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AMS / NRCAN JOINT SURVEY REPORT AERIAL CAMPAIGN

Nevada National Security Site January 20–24, 2014

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Abstract

In January 2014 the U.S. Department of Energy (DOE), National Nuclear Security Administration (NNSA) Aerial Measuring System (AMS) and the Natural Resources Canada (NRCan) Nuclear Emergency Response project conducted a series of joint surveys at a number of locations in Nevada including the Nevada National Security Site (NNSS). The goal of this project was to compare the responses of the two agencies' aerial radiation detection systems and data analysis techniques. This test included varied radioactive surface contamination levels and isotopic composition experienced at the NNSS and the differing data processing techniques utilized by the respective teams. Because both teams used the commercial aerial radiation detection systems from Radiation Solutions, Inc., the main focus of the campaign was to investigate the data acquisition techniques, data analysis, and ground-truth verification. The NRCan system consisted of four 4″ × 4″ × 16″ NaI(Tl) scintillator crystals of which two were externally mounted in a modified commercial cargo basket certified for the Eurocopter AS350; the NNSA AMS system consisted of twelve 2″ × 4″ × 16″ NaI(Tl) crystals in externally mounted dedicated pods.

For NRCan, the joint survey provided an opportunity to characterize their system's response to extended sources of various fission products at the NNSS. Since both systems play an important role in their respective countries' national framework of radiological emergency response and are subject to multiple mutual cooperation agreements, it was important for each country to obtain more thorough knowledge of how they would employ these important assets and define the roles that they would each play in an actual response.

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INTRODUCTION

The United States-Canada collaboration in aerial measurements was initiated following the January 24, 1978, crash of COSMOS 954, a Soviet nuclear-powered surveillance satellite, in the Canadian Northwest Territories. The crash scattered a large amount of radioactivity over a 124,000 square kilometer (km^2) area in Canada's North, stretching southward from Great Slave Lake into northern Alberta and Saskatchewan. Teams from both countries, using special radiation sensors, flew over the contaminated area trying to detect and localize parts of the reactor. The effort to recover radioactive material from the satellite reactor was dubbed "Operation Morning Light" (Bristow, 1978) (U.S. DOE Nevada Operations Office, 1978).

Currently, the joint radiological aerial emergency response mission resides in two agencies of the U.S. and Canadian governments. In the United States, the National Nuclear Security Administration (NNSA), an independent semi-autonomous agency within the U.S. Department of Energy (DOE), holds responsibility for the mission. The Canadian government entrusts the mission to the Geological Survey of Canada, a grouping within Natural Resources Canada (NRCan), the ministry of the government of Canada responsible for natural resources, energy, minerals and metals, forests, earth sciences, mapping, and remote sensing.

In June 2012, preliminary discussions about possible Canadian flights over the Nevada National Security Site (NNSS) to measure real man-made contamination were initiated, and in August 2012, NRCan contacted NNSA headquarters regarding the possibility of conducting a common survey using each country's aerial measurement systems. Both of these aerial measurement systems can detect and map ground contamination that may result from a nuclear/radiological accident/incident.

After approval of funding, the planning for the joint survey took place from December 2012 through December 2013, and the actual joint survey was conducted at the NNSS during the week of January 22–24, 2014. NRCan shipped one of their aerial measurement devices from Canada to Sundance Helicopters, a Las Vegas charter helicopter company that operates a fleet of Eurocopter AS350s, one of the helicopter types NRCan uses in Canada for their flights. NRCan then installed their measurement device on one of Sundance's AS350s. The U.S. system, operated by personnel from the Aerial Measuring System (AMS) project and managed by National Security Technologies, LLC (NSTec), for NNSA's Remote Sensing Laboratory, was to be flown on the NNSA Bell 412 helicopter. Such an arrangement was very important, because each team was planning to fly and operate their equipment using configurations and procedures similar to those they would use in an emergency response in their respective countries.

- For both teams, the objectives of this joint survey included:
  To observe each other's aerial measuring processes and exchange ideas.
- To gain familiarity with one another's equipment and processes to be better prepared for collaboration in the case of an eventual joint response to an emergency.
- To compare technologies, procedures, and data analysis techniques.
- To recommend the best procedures and processing method for system calibration.

For NRCan, the survey had an additional purpose:

- Because NRCan does not have access to a dedicated aircraft, the exchange provided an opportunity to further exercise the portability of their system and its field installation on a chartered helicopter, especially in an international deployment with particular logistical challenges.

The common survey provided a unique opportunity for each country to observe and learn much about how the other country conducts aerial measurement missions.

This report provides further information about the actual measurements, data analyses, and comparison of results.

MEASURING SYSTEMS

One advantage of acquiring aerial radiometric measurements lies in the high collection rate of data over large areas and rough terrain. The goal of this process is to achieve 100% area coverage. This is accomplished by collecting measurements in a regular grid pattern generated from parallel flight lines. Flight altitude is kept constant during the measurement flight with typical values recorded between 50 ft (15 m) and 300 ft (91 m) above ground level (AGL). Gamma-ray spectra are recorded in regular time intervals of one second (sec, s), yielding spatial integration over about 30 m of the flight line at a velocity of 70 knots (100–150 km/hr), although optimal speeds depend on many factors. Acquiring spectral data of this type allows separation of natural radioactivity from that of man-made sources and identification of specific isotopes, whether natural or man-made.

For the joint survey, AMS and NRCan both used radiation detection systems from Radiation Solutions Incorporated (RSI), a Canadian corporation specializing in manufacturing aerial radiation detection systems mostly for geophysical research. AMS used a radar altimeter and NRCan used radar and laser altimeters for vertical positioning (altitude over the ground); both organizations used Differential Global Positioning Systems (DGPS) for location.

AMS

AMS used a DOE Bell 412 helicopter (**Figure 1**) and the detection system developed by RSI for NNSA AMS applications (**Figure 2**).

FIGURE 1 **NNSA BELL 412 HELICOPTER DURING SURVEY.**

The AMS RSI system employs a total of 12 thallium-doped sodium iodide NaI(Tl) crystals, as log-type detectors of dimensions 2″ × 4″ × 16″. These detectors are packaged in four RSX-3 units containing three crystals each. An RS-501 aggregator box combines the inputs of each RSX-3/RS-701 unit together and provides a power distribution unit and differential GPS. The four RSX-3 boxes are fitted into the externally-mounted aluminum pods (two RSX-3 per pod) on both the left and right sides of the Bell 412 helicopter.

