DOE/NV/25946--2697

AMS GROUND TRUTH MEASUREMENTS: Calibration and Test Lines

Aerial Measuring System
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December 2015

This manuscript has been authored by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.

Introduction

Airborne gamma spectrometry is one of the primary techniques used to define the extent of ground contamination after a radiological incident. Its usefulness was demonstrated extensively during the response to the Fukushima NPP accident in March-May 2011. To map ground contamination, a set of scintillation detectors is mounted on an airborne platform (airplane or helicopter) and flown over contaminated areas. The acquisition system collects spectral information together with the aircraft position and altitude every second. To provide useful information to decision makers, the count data, expressed in counts per second (cps), need to be converted to a terrestrial component of the exposure rate at 1 meter (m) above ground, or surface activity of the isotopes of concern. This is done using conversion coefficients derived from calibration flights. During a large-scale radiological event, multiple flights may be necessary and may require use of assets from different agencies. However, because production of a single, consistent map product depicting the ground contamination is the primary goal, it is critical to establish a common calibration line very early into the event. Such a line should be flown periodically in order to normalize data collected from different aerial acquisition systems and that are potentially flown at different flight altitudes and speeds. In order to verify and validate individual aerial systems, the calibration line needs to be characterized in terms of ground truth measurements This is especially important if the contamination is due to short-lived radionuclides. The process of establishing such a line, as well as necessary ground truth measurements, is described in this document.

Calibration Line versus Test Line

One of the primary missions of the Aerial Measuring System (AMS) is mapping of the radioactive ground contamination following a radiological incident or accident. Radiation Mapping (RM) is a process whereby radiation sensing detectors are mounted on aerial-based platforms to remotely sense radiation emanating from distributed sources on or in the soil of a specified area. RM missions typically require the aircraft to fly as close to the ground as possible to map lower level radioactivity, usually for emergency response as part of the consequence management (CM) efforts, public health and safety, material cleanup, and finally remediation efforts.

The AMS standard operating procedure (NSTec OP-2200.287, "Aerial Measuring System [AMS] Mission and Survey"), which covers the radiation mapping (RM) mission, describes several quality control (QC) checks and calibration procedures used during an RM mission.

Before Mission:

1) Characterization of the system in terms of ground exposure rate or isotopic surface deposition using **the Calibration Line** in the incident vicinity
2) Weekly instruments response check using calibration source (e.g., 10 μCi Cs-137)

During Mission:

1) Preflight QC (system performance check) on the ground using NIST traceable source (detector response and energy resolution)
2) 1 min on the ground before takeoff for data acquisition system consistency
3) **Test Line** – overflown at the beginning of a flight for radon background and system stability
4) Water line (if available) – establishing radon background
5) If a large body of water is not available, a flight pass over the **Test Line** at 3000 feet (ft) above ground level (AGL)
6) Altitude spiral – local air attenuation coefficient and radon background
7) Radar altimeter in-flight altitude recording – air attenuation
8) **Test Line** – overflown at the end of a flight for radon background and system stability
9) 1 min on the ground after landing for data acquisition system consistency
10) Post flight data QC analysis
11) Software correction for timing
12) Ground truth verification using high purity germanium (HPGe) and pressurized ion chamber (PIC) detection equipment

The **Calibration Line** and the **Test Line** serve different functions in the RM mission.

The **Calibration Line** is a geographically defined straight line on relatively flat terrain about 1-2 miles (mi) long, where ground level exposure rates or surface activity of specific radioisotopes have been determined using independent methods. In case of an emergency, the calibration line should be established inside the moderately and uniformly contaminated area, where there is no chance of detection equipment saturation, and with easy and safe access for ground teams.

The **Test Line** is a geographically defined terrain feature resembling a straight line (stretch of road, railroad track, airport taxiway, etc.) and visible from the typical flight altitudes of 300 to 1500 ft AGL. The test line is flown at the beginning and at the end of each survey flight to verify the stability of system performance and radon levels. The test line should be outside contaminated areas and in an area of relatively constant natural background.

