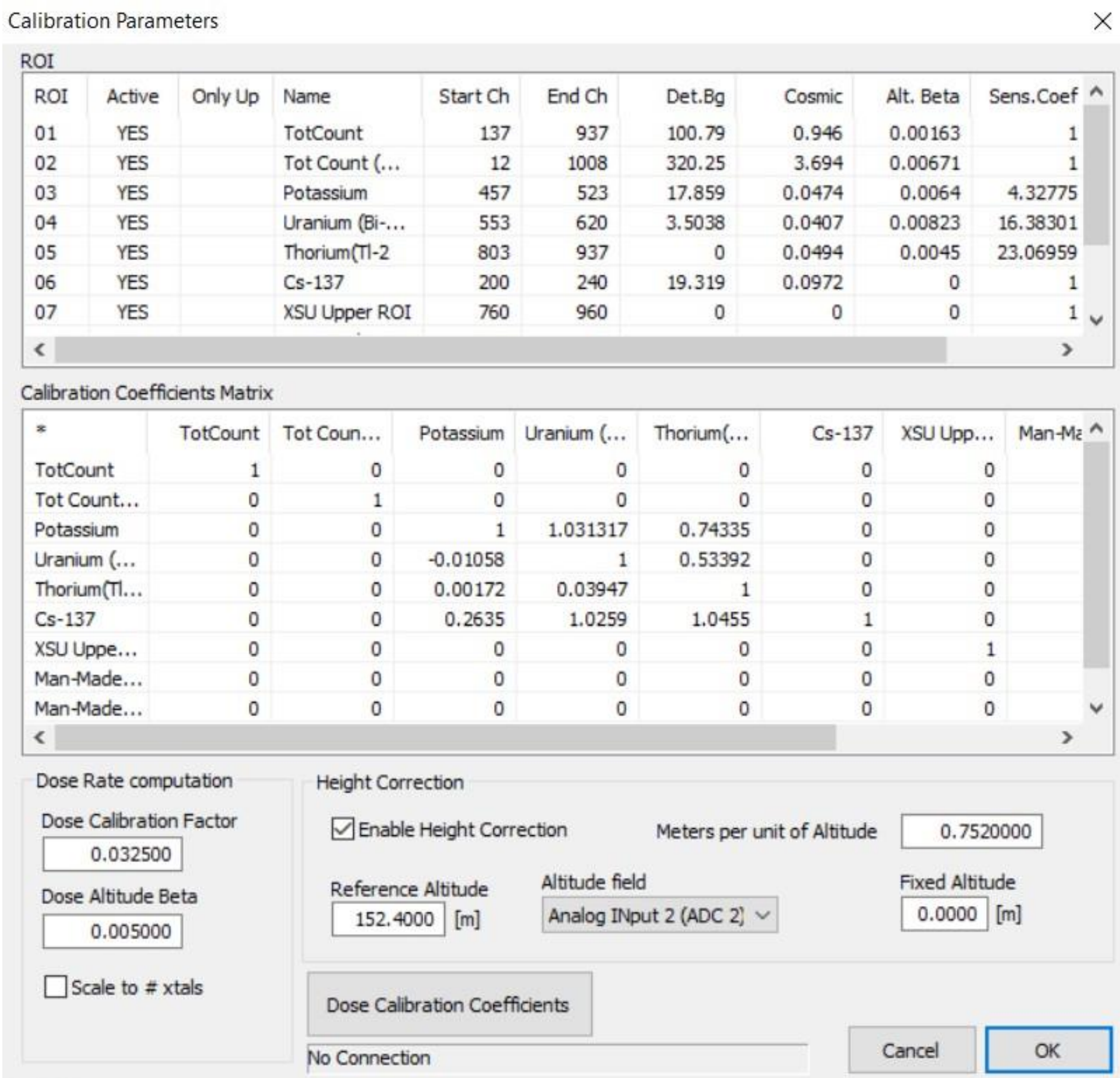
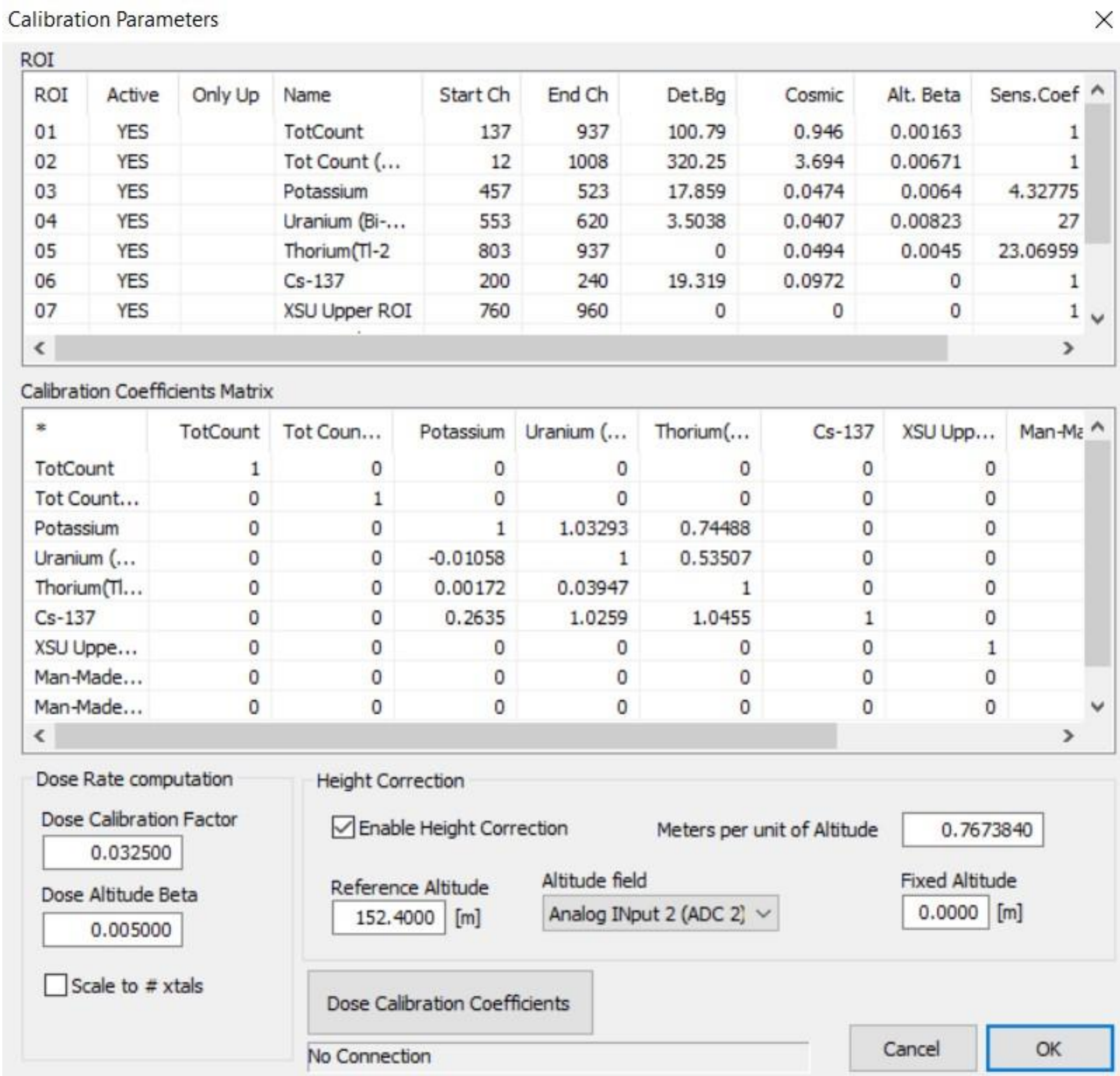