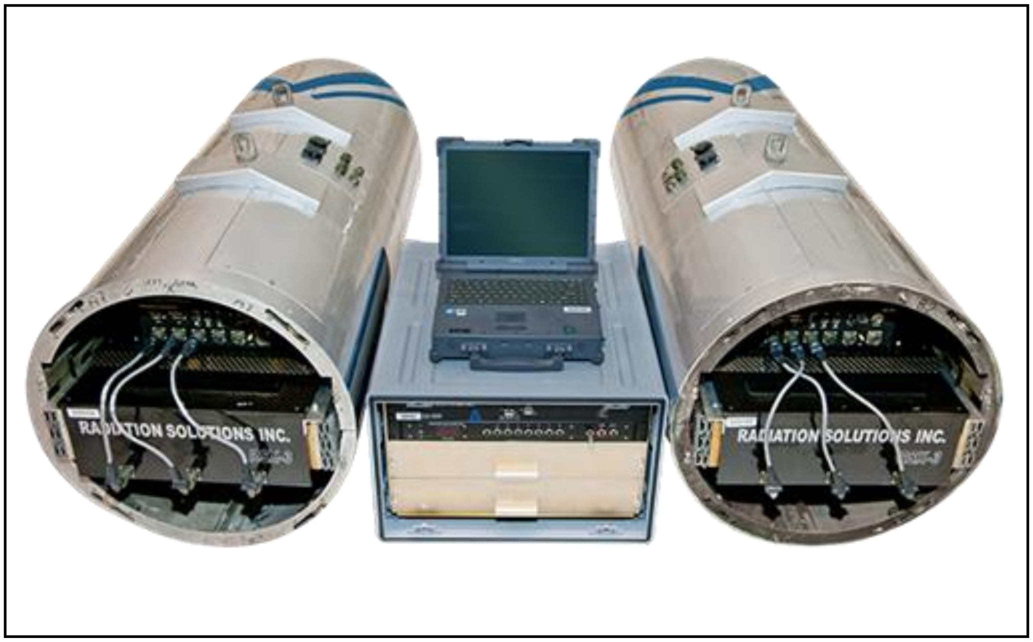

FIGURE 2 **AMS RSI SYSTEM COMPONENTS.**

Each RSX-3 carbon fiber box contains three 2″ × 4″ × 16″ (128 cubic inch or ~2 liter) NaI(Tl) crystals coupled to a photomultiplier tube that produces analog signals for digital analysis by the Advanced Digital Spectrometer (ADS) module. Each individual NaI(Tl) crystal detector has its own high-speed (60 MHz) analog-to-digital converter and a Digital Signal Processor (DSP)/field-programmable gate array assembly **(Figure 3).** This module converts the analog signal from the detector to a digital spectrum with a 10^6 channel resolution.

Using a unique detector energy calibration curve stored in the ADS module, the spectrum is linearized and compressed to the system's native 1024 channels. The high-speed adaptive DSP processing allows each pulse to be corrected, if necessary, without distortion at very high data-throughput rates, up to 250,000 counts per second (cps)/crystal detector, and up to 10/sec data sampling.

The resulting combination of near zero dead time, improved pulse pileup rejection, individual crystal linearization, and accurate detector summation produces exceptionally clean spectra. These spectra are fed by 1Mbps RS-485 data connections to the system RS-701 console. The detector processing unit continuously monitors the state of health of the individual crystals and the system. Each crystal is individually gain-stabilized using a multi-peak approach, effectively eliminating the need for any pre-stabilization with external sources. This makes the unit ideal to handle the wide dynamic range of radiation data seen in airborne applications.

FIGURE 3 **RSX-3 BOX WITH THREE 2″ × 4″ × 16″ NAI(TL) CRYSTALS.**

INTEGRATED CONSOLE (RS-701 CONSOLE)

FIGURE 4 **THE RS-701 CONSOLE ON TOP OF THE RSX-3 DETECTOR BOX.**

Each of the four RSX-3 units is controlled by the RS-701 console mounted on top of the RSX-3 box (**Figure 4**). The console uses RSI proprietary analysis techniques to automatically adjust the gain of the detectors to compensate for changing temperature and aging drift effects. The system uses spectra of natural radioactive isotopes of Uranium (U), Potassium (K), and Thorium (Th) present in all ground material to stabilize the system at startup and maintain this gain automatically during system use with no user input required. The RS-701 console has a built-in GPS receiver. However, as the AMS RSI system integrates multiple RS-701 consoles into the RS-501 aggregator, the built-in GPSs were used only as synchronizing timers and not for positioning.

INTEGRATED CONSOLE (RS-501 AGGREGATOR)

Four RS-701 consoles were integrated into a single RS-501 aggregator, shown in **Figure 5**. The RS-501 aggregator combines the inputs of each RSX-3/RS-701 unit together, and provides a power distribution unit and differential GPS. The RS-501 unit retains 96 15-minute files representing the last 24 hours of data acquisition recorded to a solid-state disk in a 24-hour circular buffer. The RS-501 is then finally interfaced with the laptop PC running the Advanced Visualization and Integration of Data (AVID) software used for system monitoring and real-time data display in flight.

FIGURE 5 **RS-501 AGGREGATOR CONSOLE WITH THE TRIMBLE GPS RECEIVER.**

AVID SOFTWARE

The AVID framework and associated modules were developed, as a joint effort between the Remote Sensing Laboratory (RSL) and the Pacific Northwest National Laboratory (PNNL), for real-time acquisition, visualization, and analysis of radiation data from aerial and mobile detection systems. The AVID software is designed to support both data acquisition and analysis functionality for radiation detection systems. It is extensible and flexible in order to provide for the integration of various modules. Initial releases were developed upon the requirements defined in the AMS Software Modernization Requirements Document in 2010.

Currently, the AVID software and associated modules are focused toward radiation detection instrumentation in support of NNSA mission objectives. The software provides an integration platform that allows developers within the NNSA Emergency Response community to develop modules for incorporation into the AVID software package, thus facilitating the re-use of existing software resources while migrating toward an integrated system approach.

The modularity and flexibility of AVID is reflected in the AVID Launcher (**Figure 6**). The purpose of the Launcher is to load an appropriate set of default settings and limit the number of modules (functions) to what is needed for the task at hand. Each mode will load an AVID configuration geared toward a specific task the user must perform. The Aerial tab contains mode buttons with default settings for the RSI On-Call Response (OCR) Fixed-Wing (FW) and Helicopter (Helo) platforms. These mode buttons contain default settings for viewing RSI detector data in AVID. The Emergency Response Training (ERT) options allow users to set up a virtual detector system that will superimpose simulated sources onto the real measurement data being collected.

