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AMS / BARC Joint Survey

Addendum Technical Report

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Executive Summary

This report details the data analysis results from data collected during the September-October 2019 joint survey series between the Department of Energy (DOE) National Nuclear Security Administration (NNSA) Aerial Measuring System (AMS) asset, and the Government of India's Department of Atomic Energy (DAE) Bhabha Atomic Research Centre (BARC). This joint survey series took place at the Nevada National Security Site (NNSS), areas of public land in Southern Nevada, and at the DOE Office of Legacy Management (LM) Large Area Calibration Pads (LACP) at the Grand Junction Regional Airport in Grand Junction, CO. The data detailed in this report were gathered at the LACP. More details regarding the setup of these surveys and personnel involvement can be found in the AMS / BARC Joint Survey Summary Report.

The data from the LACP collected by AMS are consistent with past data collection campaigns at the LACP. The AMS Bell 412 (B412) helicopter, equipped with both the standard AMS thallium-doped sodium iodide (NaI(Tl)) 2"x4"x16" 12-detector system and a subset of the BARC Aerial Gamma Spectroscopy System (AGSS) consisting of two independent 3"x3"cylindrical NaI(Tl) detectors, measured each of the five calibration pads for a minimum of 10 minutes. After the helicopter measurements, a pressurized ion chamber (PIC) was used to directly measure radiation exposure rates on each of the pads for a period 5 minutes.

The geophysical calibration procedure published by the International Atomic Energy Agency (IAEA) (Erdi-Krausz et al. 2003) was used to determine the spectral stripping sensitivity matrix for naturally occurring radiological material (NORM). The sensitivity matrix is consistent with the AMS long term average. Additionally, the PIC data was used to calibrate the AMS system for exposure rate. The results of the exposure rate analysis are also consistent with AMS long-term averages.

Introduction

Data Campaign

From September 30 to October 10, 2019, the United States Department of Energy (DOE) National Nuclear Security Administration (NNSA) Aerial Measuring System (AMS) and the Government of India's Department of Atomic Energy (DAE) Bhabha Atomic Research Centre (BARC) conducted a series of joint aerial radiation survey flights at various locations in Southern Nevada and Colorado. The flights were conducted over areas of well-characterized natural background in Nevada, at the DOE Office of Legacy Management (LM) Large Area Calibration Pads (LACP) in Grand Junction, CO, and over legacy ground contamination at the Nevada National Security Site (NNSS). The intention of the joint surveys was to compare the responses, processes, and procedures of each country's aerial radiation detection system. These systems can detect and map ground contamination that may result from a nuclear or radiological accident or incident, and play a significant role in the national radiological emergency response capabilities of both countries.

The AMS / BARC Joint Survey Summary Report presents the data acquired in Southern Nevada. This Addendum Technical Report summarizes the analysis performed on the AMS data collected at the LACP. There was no formal exchange of data as a part of this survey series, therefore AMS can only analyze their own data and place it in the context of previous visits to the LACP.

Radiation Detector Calibration Facility

The Grand Junction Calibration Pads were constructed as part of the National Uranium Resource Evaluation survey in the 1970s. They were constructed with known weight fractions of naturally occurring radiological material (NORM). These pads allow for precise calibration of radiation detection systems for geophysical measurements. (Ward 1978).

There are five pads at the calibration facility: a background pad, a potassium (K) enriched pad, a natural uranium (U) enriched pad, a natural thorium (Th) enriched pad, and a mixed enrichment pad (Figure 1). The weight fractions of K, U, and Th in each pad, determined during installation, are listed in Table 1.

Table 1: Weight fractions in each pad for K, U, and Th from Ward 1978. Pad density also reported.

Pad	K(wt%)	U PPM	Th PPM	Density ($\frac{g}{cm^3}$)
1	1.45(0.01)	2.2(0.1)	6.3(0.1)	1.91(0.00)
2	5.14(0.09)	5.1(0.3)	8.5(0.3)	2.00(0.01)
3	2.01(0.04)	5.1(0.2)	45.3(0.7)	1.92(0.00)
4	2.03(0.05)	30.3(1.6)	9.2(0.3)	1.91(0.00)
5	4.11(0.06)	20.4(1.3)	17.5(0.3)	1.97(0.00)

In 2017, the calibration pads were rehabilitated. This included resurfacing, which removed between 4 and 5 cm of material from the top of each pad (U.S. DOE LM 2017). Until this measurement campaign it was unknown to AMS whether or not future measurements at this facility would be impacted.