Figure 126: RadAssist calibration parameters for Western Agency Navajo Nation Zone 2c, Flight 3, June 26, 2018


Calibration Parameters

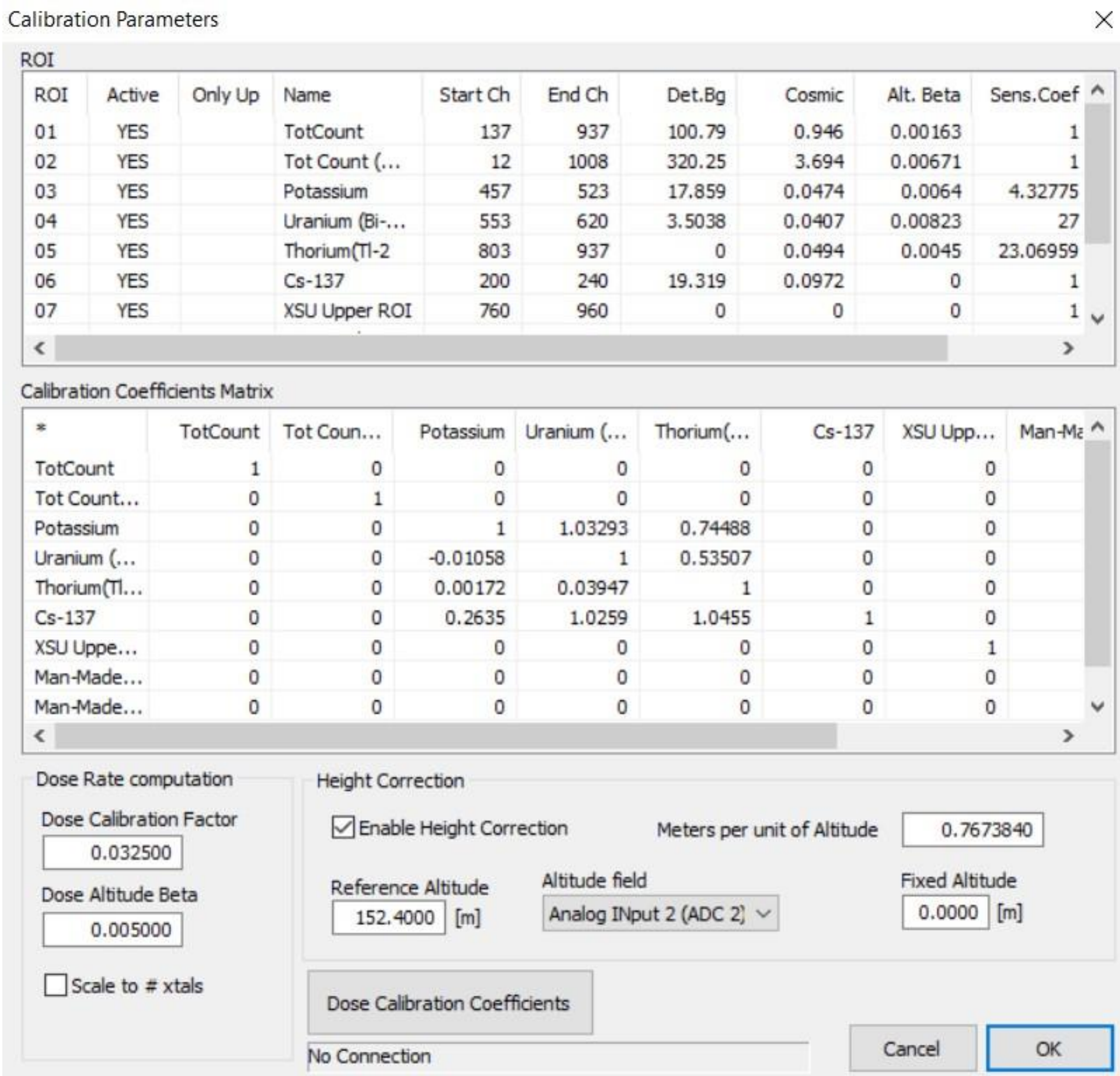
ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	27
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03293	0.74488	0	0	
Uranium (...	0	0	-0.01058	1	0.53507	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 127: RadAssist calibration parameters for Western Agency Navajo Nation Zone 2d, Flight 4, June 27, 2018


Calibration Parameters

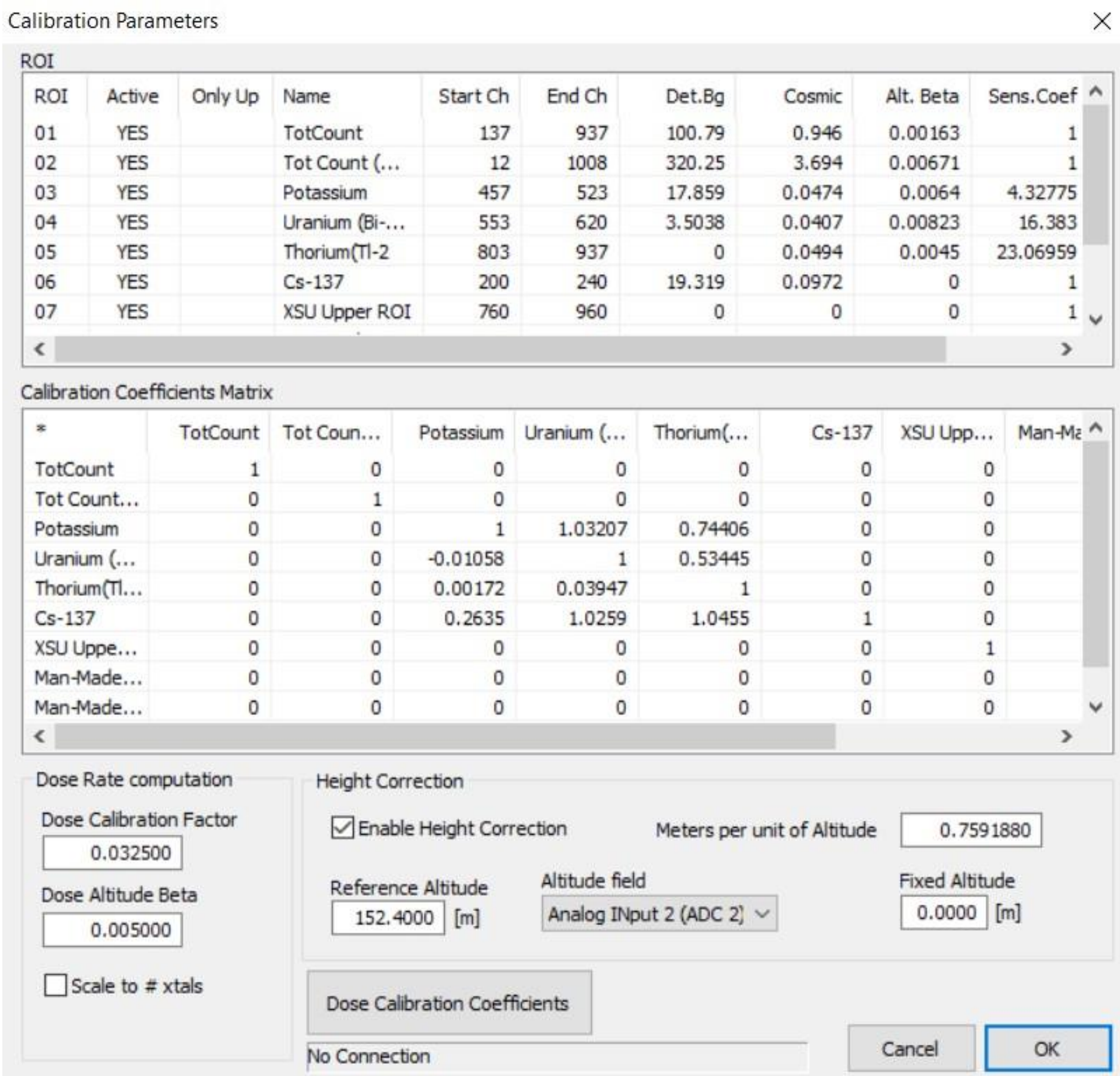
ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	27
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03293	0.74488	0	0	
Uranium (...	0	0	-0.01058	1	0.53507	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 128: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3a, Flight 4, June 27, 2018