FIGURE 6 **AVID LAUNCHER SCREEN.**

The AVID user screen presented in **Figure 7** shows the typical, user-configurable screen layout for the aerial mission. However, this view can be quickly changed according to the mission's needs and the operator's personal preference. The screen in Figure 7 shows the moving map window on the left, spectrum window (top right), strip chart window (bottom right), and waterfall (top far right).

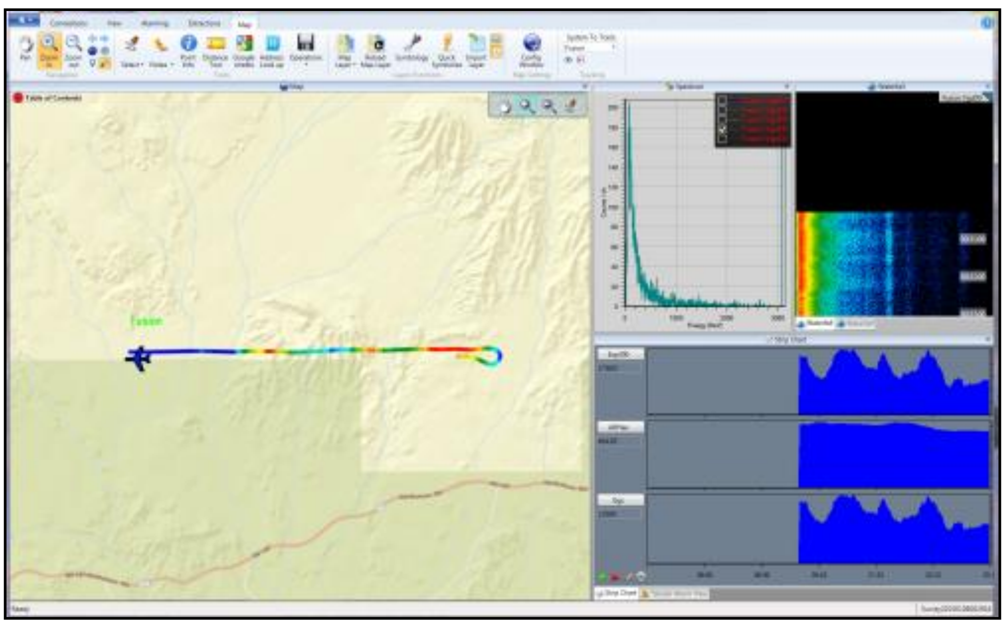

FIGURE 7 **AVID USER SCREEN IN TYPICAL FLIGHT CONFIGURATION.**

AVID saves all the acquired data in the Microsoft SQL Server database, and supports several methods for exporting data to a variety of file formats (N42, CSV, KML, ESRI shape files) for use in other applications. As AVID is a pure acquisition software ("system agnostic"), the RSI RadAssist software (version 5.1) is used to communicate via Ethernet link with the RS-501 aggregator console to configure the virtual detectors and receive and interpret data reliably.
For steering guidance provided to the pilots, AMS uses a commercial system from Trimble shown schematically and during flight in **Figure 8**. The system requires input of the flight area boundary and an "AB line" indicating flight direction. During flight, pilots are guided with the help of the light bar.

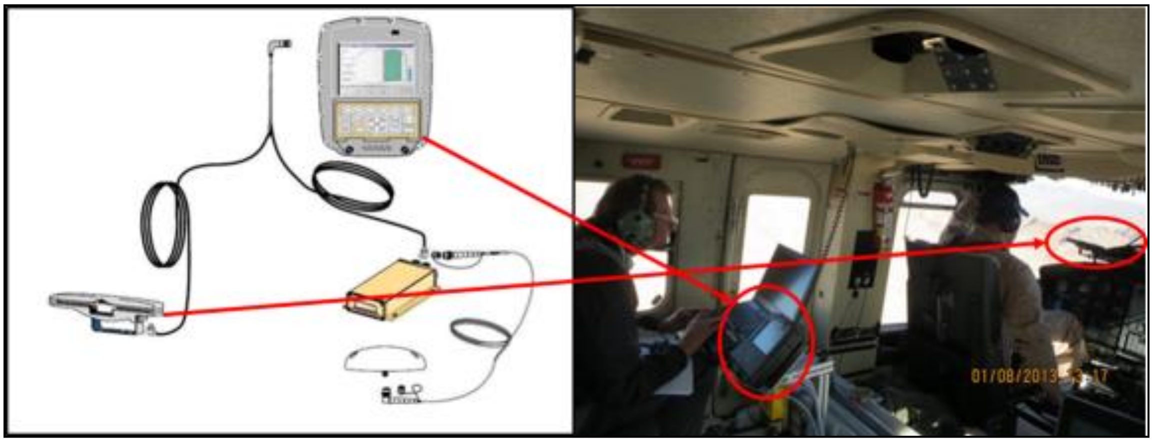

FIGURE 8 **TRIMBLE STEERING SYSTEM IN USE DURING AMS FLIGHT.**

NRCan

Since NRCan's response mission requires the ability to respond quickly to cover any location across a large geographical area and NRCan has no dedicated aircraft, the system design emphasizes aircraft independence and flexibility of configuration and installation. Depending on specific mission requirements and type of aircraft available, several detection system configurations, all based on RSI spectrometers, can be fielded.

For the joint survey, NRCan used a standard RSI Mobile Radiation Monitoring System RS-705 with four RSX-1 4" × 4" × 16" (10 cm x 10 cm x 40 cm) crystals and a single RSN-4 neutron detector. The RS-700 is a self-contained gamma-ray and neutron (optional) radiation detection and monitoring system. It can be used in land vehicles, helicopters, UAVs, or at a fixed location. The system has a built-in GPS receiver to accurately locate each measurement. It is also supplied with the RadAssist survey software program for user control, monitoring, and recording.

Two of the crystals (2 × RSX-1) and associated electronics are mounted inside an externally attachable Dart Aerospace basket shown in **Figure 9**. The "in-line" arrangement maximizes detector surface available for detection.