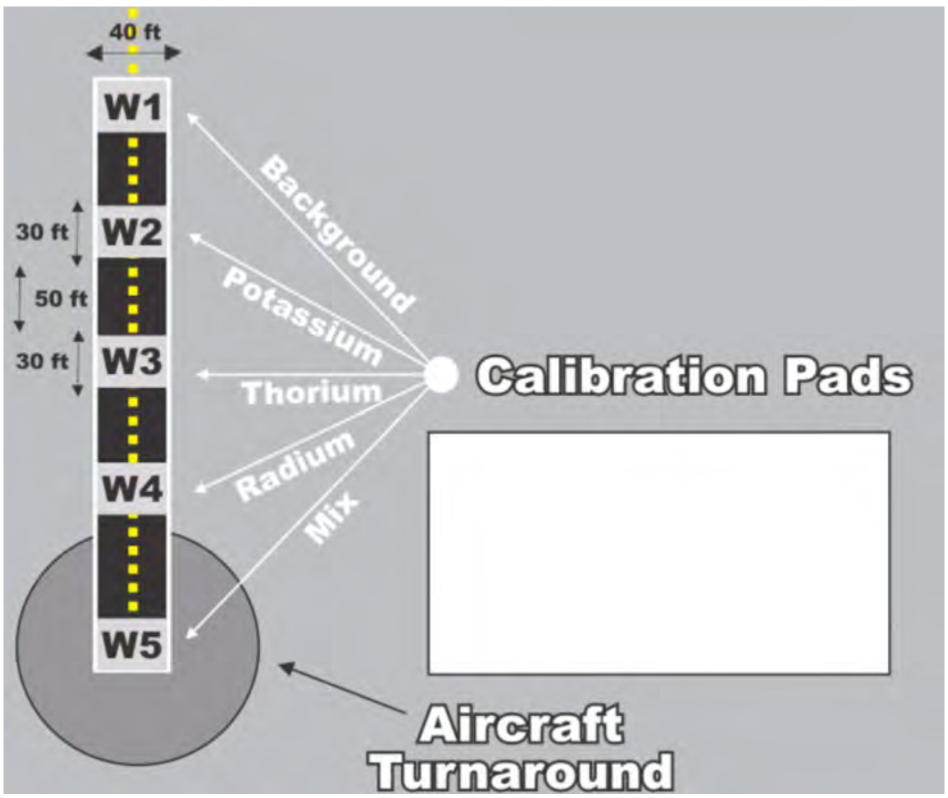

Figure 1: Drawing of the layout of the Large Area Calibration Pads in Grand Junction, Colorado adapted from U.S. DOE LM 2013.

Methods

Data Collection

Data were collected over each of the five calibration pads at the LACP with the respective countries' aerial detection systems. The BARC system, consisting of two independent 3"x3" cylindrical thallium-doped sodium iodide (NaI(Tl)) detectors, was mounted inside the AMS aircraft and therefore collected data in coincidence with AMS. Each pad was measured for a period of no less than 10 minutes to ensure a statistically robust result. The primary detection system for the AMS Bell 412 (B412) is comprised of 12 2"x4"x16" NaI(Tl) crystals divided into two pods on the port and starboard sides of the aircraft. The detectors are approximately 1 meter off the ground when the aircraft is landed.

Data were also collected with the AMS ground-based pressurized ion chamber (PIC) for a period of 5 or more minutes per pad. The PIC is used to calibrate the aerial detection system against radiation exposure rate in micro-Roentgen per hour (μR/h).

Geophysical Calibration

The LACP allow AMS to calibrate against known weight fractions of K, U, and Th for geophysical surveying and to verify the spectral calibration of the system. To calibrate the aerial radiological system, known quantities of K, U, and Th are measured from the calibration pads in Grand Junction, Colorado and calibration factors are determined from the spectral regions of ^{40}K (1.46 MeV), and prominent daughters of ^{238}U (1.764 MeV), and ^{232}Th (2.642 MeV).

The standard method is outlined in Erdi-Krausz et al. 2003 published by the International Atomic Energy Agency (IAEA). This method involves building a matrix of sensitivities to account for down scattering in K, and U window regions. To do this, the respective spectral windows for K, U, and Th are summed for each pad, and then subtracted from the sum of those windows in the background pad (pad 1); the weight fraction data in Table 1 are also subtracted from the background pad. The data are arranged in two 3x3 matrices consisting of data from pads 2-4, and the pad 5 data are used to validate the results. The sensitivity matrix is then calculated according to Equation 1.

$$S \approx \Delta N \Delta C^{-1} \tag{1}$$

Where: S = the 3x3 matrix of sensitivity
ΔN = the 3x3 matrix of background adjusted mean count rate per energy region
ΔC = the 3x3 matrix of background adjusted weight fractions

This sensitivity matrix allows calculation of calibrated weight fractions of K, U, and Th from arbitrary spectra collected by the same instrument. The concentrations can be found by multiplying net counts collected from the spectral regions' windows for each isotope by the sensitivity matrix correcting for the altitude of the measurement.