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03207	0.74406	0	0	
Uranium (...	0	0	-0.01058	1	0.53445	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 129: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3b, Flight 5, June 27, 2018

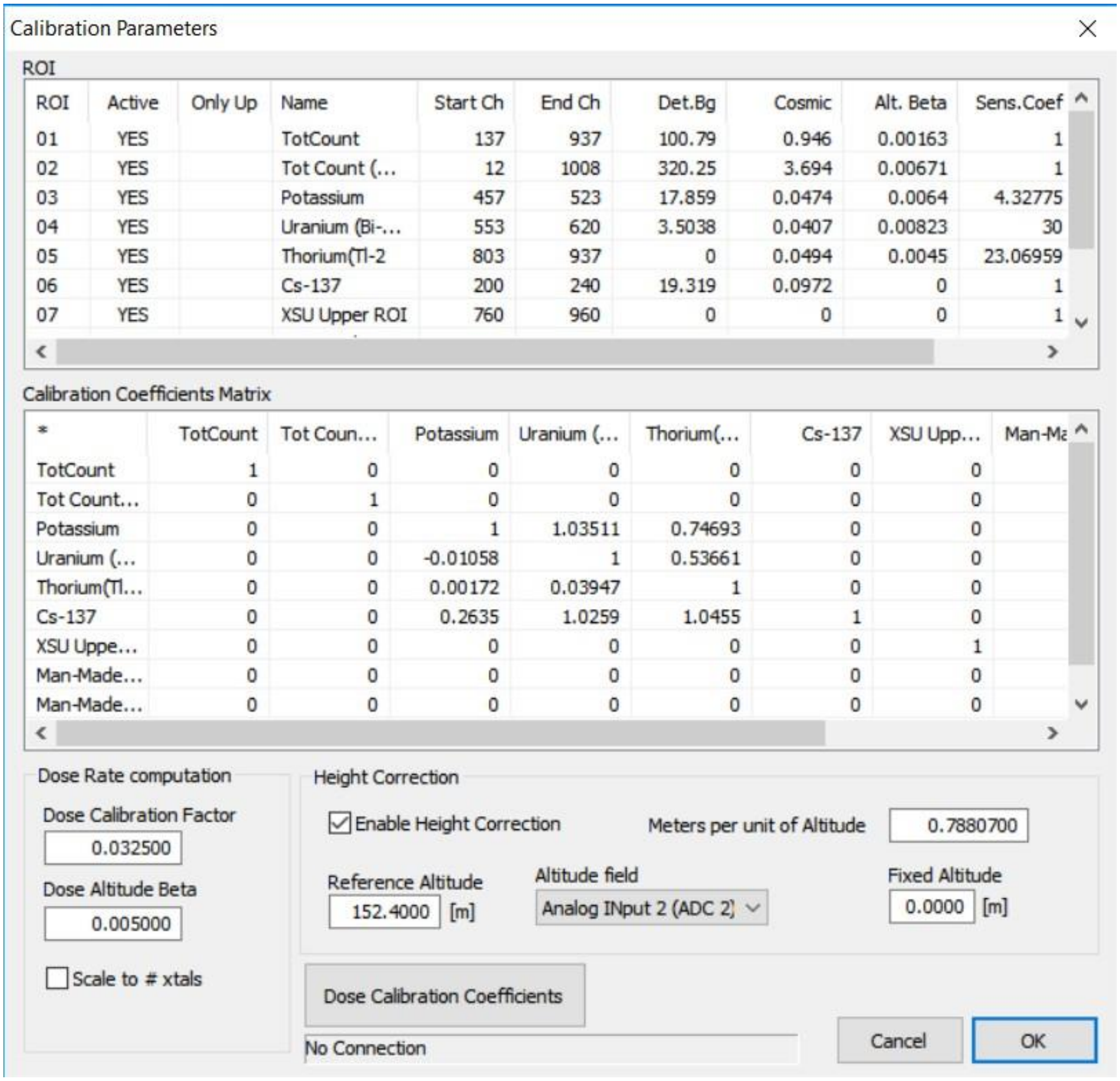


Figure 130: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3c, Flight 6, June 28, 2018