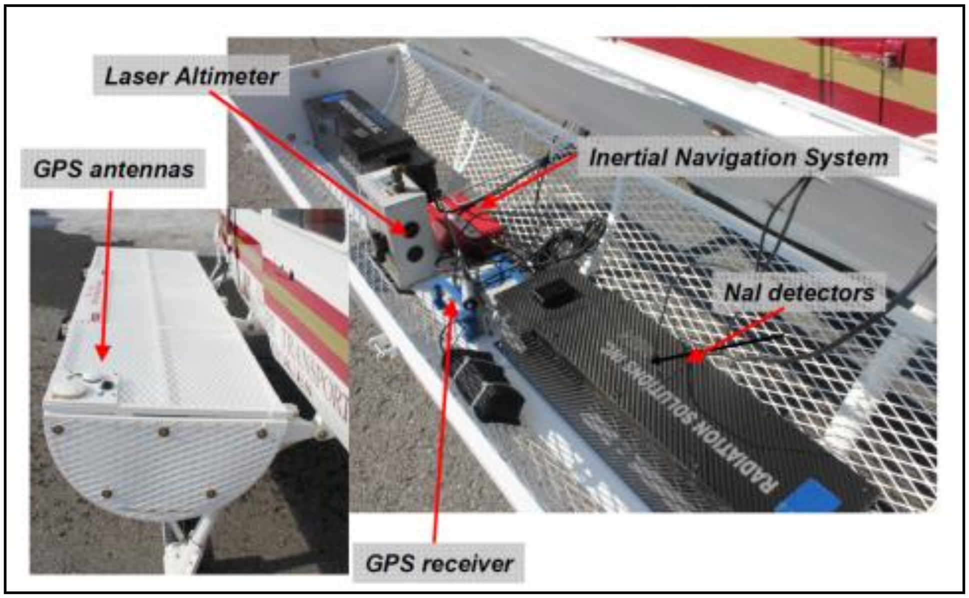

FIGURE 9 **NRCAN RSI DETECTORS AND SUPPORT INSTRUMENTATION: 2 DETECTORS, LASER, RADAR ALTIMETERS AND GYROSCOPES.**

Two additional RSX-1 crystals were mounted inside the aircraft in one of the rear seat positions. The detection system also included an RSN-4 neutron detector located within the aircraft cabin. The RSN-4 consists of four He-3 proportional tubes within a polyethylene moderator case. The read-out electronics for the RSN-4 include features to suppress false signals due to shock or micro-phonics.

The detailed description of RSI technology in the above section on the AMS system is applicable to the NRCan system as well.

The four RSX-1s and the RSN-4 were connected to the RS-705 console (similar to the RS-701 but allowing up to five detectors) mounted inside the helicopter cabin. The system was configured to record separate data elements for the internal and external detectors; this report presents only data from the external detector pair.

The NRCan external basket was mounted on the skid on the left-hand side of a chartered Eurocopter AS350 (**Figure 10** and **Figure 11**). The internally mounted equipment is shown in **Figure 12**.

FIGURE 10 **INSTALLATION OF THE NRCAN SYSTEM ON THE SUNDANCE AS350 HELICOPTER.**

FIGURE 11 **NRCAN BASKET WITH RSI DETECTORS MOUNTED TO THE AS350.**


FIGURE 12 **INTERALLY MOUNTED EQUIPMENT: ON THE BOTTOM TWO RSX-1 CRYSTALS AND RSN-4 NEUTRON DETECTOR; ABOVE THAT, THE BATTERY BOX AND POWER DISTRIBUTION SYSTEM WITH RS-705 CONSOLE ON TOP. THE POWER DISTRIBUTION SYSTEM AND CONTROLLING LAPTOP ARE BARELY VISIBLE BEHIND THE BATTERY BOX AND CONSOLE. EQUIPMENT WAS STRAPPED TO TIE DOWNS IN THE AIRCRAFT.**

In addition to radiation data, during flights NRCan collects supplemental information: GPS positioning using a Novatel DL-V3 receiver with sub-meter precise point positioning accuracy; an inertial navigation system (INS) (Oxford Solutions Inertial+) for cases when the GPS antenna's field of view is obstructed by the helicopter body or during periods of weaker GPS reception and blackouts; a radar altimeter (FreeFlight Systems RA-4500); and a laser altimeter (Riegl LD90-3800VHS-FLP) for the flight altitude measurements. The antennas for the radar altimeter were attached to the skids of the helicopter using a purpose-built set of brackets from Dart Aerospace.

The radar altimeter was connected directly to the RS-705 console and the altitude was sampled at the same data acquisition rate (once per second) as the radiation data. The laser altimeter, however, was configured to acquire data at a rate of 100 Hz to a supplementary laptop. The high rate and narrower field-of-view of the laser allows reconstruction of a more accurate representation of the terrain directly beneath the aircraft during post-processing.

The Novatel GPS and Oxford Systems INS systems were configured for internal recording and their data are available for consolidation with the console-recorded data in post-processing. The RS-705 console GPS system was used for time synchronization and for rough positioning. A second Novatel GPS system was set up as a base station at Las Vegas' McCarran International Airport and later at Desert Rock Airport (DRA) at the NNSS to provide supplemental GPS correction data.

Also connected to the RS-705 console was an air pressure/temperature sensor (Honeywell PPT0020AWN2VA-C). The air pressure and temperature values can be used in post-processing to provide additional constraints on air density and, thus, on gamma attenuation factors.

Power for the equipment was supplied through a power distribution system, built by NRCan, which can take input from the aircraft's power of differing types as well as from batteries to support independence from the aircraft. For these flights, power was supplied from a lithium-iron-sulphate battery (Valence Technologies), exchanged between sorties and recharged.

For pilot steering, the NRCan team uses custom-made flight plans uploaded to a portable aviation GPS unit. This unit is a Garmin 696 mounted with suction cup to the helicopter windscreen during flight to provide the pilot with visual line tracking as shown in **Figure 13**.

FIGURE 13 **GARMIN 696 NAVIGATION UNIT AS USED BY NRCAN BY THE PILOT FOR SURVEY NAVIGATION.**

NRCan used a laptop PC running the RSI RadAssist software for data acquisition and detector performance monitoring in flight. A view of the RadAssist software is presented in **Figure 14** .The operator is able to view the current spectrum, as well as a waterfall plot of the previous few minutes of acquisition. In addition, it is possible to configure the software to calculate in real-time various quantities from the data, such as counts with a given energy region of interest. Such quantities, in addition to being recorded with the data, can be viewed in strip chart format.

Data are recorded both internally in the console, on the laptop in RSI proprietary RSV format, and potentially in N42 format as well. The console stores 24 hours of data from the time of acquisition in 15 minute segments NRCan finds that extracting the data from the console, though slightly more work, provides the most complete and flexible data format for further processing.