Characteristics of the Calibration Line

For RM background surveys, **the Calibration Line** is selected in advance based on the uniformity of the natural background, flat terrain, easy access for ground measurements, and safety for overflying it at multiple altitudes from 50 to 3000 ft AGL, and finally, if possible, proximity to a large body of water (lake, bay, etc.). According the IAEA (IAEA-TECDOC-1363: Guidelines for radioelement mapping using gamma ray spectrometry data, July 2003: "*Calibration sites for helicopters should ideally be level areas with uniform radioactivity over several hundred meters. For fixed wing aircraft calibration ranges several hundred meters wide and 1 km or greater long should be defined. Ideally, a series of such sites should be defined spanning a range of exposure rates, and representing a mixture of nuclides and photon energy distribution typical of the unknown survey areas . . ..*" AMS selected the length of the calibration line to be sufficient to collect at least 1-min worth of data (60 points assuming 1-sec acquisition time); therefore, considering 70 knots (120 ft/sec) flight speed, the calibration line should be about 1.5 - 2 mi long.

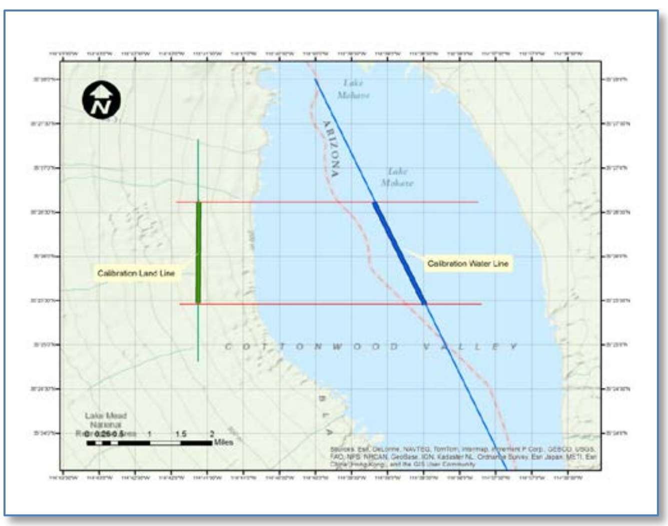


Figure 1 Lake Mohave Calibration Line (LMCL) used by AMS Nellis

An example of a well-characterized calibration line is the Lake Mohave Calibration Line (LMCL) located approximately 0.6 mi (1 kilometer [km]) west of the western shoreline of Lake Mohave, Nevada, and 12.4 mi (20 km) east of Searchlight, Nevada. The LMCL is approximately 2.8 mi (4.6 km) long with elevation variations along the test line between 780 ft (240 m) to 960 ft (290 m) Mean Sea Level (MSL).

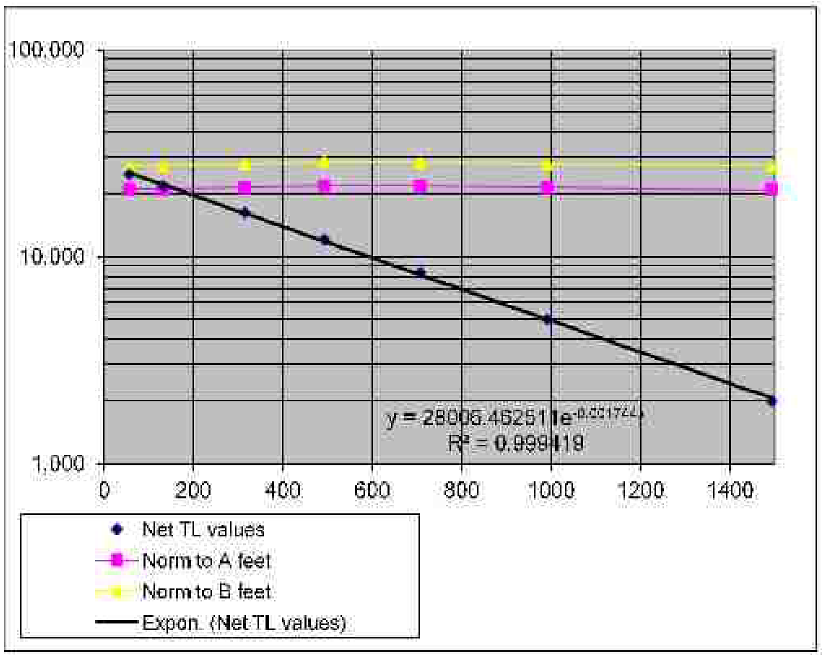
Since 1995, the LMCL has been used by the AMS-Nellis crew (a similar facility exists for use by AMS-Andrews) as an environmental reference standard flight line to monitor and verify the integrity of RSL's AMS acquisition systems.