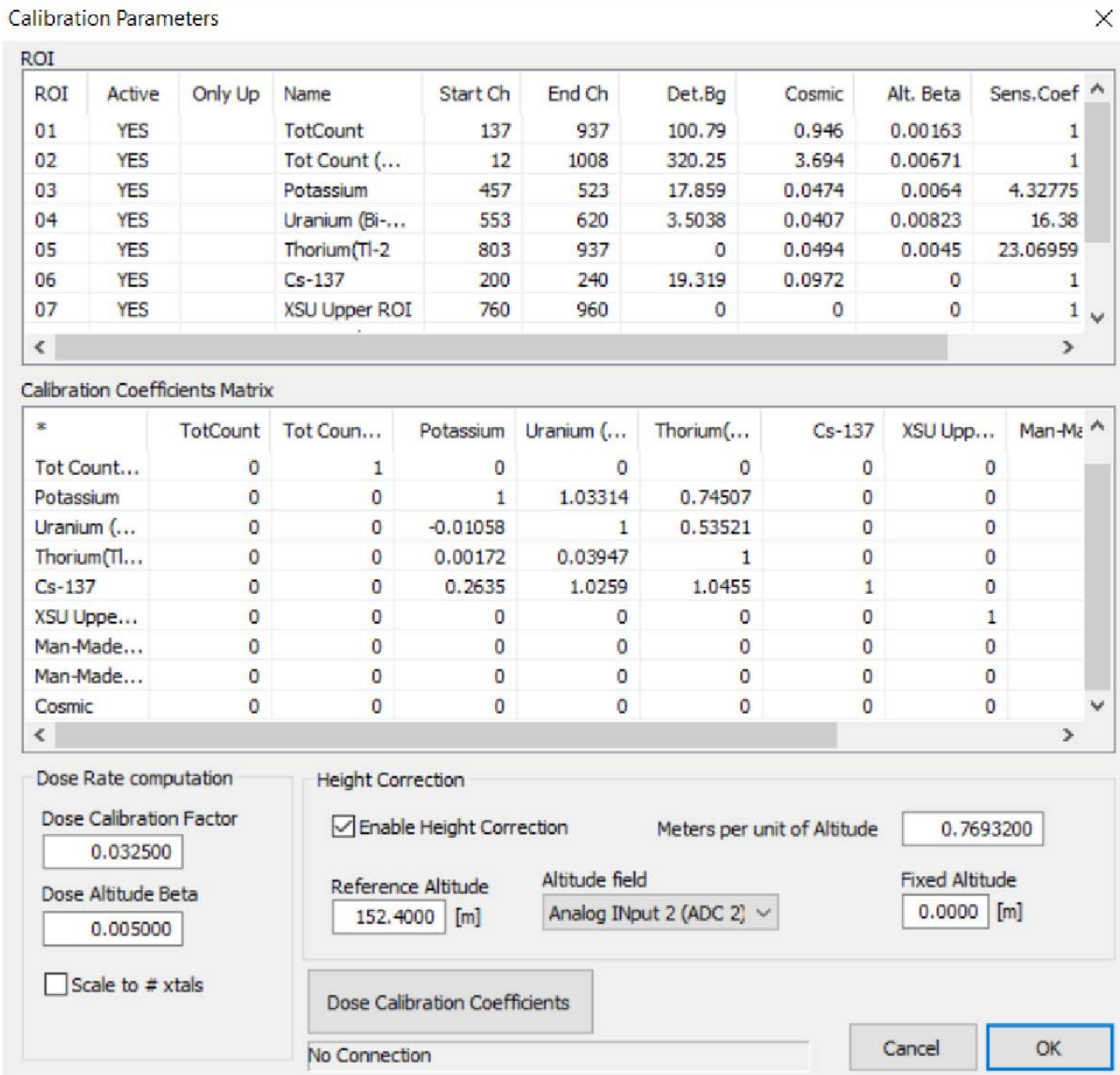
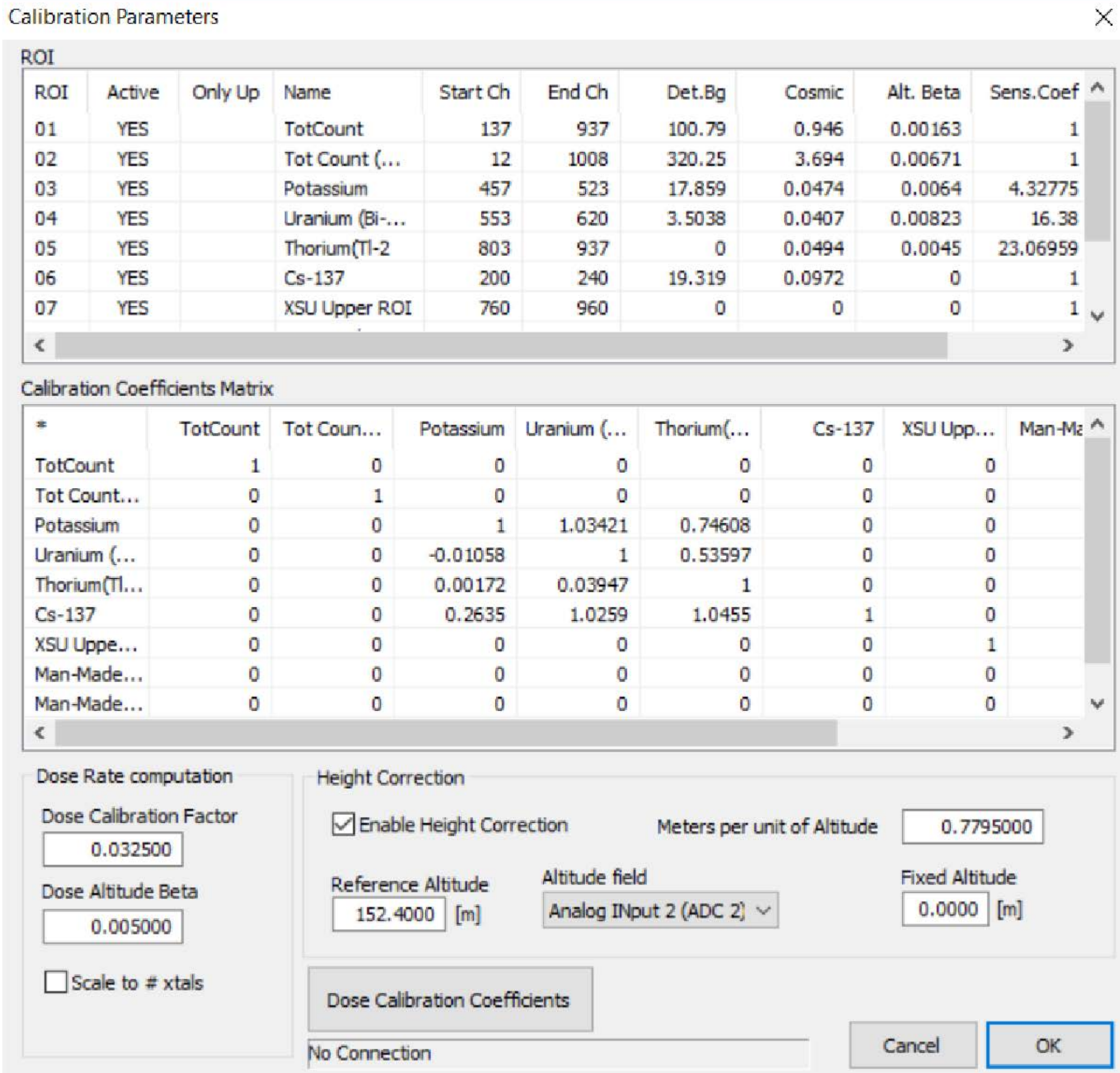


Figure 131: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3d, Flight 7, June 28, 2018



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.38
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03421	0.74608	0	0	
Uranium (...	0	0	-0.01058	1	0.53597	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation
Dose Calibration Factor: 0.032500
Dose Altitude Beta: 0.005000
Scale to # xtals