FIGURE 14 **RADASSIST DATA VIEW SCREEN.**

DATA EVALUATION METHODS

AMS

AMS uses its own dedicated data processing methodology, developed in-house and incorporated into the AVID framework. The collected spectral data are processed in several steps, starting with the correction of the gross-counts to the nominal flight altitude, and correction for all background components (radon, cosmic, helicopter). These results can be used later for deriving terrestrial exposure rate, extracting man-made activity, and finally extracting individual isotopes. All data are then presented as contour maps using commercial ArcGIS software from ESRI. To match NRCan data analysis, AMS data were corrected for the time shift and projected on the maps in a Universal Transverse Mercator (UTM) coordinated system.

GROSS COUNT

The gross count (GC) extraction method utilizes the integral counting rate in a single spectral window covering the spectral range.

$$GC^{\mathrm{RAW}}{}_{\mathrm{GC}} = \left(\frac{1}{t_{\mathrm{Live}}}\sum_{E=24}^{3026} c(E)\right) \qquad \textbf{EQUATION 1}$$

HEIGHT ATTENUATION COEFFICIENT MEASUREMENT AND CORRECTION

Of greater interest could be the altitude and non-terrestrial background-corrected value of the gross count.

Typical background in that window (assumed constant for a complete flight) is removed and the net count rate is adjusted to the nominal flight altitude by the following relationship:

$$C_{\mathrm{GC}} = \left(\frac{1}{t_{\mathrm{Live}}}\sum_{E=24}^{3026} c(E) - C_{\mathrm{N}}\right) e^{\lambda(H-H_0)} \quad \textbf{EQUATION 2}$$

Where:

- C_{GC} = gross count rate at nominal survey altitude (cps)
- t_{Live} = live time during collection of gamma spectrum (s)
- $c(E)$ = counts in the gamma-ray energy spectrum at the energy E (counts)
- C_{N} = count rate attributable to nonterrestial sources (cps)
- H = actual aircraft (radar measured) altitude (ft or m above ground level)
- H_0 = nominal flight altitude (ft or m)
- λ = gamma ray height attenuation coefficient (ft^{-1}or m^{-1})

The nonterrestrial background count rate, C_{N}, was determined initially from the test line altitude profile and adjusted on a flight-by-flight basis, with contributions from cosmic rays, the aircraft system, and airborne radon. It should be noted that the use of an exponential parameterized by a *height attenuation coefficient* for the altitude dependence of the count rate is an empirical approximation. More correct expressions, which explicitly include geometrical effects, use a form of the exponential integral. See, for example, *Gamma Spectrometry of the Natural Environments and Formations* (Kogan, 1971).

In this document we include a comparison of the corrections, but do not report corrected values. This will be deferred to a later publication. The air attenuation coefficient λ, also determined from the NNSS test line data, was 0.00165 feet^{-1} (0.00541 m^{-1}). AMS derives the height attenuation coefficient from the altitude spiral flown over the test line located in the vicinity of the survey area, so when we flew a survey over Government Wash, AMS used the coefficient derived from the data acquired when flying at the calibration line at Lake Mohave. When AMS flew a survey over NNSS Area 3, we derived the attenuation coefficient from a spiral flown over a test line at NNSS. The values, therefore, are survey location-dependent.

MAN-MADE GROSS COUNT

The aerial data were also used to determine the location of man-made radionuclides. The man-made gross count (MMGC) is the portion of the gross count that is directly attributed to the gamma rays from man-made radionuclides. Evidence of man-made radionuclides is sometimes indicated by obvious increases in the gross count rate. However, slight variations in the gross count do not always indicate the presence of a man-made anomaly, because significant variations can result from geological fluctuations or changes in the ground features (e.g., rivers, dense vegetation, buildings), as well as altitude changes.

An MMGC algorithm has been developed that uses spectral energy extraction techniques to suppress natural variations and improve separation of man-made from natural radioactivity. This algorithm takes advantage of the fact that while background radiation levels often vary by a factor of two or more within a survey area, background spectral shapes remain essentially constant. More specifically, the ratio of natural components in any two regions (windows) of the energy spectrum is nearly constant.

Although this procedure can be applied to any region of the gamma energy spectrum, for general man-made activity, common practice is to place all counts from 38 to 1394 keV into the man-made window (low energy sum), where most of the long-lived, man-made radionuclides emit radiation, and to place all counts from 1394 to 3026 keV into the natural window (high energy sum), where mostly the naturally occurring radionuclides emit radiation. The MMGC rate can be expressed analytically in terms of the integrated count rates in specific gamma energy spectral windows (keV):

$$C_{\mathrm{MM}} = \sum_{E=24}^{1394} c(E) - K_{\mathrm{MM}} \sum_{E=1394}^{3026} c(E) \qquad \text{EQUATION 3}$$

Where:

C_{MM} = MMGC rate at the survey altitude (cps)

$c(E)$ = count rate in the gamma-ray energy spectrum at the energy E (cps)

and

$$K_{\mathrm{MM}} = \frac{\sum_{E=24}^{1394} c_{\mathrm{ref}}(E)}{\sum_{E=1394}^{3026} c_{\mathrm{ref}}(E)} \qquad \text{EQUATION 4}$$

The K_{MM} ratio is of the low-energy counts to high-energy counts in the background spectrum measured over an area that only contains gamma radiation from naturally occurring radionuclides. $c_{\mathrm{ref}}(E)$ represents count rate in the reference gamma-ray energy spectrum at the energy E in cps. This MMGC algorithm is sensitive to low levels of man-made radiation even in the presence of large variations in the natural background. When man-made radioactivity has been identified, a detailed analysis of the gamma energy spectrum is conducted to ascertain which radionuclides are present.

NRCan

For post-processing of the data and map preparation, NRCan uses the program Oasis Montaj (Geosoft Inc.) with the addition of internally authored scripts and add-ons. Geosoft is a processing and mapping program suitable for handling large-volume geoscientific data sets. After initial processing the map data provided from Geosoft can be exported in ESRI data formats for incorporation with base map data and further GIS processing. NRCan data are corrected for the time shift and projected on the maps in a UTM-coordinated system.

For this report NRCan has performed analyses of Gross Count, Attenuation, and MMGC in a similar manner to that described above and presents it in a manner to allow inter-comparison with AMS results.

Data Preparation

Prior to the main operations with the data, some preparatory steps are required to obtain optimal quality. These include verification of location information validity for potential GPS drop outs: typically such data is “dummied” and not used. Radar altitude measurements are usually lightly filtered to smooth noise spikes.