The LMCL was characterized during an *in situ* radiological measurements campaign in May 1995 that covered a 72,900-square-foot (6,770-square-meter) area. The LMCL characterization is presented in the RSL Report *"Radiological Characterization of the Lake Mohave Test Line"* by Colton and Hendricks (DOE/NV/11718-024, June 1999). A total of one hundred (100) *in situ* measurement locations were examined using three HPGe portable gamma spectrometer systems and two portable pressurized ionization chambers (PICs). Gamma radiation data were collected as an energy spectrum ranging from 10 to 3,000 keV, for a live time collection interval of 600 sec (10 min), and as an integrated total exposure rate (includes terrestrial, cosmic. and radon contributions) in microroentgens per hour (μR/h), respectively. The total exposure rate measurements were integrated over a period of approximately 240 sec (4 min). The PIC and HPGe-estimated results were reported as total external exposure rates and soil concentrations for cesium-137, which is a remnant of worldwide fallout from the early foreign and domestic atmospheric nuclear weapons tests and the naturally occurring radionuclides associated with the uranium, thorium, and potassium decay chains. The total external exposure rates varied from 13 to 16 μR/h at 1m above ground level (AGL), with an average external exposure rate of 14.6 μR/h. A set of PIC measurements were acquired off-shore at the Lake Mohave Cottonwood Cove Marina on a fiberglass bass boat that was positioned approximately 1,000 ft (300 m) from land. The off-shore total exposure rate measurements were integrated over a period of approximately 2,700 sec (45 min). The resulting comparison of these data indicated that the estimated net surface terrestrial exposure rate of the LMCL was 8.5 μR/h (which does not include any cosmic or radon contributions).

From 1995 the LMCL has been used by AMS to derive the local air attenuation coefficient and conversion factors from counts at altitude to ground terrestrial exposure rate. This is accomplished by flying a so-called altitude spiral. The results of a typical altitude spiral are presented in Fig. 2. From the normalized count rate f_a at altitude z_0, the conversion coefficients α are derived using following equation:

$$\alpha = \frac{8.5\ \mu R/h}{f_a}$$

Nominal Altitude (feet)	Average Altitude (feet)	cps at altitude	water cps	net cps at altitude	calc cps at A feet	calc cps at B feet
			Enter desired norm ft		150	0
			Enter alt coeff from fit		0.00174	0.00174
50	55.5	26289	1437	24852	21076	27378
150	133.3	23429	1560	21869	21241	27593
300	314.1	17892	1682	16210	21581	28034
500	493.2	13973	1785	12188	22176	28806
750	707.5	10229	1868	8361	22106	28716
1000	990.9	6937	1932	5005	21693	28179
1500	1494.6	4065	2048	2017	21044	27336
3000	3000	2348	2234	114		
				Average	21559	28006
				Std Dev	465	604



B412 Count Altitude Profile, calibrated at Lake Mojave, RSI system with 12 detectors 2 x4 x16 ", Oct 18 2010

Figure 2 Results of the altitude spiral flight over Lake Mohave

Another example of the calibration line was the line established during the AMS response to the Fukushima NPP accident. The line was established in a moderately contaminated area approximately 50 miles west from the Fukushima Dai-chi Nuclear Power Plant (NPP) (Fig 3).