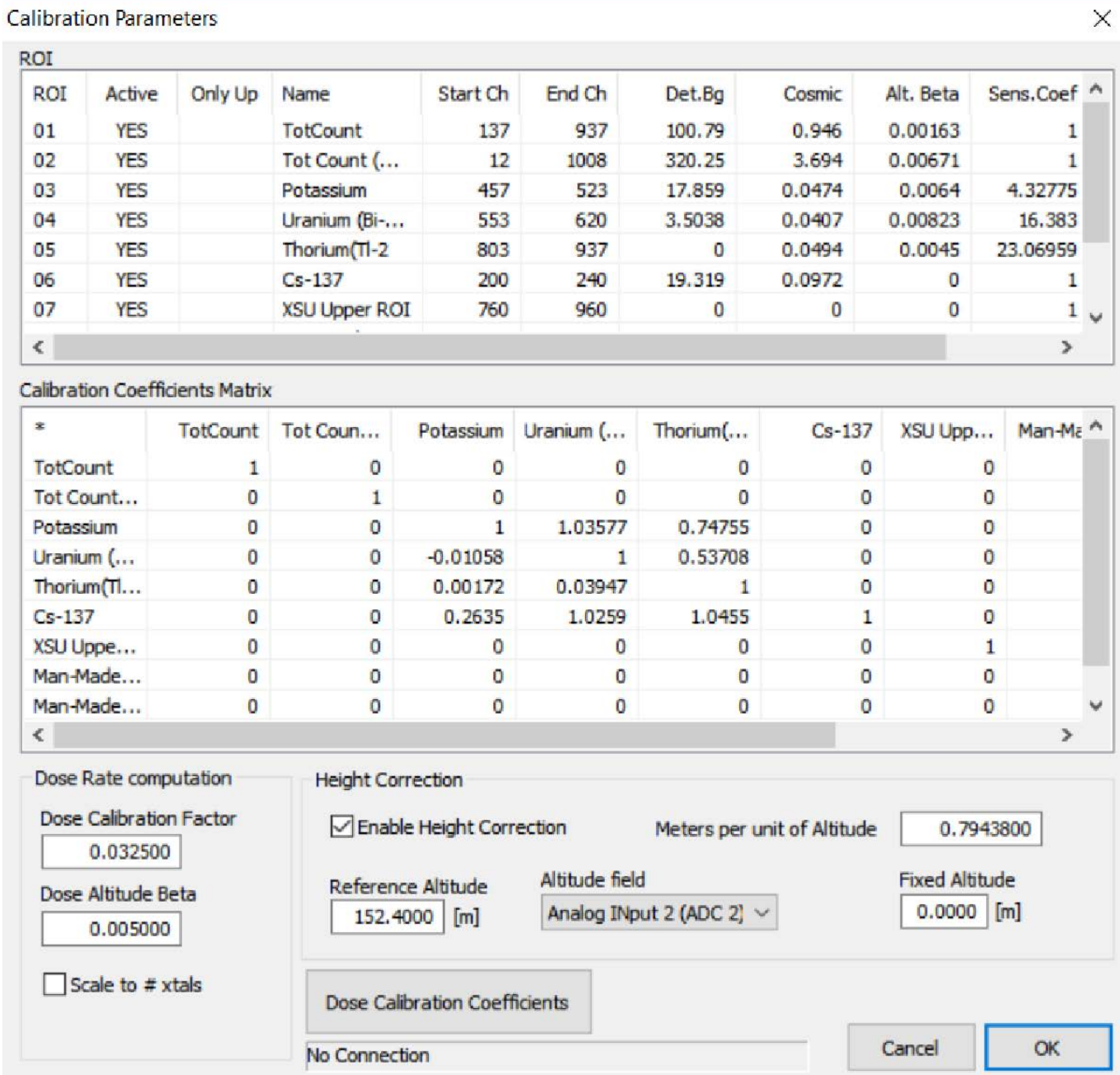
Height Correction
Enable Height Correction
Meters per unit of Altitude: 0.7795000
Reference Altitude: 152.4000 [m]
Altitude field: Analog INput 2 (ADC 2)
Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients

No Connection

Cancel | OK

Figure 132: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3f, Flight 9, June 29, 2018



Calibration Parameters

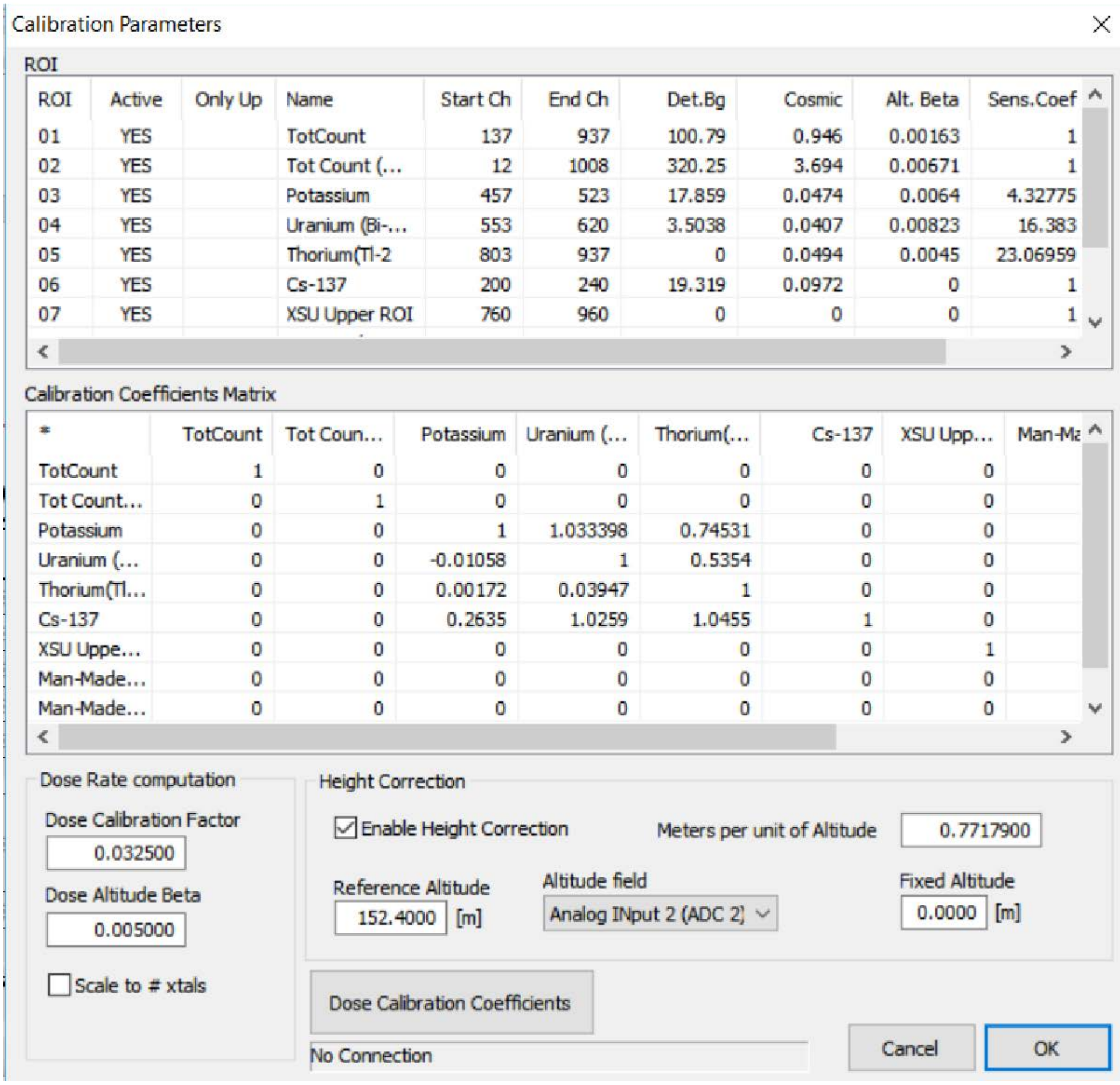
ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03577	0.74755	0	0	
Uranium (...	0	0	-0.01058	1	0.53708	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 133: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3g, Flight 11, July 1, 2018



ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.033398	0.74531	0	0	
Uranium (...	0	0	-0.01058	1	0.5354	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Figure 134: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3h, Flight 12, July 1, 2018