GPS Post-Processing

Although differential GPS data was acquired, for this report the GPS data were taken only from the internal RSI console system.

Altitude Measurements

For this initial report altitude data were taken from the radar altimeter.

Gross Count

NRCan's procedure for gross count calculation and correction is very similar to that used by AMS. The procedure involves the summing of all the counts in the spectrum, subtracting non-terrestrial components and levelling to a reference altitude using an exponential approximation of the attenuation process as expressed in Equation 1. There is a slight variation in the selection of the energy range. NRCan uses [24-3042] keV rather than the [24-3026] keV used by AMS. This is done for consistency with the energy range that RSI uses for their dose rate calculation. Non-terrestrial backgrounds are subtracted as a function of altitude using a linear fit to data collected over water.

Man-Made Gross Count

To allow direct comparison of results between the two organizations, NRCan reports the MMGC using the same form as AMS.

NRCan evaluated K_{MM} in a number of areas believed to be free of man-made activity. Mean values ranged between 19.6 and 23.5. For the maps in this report a value of 21.5 was used.

Gridding (Contouring)

Contouring, or more precisely in NRCan's terminology Gridding, is performed with Oasis Montaj. Various gridding algorithms are available within this system; NRCan generally uses a Minimum Curvature algorithm (Briggs, 1974). As a rule of thumb the cell size used in the gridding calculation is set to one-half of the flight line spacing, and the data is extrapolated to a distance of two cell-sizes from the closest measured point.

Color Scales

On the NRCan maps, color scales were chosen so as to optimize comparison with the AMS maps. Since this NRCan data analysis uses two crystals compared to the AMS 12 crystal system, gross count or man-made gross count scales had to be translated between the AMS color choice and that used on NRCan maps. This was done by taking the count range assigned to each color from each of the AMS maps and calculating the fraction with respect to their respective minimums and maximums. These fractions were then mapped to the count range covered by the corresponding NRCan map.

Organization of the Campaign

Description of Survey Sites

Government Wash

The Government Wash site is located 10 miles (16 km) north from RSL and is characterized by varied geology. AMS has been using it for evaluation of responses of aerial acquisition systems to varied natural background (see **Figure 15**). The survey area covers a little over 3 square miles (8 km^2).

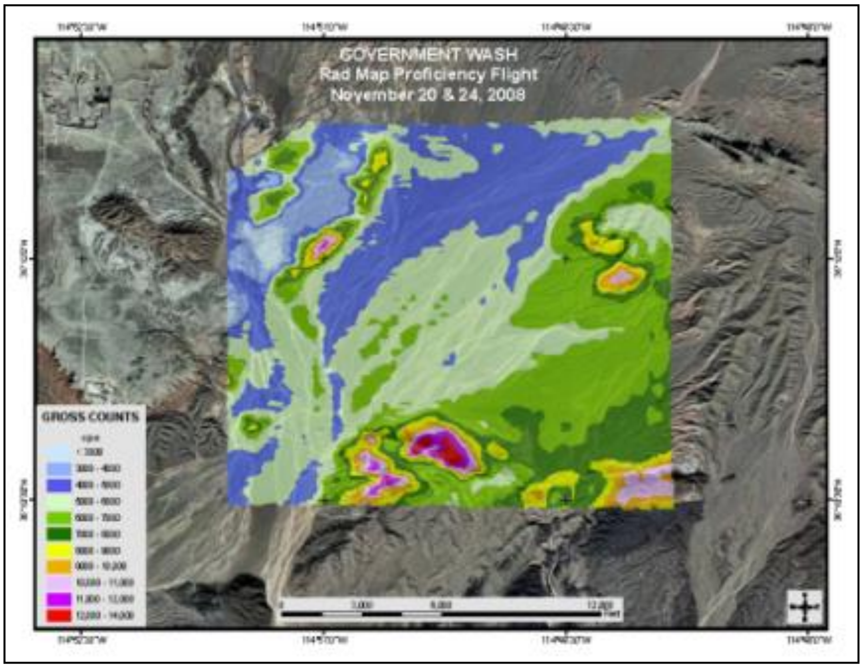

FIGURE 15 **RADIATION GROSS COUNTS CONTOUR MAP OF NATURAL BACKGROUND AT GOVERNMENT WASH SITE FROM EARLIER AMS SURVEY DATA.**

LAKE MOHAVE CALIBRATION RANGE

Since 1995, the Lake Mohave Calibration Range (LMCR) has been used by the AMS-Nellis crew as an environmental reference standard flight line to monitor and verify the integrity of AMS acquisition systems. The LMCR is located approximately 0.6 mi (1 km) west of the western shoreline of Lake Mohave, Nevada, and 12.4 mi (20 km) east of Searchlight, Nevada (**Figure 16**). The land calibration line at LMCR 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).

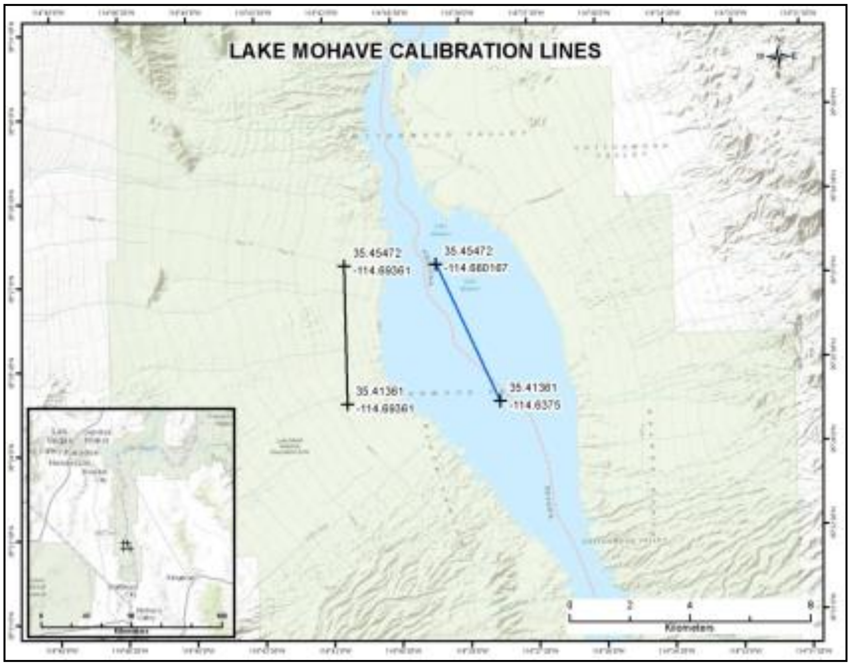

FIGURE 16 **THE LAND AND WATER CALIBRATION LINES AT THE LAKE MOHAVE CALIBRATION RANGE.**

Nevada National Security Site

Starting in January 1951, the Nevada Test Site (NTS) became the primary U.S. site for testing nuclear weapons and for studying their effects on structures and military equipment. The NTS is located approximately 65 mi (105 km) northwest of Las Vegas. It covers an approximately ~1,350 mi^2 (~3500 km^2) area. The elevation above MSL ranges from ~2,690 ft (~809 m) to ~7,680 ft (~2340 m). The site has been renamed the Nevada National Security Site (NNSS).
Four test sites areas were flown:

Area 3 was the location of several tests. In the southern portion, Fizeau was detonated on a tower on September 14, 1957, with a yield of 11 kt. The central portion hosted two tests conducted from towers: Harry (May 19, 1953; 32 kt) and Hornet (March 12, 1955; 4 kt). Also in this immediate area were two other test locations: Coulomb-A (July 1, 1957; 0 kt), a safety experiment conducted at ground level, and Rio Arriba (October 18, 1958; 0.09kt) on a tower. The AMS 1994 (Hendricks & Riedhauser, 1999) survey located five regions of man-made activity. The three main test areas all contained ^{60}Co, ^{137}Cs, ^{152}Eu, and ^{241}Am.

Area 11 (Pu Valley) is the site of four safety experiments that occurred during November 1955 through January 1956. The four safety experiment locations have identifiable amounts of ^{241}Am.

Area 8 and 10 is the location of the Sedan test. Sedan was a Plowshare test conducted on July 6, 1962, with a yield of 104 kt. This excavation experiment created a crater with a depth of 98 meters and a diameter of 390 meters. The test resulted in the release of radioactivity that was detected off-site. The spectrum of this region contained ^{60}Co, ^{65}Zn, and ^{137}Cs.

Area 30 is the location of the Buggy test, which included simultaneous detonations on March 12, 1968, as part of the Plowshare program. The purpose of the test was to assess the ability to carve a channel through the ground using nuclear devices. Each of the five devices produced a published yield of 1.08 kt. As at the Sedan location, the identified isotopes at Area 30 were ^{60}Co, ^{137}Cs, ^{241}Am. This area was of particular interest for its topography with the test having taken place on a plateau surrounded by deep canyons.

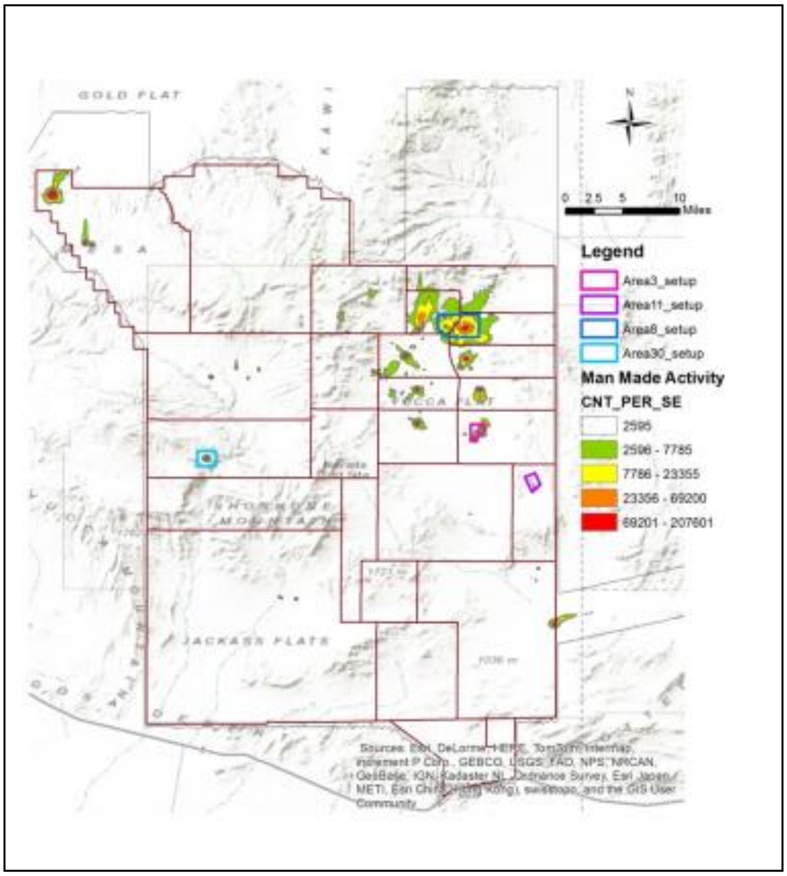

FIGURE 17 **LOCATIONS OF THE SURVEY AREAS AT THE NNSS.**

Historical operations in these areas resulted in contamination consistent with that of a nuclear/radiological accident/incident with different types and amounts of dispersed radioactive materials. The relative locations of the four areas at the NTS are presented in **Figure 17**. The contours of man-made activity presented in **Figure 17** are derived from the aerial survey of the entire NNSS carried out by AMS in 1994. The 1994 survey was flown at an altitude of 200 ft (60 m) AGL, flight line spacing of 500 ft (150 m), and an aircraft speed of 75 knots (39 m/s).

For the AMS/NRCan joint survey the planned flight parameters included flight altitude of 150 ft (46 m) AGL. AMS chose a line spacing of 300 ft (91 m) and an aircraft speed of 36m/s (70 knots), except for Area 11 where an altitude of 50 ft (15 m) and line spacing of 100 ft (30 m) were planned. NRCan chose different flight speeds and line spacing motivated by aircraft and detector system differences: 20 m/s, and 50 m (but 25 m for Area 11).

Actual flight parameters did differ from the planned one to some extent. The actual values are indicated with the result maps in the following sections.

The survey areas selected for the joint survey provided a variety of radionuclides in the ground contamination, which created a test bed for both teams to carry out spectral analyses of collected data.