Exposure Rate Calibration

The PIC data were processed by evaluating the background adjusted data from pads 2-5; a proportionality constant between the background adjusted weight fractions and detector counts is determined by Equation 2.

$$\alpha_p = \frac{\Delta C_p}{\Delta N_p} \tag{2}$$

Where: α_p = the count to exposure rate (μR/h) coefficient for each pad.
ΔC_p = the background adjusted radiation exposure rate in μR/h for each pad.
ΔN_p = the background adjusted mean count rate for each pad.

A single value of α is then determined from a least square fit simultaneously on all 5 pad measurement results. This method has consistently compared well to calibration coefficients determined from spiral flights over the AMS Lake Mojave calibration line.

Results

Geophysical Calibration

The NORM sensitivity matrix was generated using the AMS NaI(Tl) measurements and the reference isotopic concentrations from "Project Summary Report Pre-and Post-Rehabilitation Source Reduction Modeling and Radiometric Surveys" (U.S. DOE LM 2017). The result shown in Figure 2 was built from taking the net measurements on the calibration pads and applying Equation 1.

$$\begin{bmatrix} 15.57 & 1.36 & 0.43 \\ 0 & 1.38 & 0.31 \\ 0 & 0.11 & 0.66 \end{bmatrix}$$

Figure 2: Matrix of sensitivity scaled to one 2"x4"x16" crystal for the AMS detection system determined from the measurements at the LACP.

Very little difference in terms of count rate was observed between previous LACP visits and this particular visit. This indicates that both the AMS system and the environment at the LACP have remained stable through time which is consistent with the reported renovation results remaining within 1% of the pre-renovation isotopic values for K, U, and Th (U.S. DOE LM 2017).

Exposure Rate Calibration

The terrestrial exposure rate is a fundamental product generated by AMS for nuclear emergency response. Typically, the exposure rate measured by an AMS detection system is calculated from a gross count conversion coefficient determined by a calibration flight and fit to empirical ground measurements, valid for NORM environments. The pads at the LACP provide an alternative to a calibration flight that is unique in that it allows AMS to calibrate the NORM conversion coefficient against a well-established standard and validate the calibration flight method.

To determine the calibration factor, the raw PIC measurements must be corrected for far field effects (ground and sky shine), cosmic background radiation, and variable radon levels. To achieve this, measurements from each pad 2-5 are subtracted from the background pad 1 measurement. The distribution of the background adjusted exposure rate measurements from pads 2-5 are displayed in Figure 3. These data are used to relate recorded counts in the AMS system to exposure rate to determine the conversion coefficient discussed previously. Table 2 displays the conversion coefficients determined for each of the four pads as well as a least squares solution from the four net pad measurements collected by the NaI(Tl) detectors on the Bell 412.

Table 2: Count to exposure rate conversion coefficients for each calibration pad.

Net Pads	Net Exposure Rate (μR/h)	Net Counts	α
2 - 1	4.87	11912.3	0.000409
3 - 1	8.73	25677.6	0.00034
4 - 1	12.2	40816.2	0.000299
5 - 1	11.38	35700.9	0.000319
		Least Squares:	3.17E-04

In order to compare the PIC measurements on each pad to the AMS NaI(Tl) data it is necessary to account for cosmic and radon contributions. The LACP is located at a mean sea level (MSL) of 4854 ft at a latitude of 39.12N which gives an estimated cosmic exposure contribution of 5.4 μR/h (Boltneva, Nazarov, and Fridman 1974).

Table 3: Ground measurement reconstruction

	NaI Measurement		Ion Chamber Measurement		
Pad	Net Gross Counts	Terrestrial Exposure (µR/h)	Total (µR/h)	Cosmic Corrected (µR/h)	Excess Exposure Rate (µR/h)
1	13266	4.2	12.8	7.4	3.2
2	25178	8.0	17.6	12.2	4.2
3	38944	12.3	21.5	16.1	3.7
4	54082	17.1	25.0	19.6	2.4
5	48967	15.5	24.1	18.7	3.2
					Mean 3.4

In Table 3, the net gamma counts are calculated over each pad by subtracting gross gamma counts from a high altitude flight line over Grand Junction, flown at $\sim$ 3000ft above ground level. The PIC measurements are corrected to terrestrial exposure by subtracting the published cosmic contribution (Boltneva, Nazarov, and Fridman 1974). The residual PIC exposure measurement still contains contributions from radon, sky shine, and ground shine with a mean excess exposure of $\sim$3.4 μR/h.