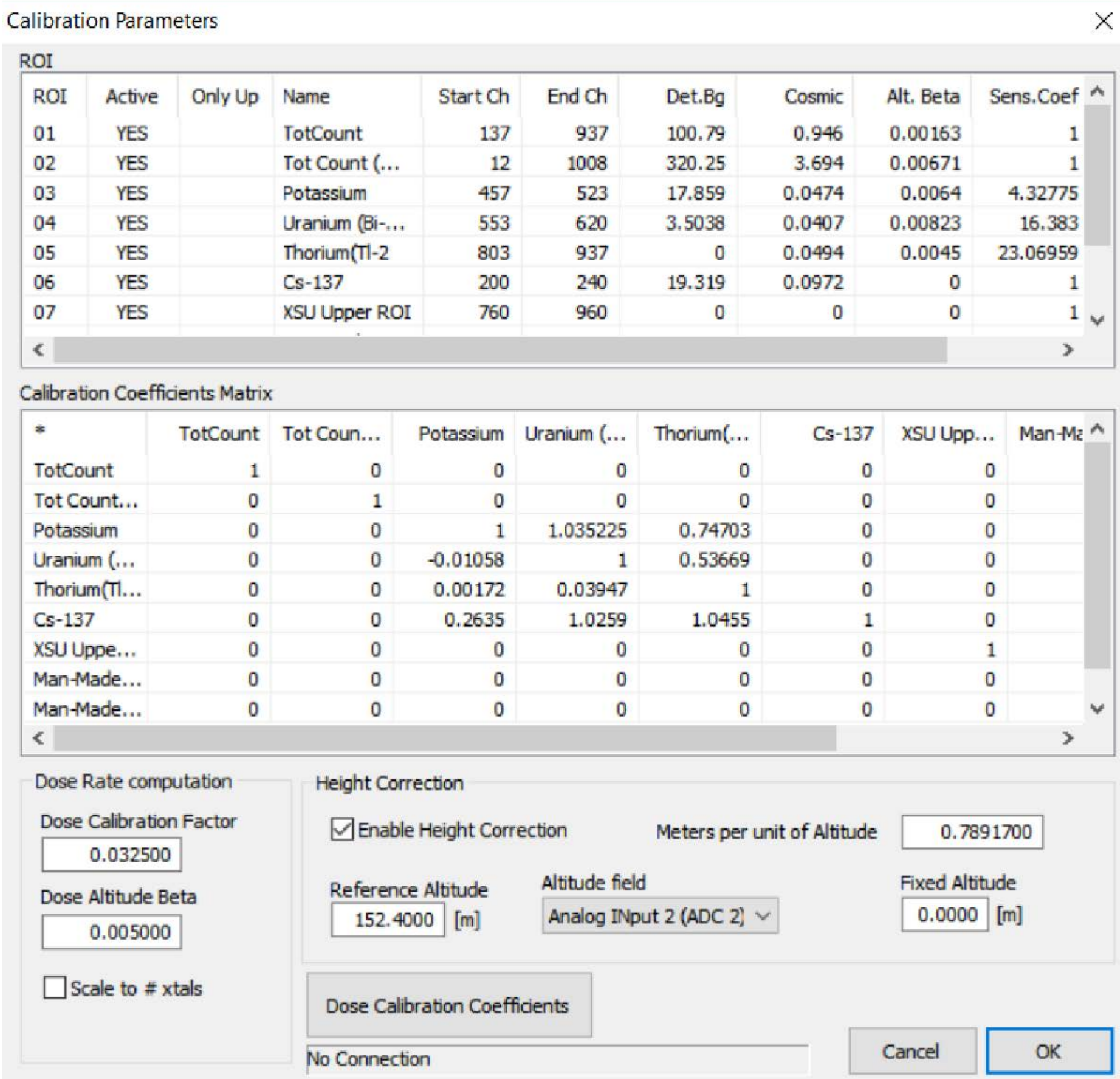
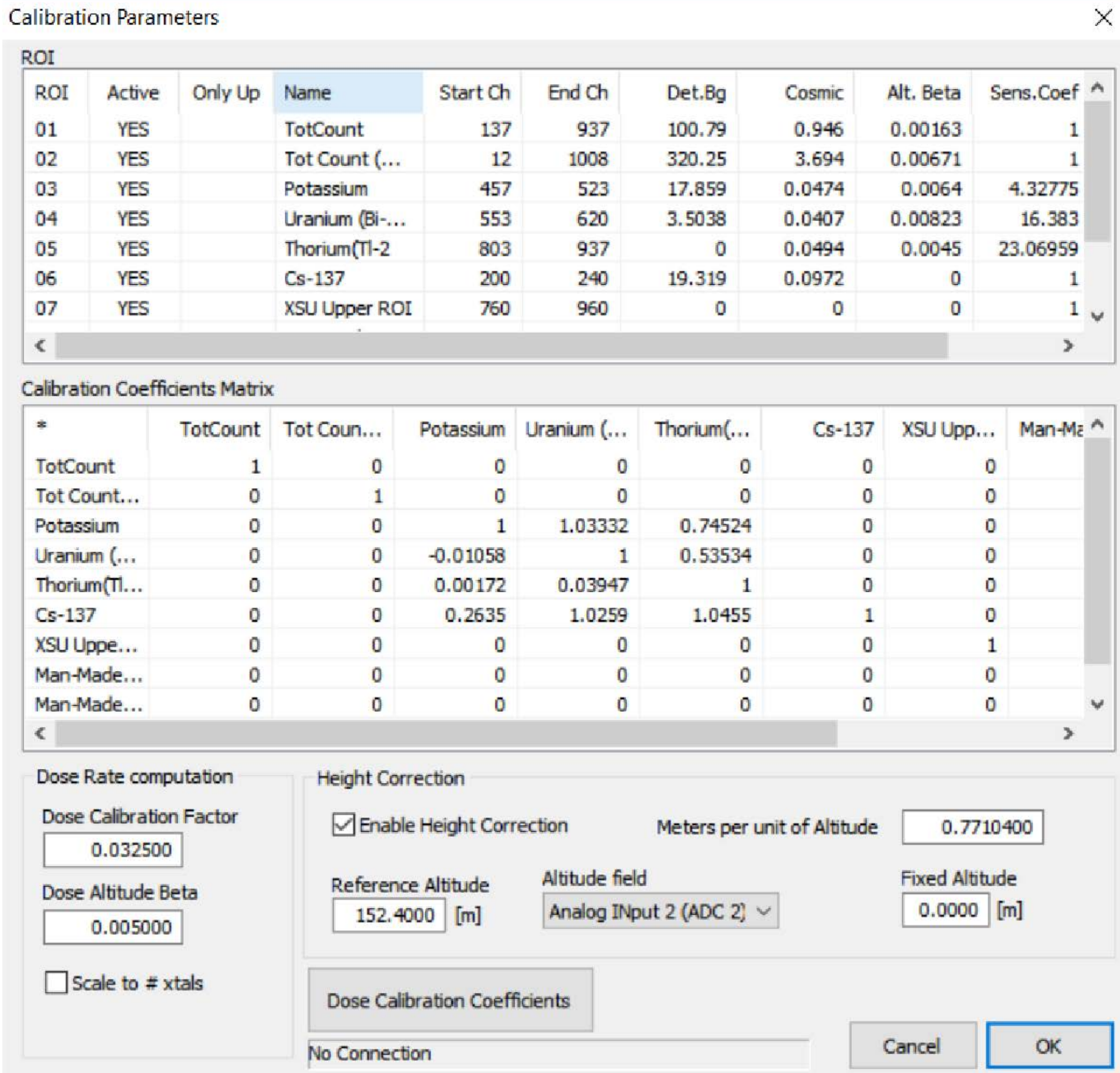


Figure 135: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3i, Flight 13, July 2, 2018



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03332	0.74524	0	0	
Uranium (...	0	0	-0.01058	1	0.53534	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