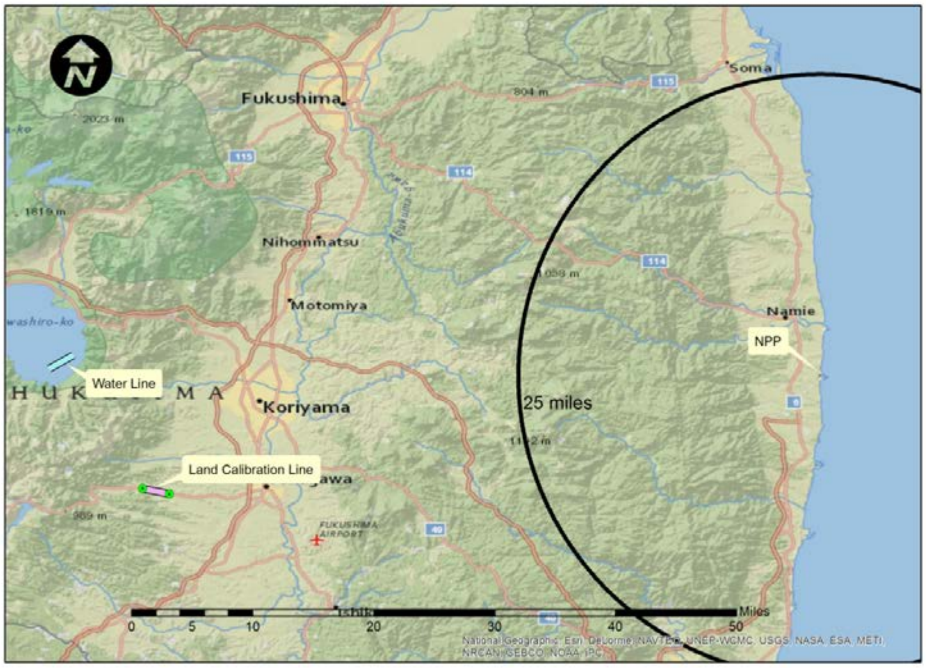


Figure 3 Calibration line used during response to Fukushima NPP accident

The line was a 2-mi long stretch of a road visible from the flight altitudes of 500 and 1000 ft AGL. DOE field teams collected exposure rate data with PIC and gamma ray spectra with mechanically cooled HPGe. This calibration line was used to derive the local air attenuation coefficient by flying the altitude spiral, as well as to derive the conversion coefficient of airborne detector outputs in counts per second to the exposure rates on the ground, or surface activity of selected isotopes. In addition the calibration line was used to normalize data collected from different acquisition systems flown on different aircraft. The process of establishing the calibration line is critical when dealing with contamination by short-lived radioisotopes, when numerical correction can be verified by periodic flights.

Figure 4 Member of the ground team carries ground truth measurements with HPGe in Japan.

Characteristics of the Test Line

The collection of aerial radiological measurements is a very dynamic and complex process. Therefore, according to the IAEA "*Guidelines for radioelement mapping using gamma ray spectrometry data*" *(IAEA-TECDOC-1363, July 2003)*, survey monitoring procedures are designed to ensure that the raw airborne gamma ray spectrometric data acquired during survey operations is of the highest quality. This requires that the airborne gamma ray spectrometer is both adequately calibrated and functioning correctly. According to IAEA, a survey test line is a line flown at the start and at end of each day. The line serves two purposes. First, it serves as a final check on system sensitivity and the radioactivity of the aircraft. Second, it serves to monitor the effect of soil moisture in the survey area. The survey test line should be easy to navigate, have uniform distribution of radioactivity (a nearly constant count rate), and should be flown at an altitude similar in elevation to the area flown during the survey.

An example of the test line is the Government Wash Test Line (GWTL) used by AMS-Nellis during proficiency flights and periodic background surveys in the vicinity of Las Vegas, Nevada. The GWTL is a 2-mi stretch of a dirt road located in the vicinity of Lake Mead, Nevada, in an area called Government Wash. This test line is flown before and after each AMS survey flight for acquisition system quality control and radon normalization. The location of the GWTL is illustrated in Fig. 5.

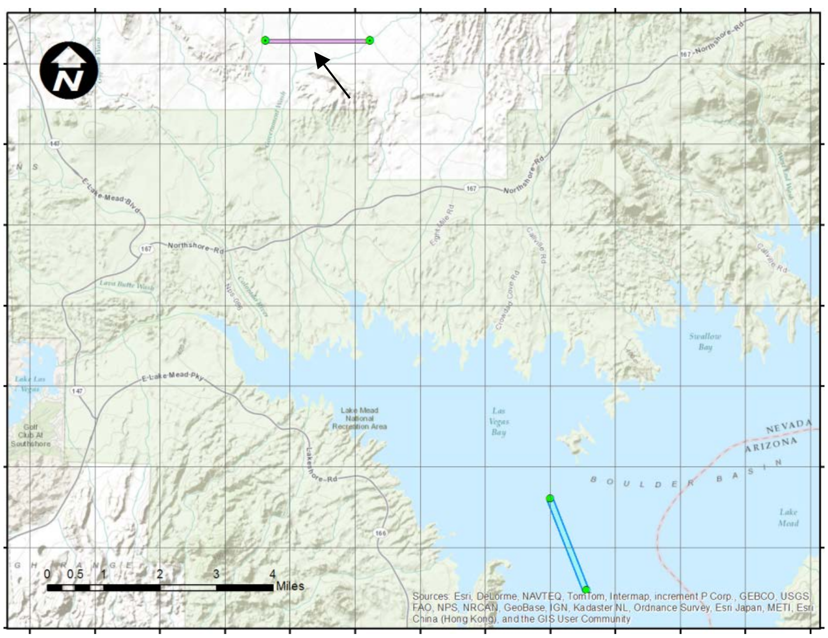


Figure 5 Las Vegas test line at Government Wash

The use of the test line during actual survey flight is shown in Fig. 6, when the test line and water line are flown twice, at the beginning and end of each survey flight at the nominal survey flight altitude.