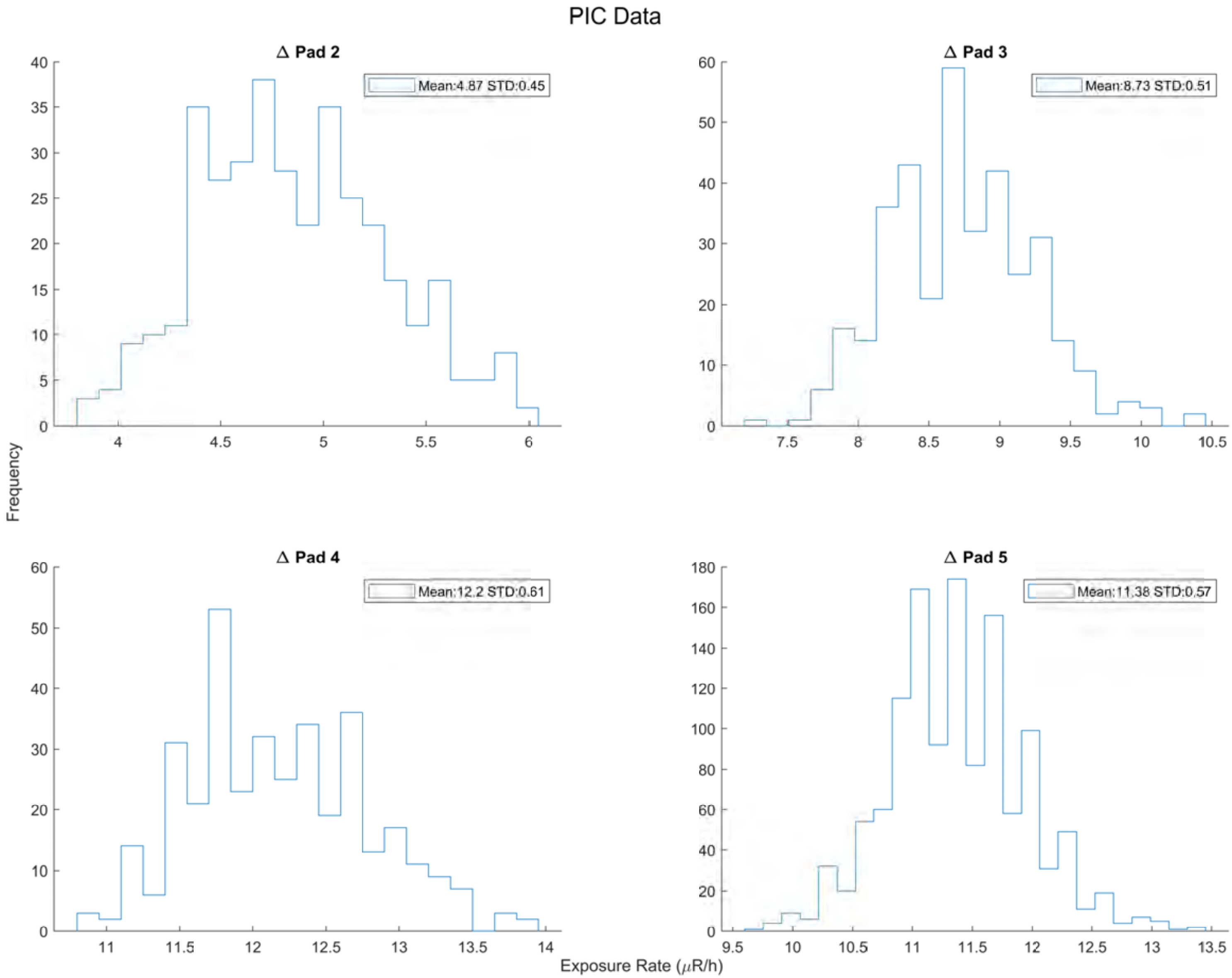

Figure 3: Histogram-series of background adjusted radiation exposure rates in μR/h for pads 2-5.

Conclusion

The results from both the geophysical and exposure rate calibration procedures are in line with previous AMS results. This indicates that the AMS system is performing as expected, and that there was no significant change in the environment from previous LACP visits despite the resurfacing of the calibration pads. Therefore, the BARC detection system should have acquired data that is valid for calibration. In the event of a joint response, these data can be referenced and compared against BARC data in an effort to resolve any observed differences in measurements.

These results are also significant in that they provide additional data for long term AMS system performance tracking. Long term average results are a key component of the set of assumptions that are used in an emergency response scenario.

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