☐ Scale to # xtals

Height Correction

☑ Enable Height Correction

Meters per unit of Altitude: 0.7710400

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

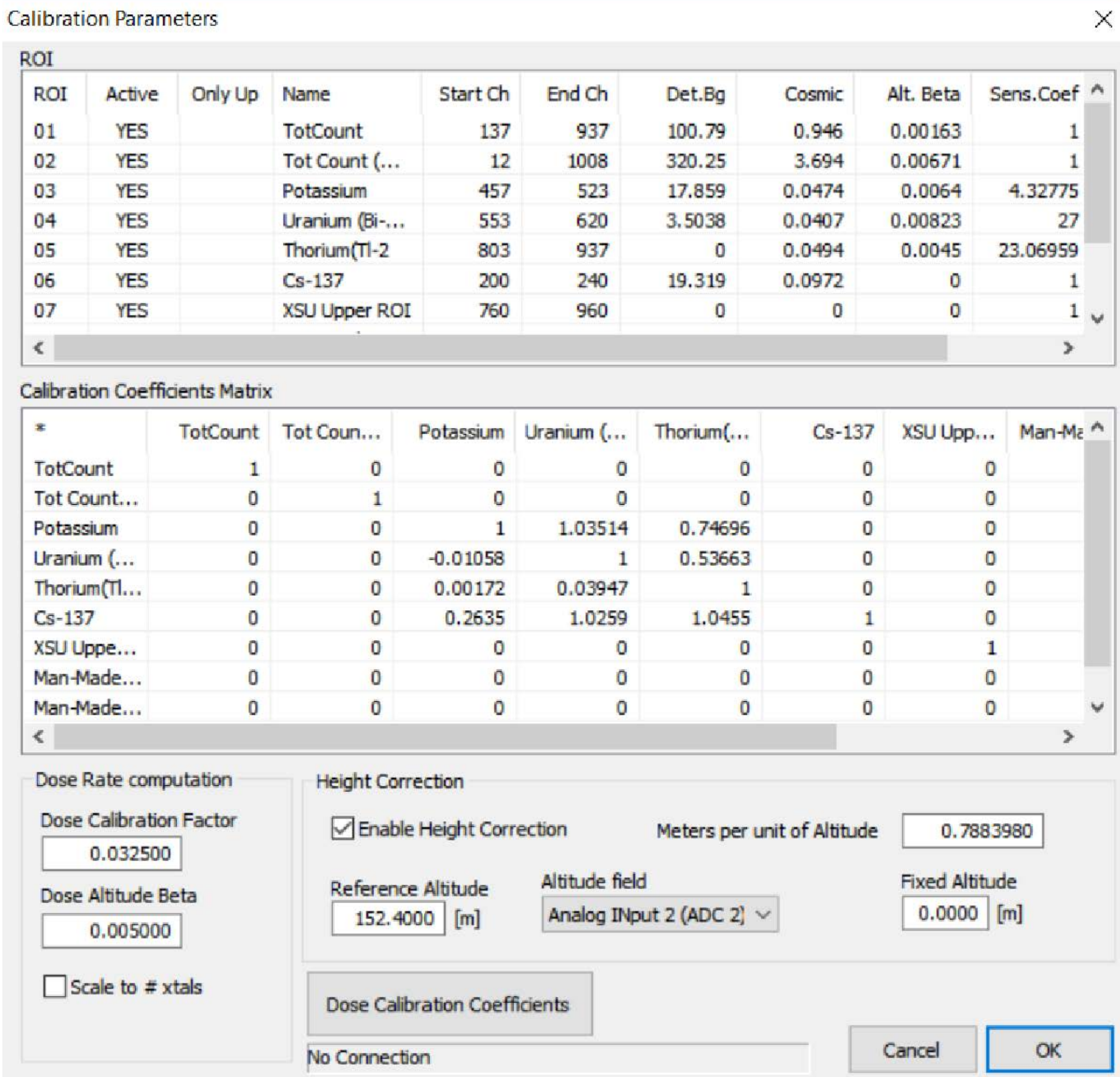
Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients

No Connection

Cancel | OK

Figure 136: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3j, Flight 14, July 2, 2018



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	27
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03514	0.74696	0	0	
Uranium (...	0	0	-0.01058	1	0.53663	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

☐ Scale to # xtals

Height Correction

☑ Enable Height Correction

Meters per unit of Altitude: 0.7883980

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

Fixed Altitude: 0.0000 [m]

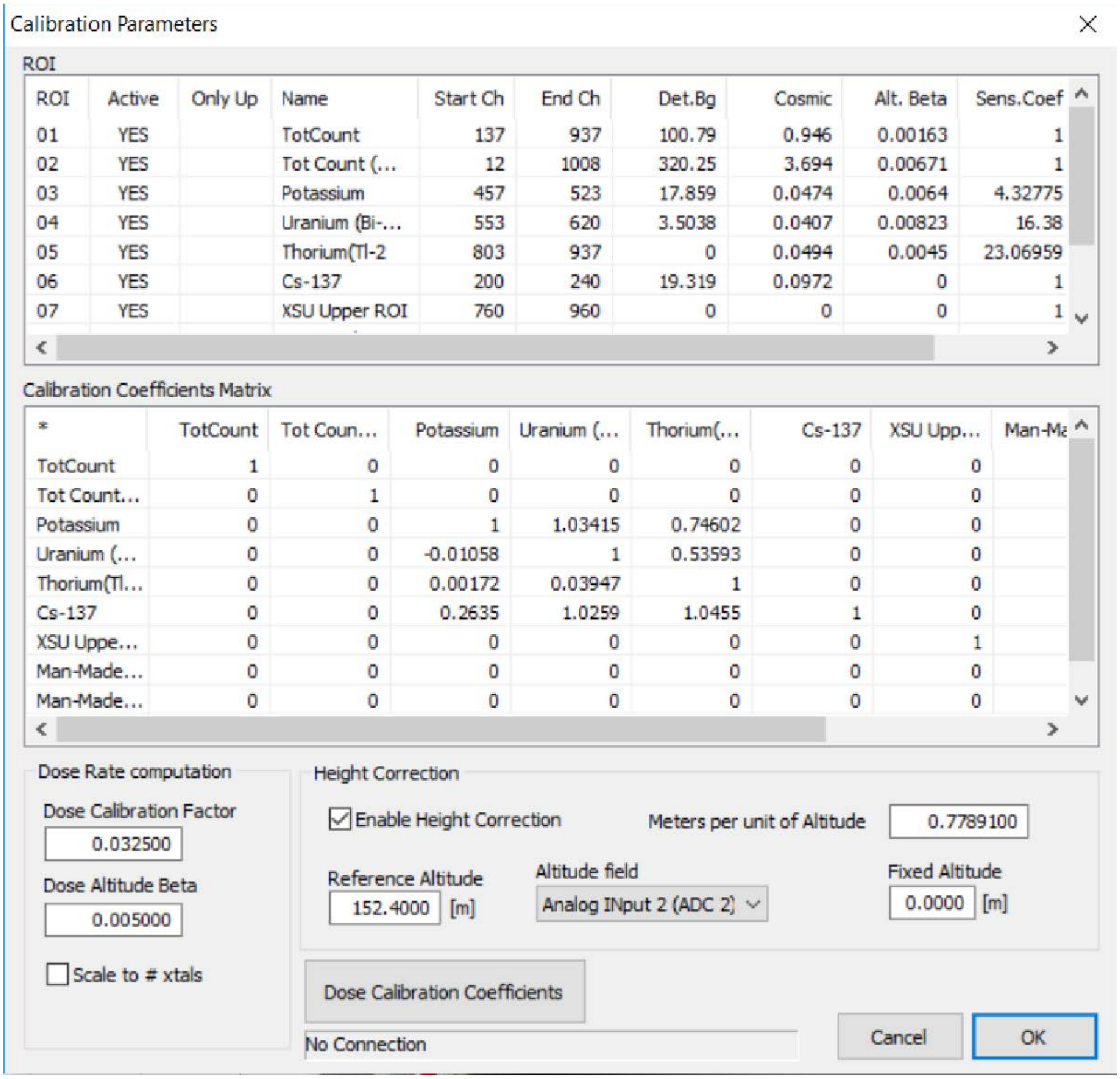
Dose Calibration Coefficients

No Connection

Cancel

OK

Figure 137: RadAssist calibration parameters for Western Agency Navajo Nation Zone 3k, Flight 15, July 3, 2018