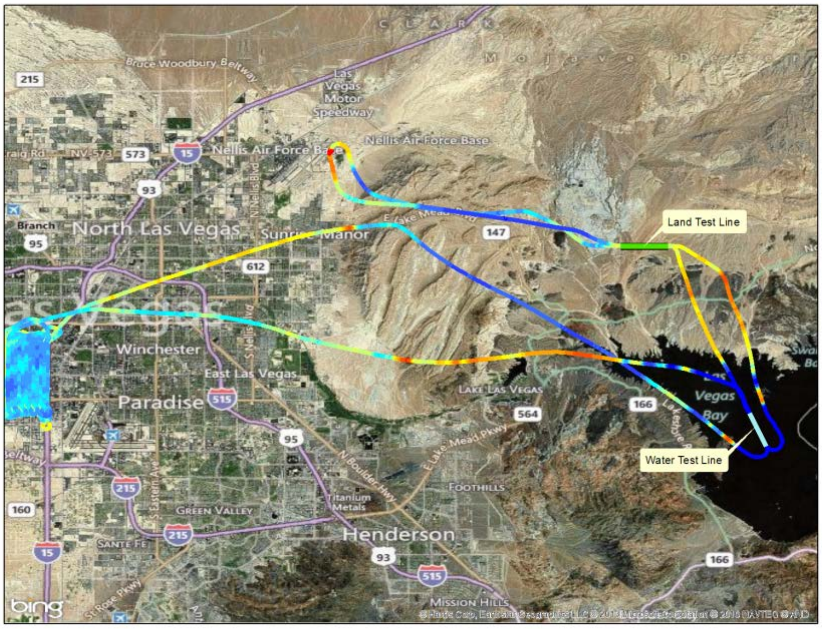


Figure 5 The survey flight with test lines

In Japan, during the Fukushima response, a taxiway at Yokota Air Base was used as the test line. Each aircraft had overflown this test line at the beginning and at the end of survey flight.

Figure 6 Test Line used during Fukushima response

Conclusions

The calibration line and the test line serve different purposes during aerial measurements. The calibration line is used to derive a local conversion coefficient from counts or spectral data collected from the airborne platform to physical quantities on the ground (exposure rate or surface activity of selected isotope) as well as a local air attenuation coefficient. The derivation is based on collecting the ground-based measurements using a method independent of the flying, e.g., use of a PIC or carrying in-situ HPGe spectroscopy. The calibration line should be used as well to derive a local air attenuation coefficient.

The test line is established operationally as a convenient quality check of the aerial acquisition system's in-flight performance. By flying over the test line at the beginning and at the end of each survey flight, the system's stability and impact of the variability of radon levels can be established and verified. This procedure is very important during multi-day or -week surveys.

Appendix A

Guidance for Establishing and Characterizing the AMS Calibration Line

Establishing a field calibration line facilitates ground contamination survey mapping by aerial measuring systems, and is an essential step in creating a quality final product. The calibration line enables the ability to derive local conversion coefficients from measured count rates and spectra to physical quantities on the ground, e.g., exposure rate or surface activity of selected isotopes. The calibration line becomes even more important to normalize acquired data, when several aerial assets are responding to the same emergency, with the goal to create a final merged-data map product.

Ideally the proposed calibration line should be in an area that has previously been surveyed and shown to have relative uniformity of contamination. The area should be approximately 2 mi long by 0.5 mi wide and have distinguishing feature(s) (road, railroad track) for visual recognition for pilots and crew alike. If possible, the line should be located in an unpopulated area, preferably with a large body of water nearby, and contain safe enough radioactivity levels for collection of ground measurements, but high enough for statistically significant aerial data. In the first approximation, it is assumed that the field of view (FOV) of the airborne detector is circular with the radius equal to the flight altitude. Therefore, if we assume that a stretch of a road was selected as the calibration line, the ground measurements would need to be carried out not only on the center of the road (a typical two-lane road is only about 24 ft wide and the FOV of the helicopter flying at 500 ft AGL would be approximately 1,000 ft in diameter), but some distance sideways from it as well, due to characterization changes in the ground coverage between tarmac and vegetation.

The characteristics of a calibration line:

- For helicopters, a 1-mi long calibration line should ideally be in a level area with uniform radioactivity levels over several hundreds of feet in all directions (for a flight at 500 ft AGL, 500-1,000 ft on each side of the line would also need uniformly distributed activity levels).

- For fixed wing aircraft, a much longer calibration line of 2-3 mi, with surrounding terrain characteristics similar to the helicopter calibration line at least 1000 ft on each side should be defined (for a flight at an altitude of 1,000 ft AGL, 1,000-2,000 ft on each site should also be uniformly distributed activity levels).

- The calibration line should represent a mixture of nuclides and photon energy distribution typical of the unknown survey areas.

- The surrounding environment (ground coverage, vegetation) should be similar to the contaminated site.

- In order to characterize an AMS calibration line, a spatially representative measurement or sampling scheme should be used to define the dose rate and/or nuclide-specific activity profiles of the calibration site(s):
    - Collection of 5-min HPGe spectra
    - Collection of 5-min PIC exposure rate measurements

- On the actual calibration line, point measurements should be spatially distributed about 500 ft apart resulting in about 20 data points along the center line of a 2-mi-long calibration line.

- Point measurements can be supplemented by mobile data collected from a detector mounted on a vehicle. Such measurements should be carried out by driving the calibration line at 7 mph (10 ft/sec) assuming 1-sec collection time.

- Additional HPGe and PIC point measurements should be collected at locations about 250 ft to 500 ft on each side of the calibration line, and need to have approximately 1,000 ft spacing between each point.

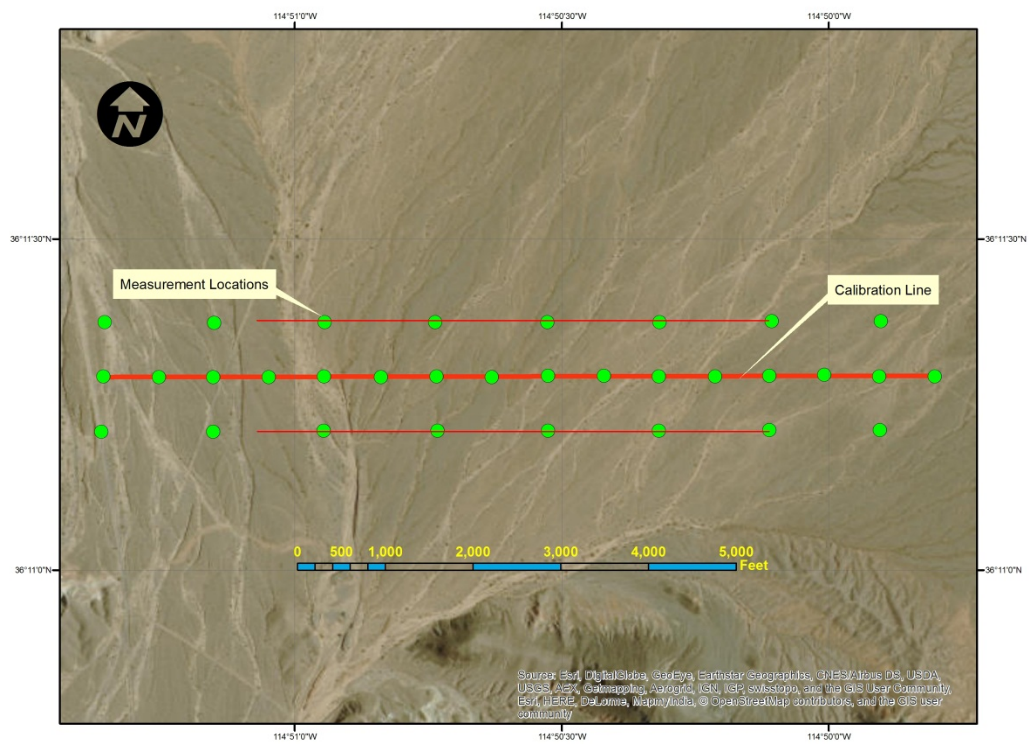


Figure 7 Example of the measurement locations for calibration line characterization

Figure 9 The PIC and HPGe setup for measurements of the calibration line characterization