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.38
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03415	0.74602	0	0	
Uranium (...	0	0	-0.01058	1	0.53593	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude: 0.7789100

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients

No Connection

Cancel

OK

Figure 138: RadAssist calibration parameters for Western Agency Navajo Nation Zone 4a, Flight 16, July 3, 2018

Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	16.383
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03174	0.74375	0	0	
Uranium (...	0	0	-0.01058	1	0.53422	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

☐ Scale to # xtals

Height Correction

☑ Enable Height Correction

Meters per unit of Altitude: 0.7560600

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

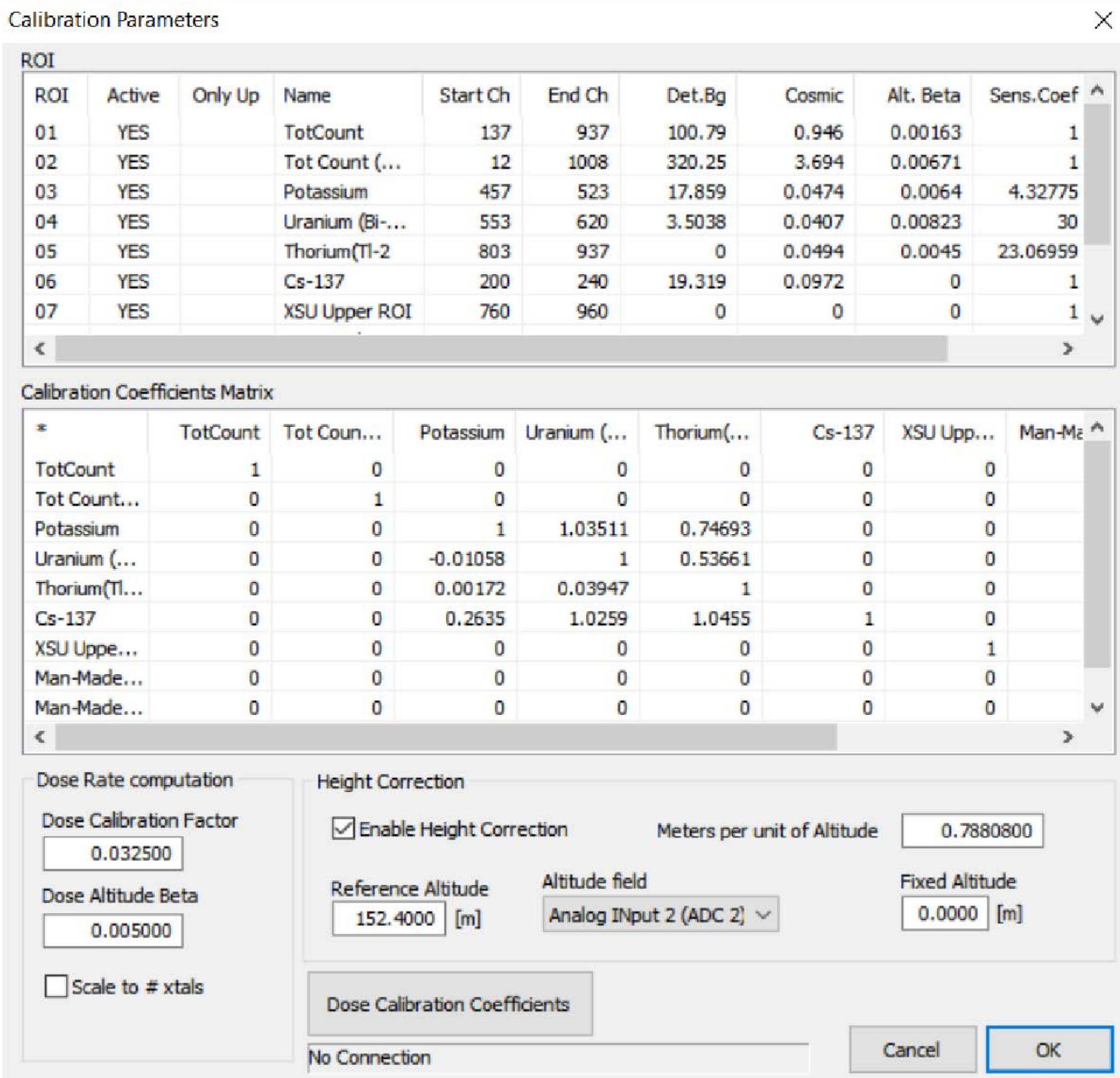
Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients

No Connection

Cancel | OK

Figure 139: RadAssist calibration parameters for Western Agency Navajo Nation
Zone 4b, Flight 17, July 4, 2018
Zone 5, Flight 17, July 4, 2018
Zone 6a, Flight 17, July 4, 2018



Calibration Parameters

ROI

ROI	Active	Only Up	Name	Start Ch	End Ch	Det.Bg	Cosmic	Alt. Beta	Sens.Coef
01	YES		TotCount	137	937	100.79	0.946	0.00163	1
02	YES		Tot Count (...	12	1008	320.25	3.694	0.00671	1
03	YES		Potassium	457	523	17.859	0.0474	0.0064	4.32775
04	YES		Uranium (Bi-...	553	620	3.5038	0.0407	0.00823	30
05	YES		Thorium(Tl-2	803	937	0	0.0494	0.0045	23.06959
06	YES		Cs-137	200	240	19.319	0.0972	0	1
07	YES		XSU Upper ROI	760	960	0	0	0	1

Calibration Coefficients Matrix

*	TotCount	Tot Coun...	Potassium	Uranium (...	Thorium(...	Cs-137	XSU Upp...	Man-Ma
TotCount	1	0	0	0	0	0	0	
Tot Count...	0	1	0	0	0	0	0	
Potassium	0	0	1	1.03511	0.74693	0	0	
Uranium (...	0	0	-0.01058	1	0.53661	0	0	
Thorium(Tl...	0	0	0.00172	0.03947	1	0	0	
Cs-137	0	0	0.2635	1.0259	1.0455	1	0	
XSU Uppe...	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	

Dose Rate computation

Dose Calibration Factor: 0.032500

Dose Altitude Beta: 0.005000

Scale to # xtals

Height Correction

Enable Height Correction

Meters per unit of Altitude: 0.7880800

Reference Altitude: 152.4000 [m]

Altitude field: Analog INput 2 (ADC 2)

Fixed Altitude: 0.0000 [m]

Dose Calibration Coefficients

No Connection

Cancel

OK

Figure 140: RadAssist calibration parameters for Western Agency Navajo Nation Zone 6b, Flight 19, July 5, 2018
Bridge, Flight 19, July 5, 2018

7 References

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