Source Overflight at Desert Rock Airport

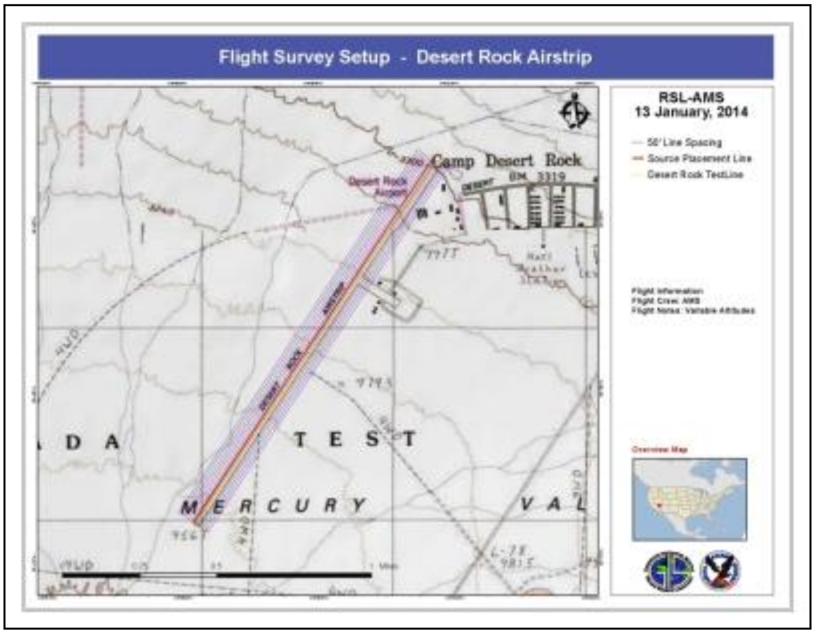

FIGURE 18 **SETUP FOR SOURCE OVERFLIGHT AT DRA**

To investigate the response of the AMS and NRCan systems and radiological anomaly detection techniques, radioactive sources listed in **Table 1** were placed every 1,000 ft (~300 m) along the runway at Desert Rock Airport (DRA). DRA is a private-use airport located 3 mi (5 km) southwest of Mercury, in Nye County, Nevada, United States. The airport is located on the Nevada National Security Site and is owned by the U.S. Department of Energy.

TABLE 1 **LIST OF RADIOACTIVE SOURCES USED DURING THE DRA OVERFLIGHTS**

Source	Number of Each	Activity(mCi)	Activity (MBq)	HazCode
Am-241	2	9.45 9.37	350.0 347.0	2 2
Ba-133	1	8.07×10^{-2}	2.99	2
Co-60	2	1.63 3.33	60.3 123.0	3 3
Cs-137	1	24.4	902.0	4

The planned flights included flying directly over the sources at different altitudes and flying offset lines from the center line as shown in **Figure 18**.

Joint Survey Activity Plan

Planning for the joint survey required coordination of two helicopters flying over test ranges and several contaminated sites at the NNSS: the Sundance AS350 with the NRCan equipment and operator, and the DOE Bell 412 with the AMS equipment and operator. The operations plan included flights over the AMS calibration ranges at Government Wash and Lake Mohave, and survey flights over Areas 3, 8, 11, and 30 at the NNSS. The Sundance AS350 was taking off from its base at Las Vegas' McCarran Airport and the DOE Bell 412 from Nellis Air Force Base. The flights' area logistics were scheduled in a way to assure proper separation between the helicopters during flight operations. The last day of the exchange was dedicated to discussions of the results and plans for future cooperation.

The detailed activity plan for the survey week is presented in Appendix B.

RESULTS

ATTENUATION AND SENSITIVITY

LAKE MOHAVE CALIBRATION RANGE

The flights over the calibration line at the Lake Mohave Calibration Range were used to verify system's sensitivity and response to natural background radiation. Different altitudes were used in the AMS and NRCan studies.

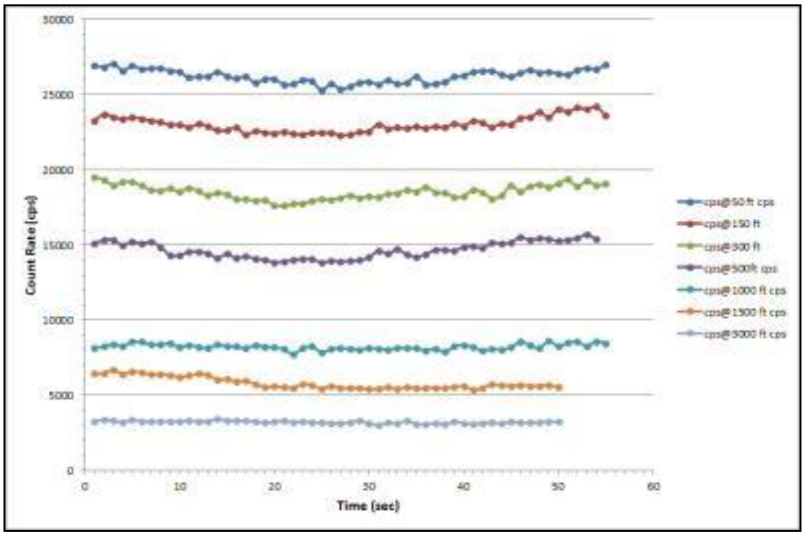

FIGURE 19 **NET COUNT RATE TIME SERIES OVER THE LAND CALIBRATION LINE FOR THE AMS SYSTEM.**

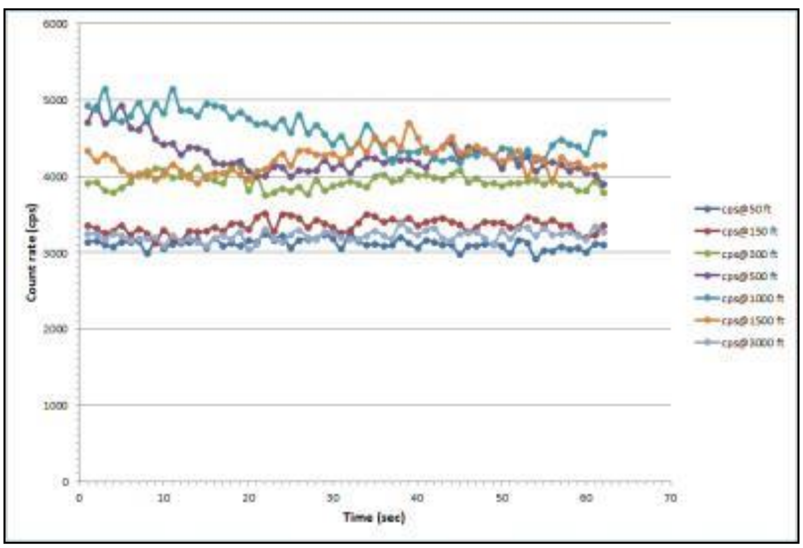

FIGURE 20 **COUNT RATE TIME SERIES OVER THE WATER LINE FOR THE AMS SYSTEM.**

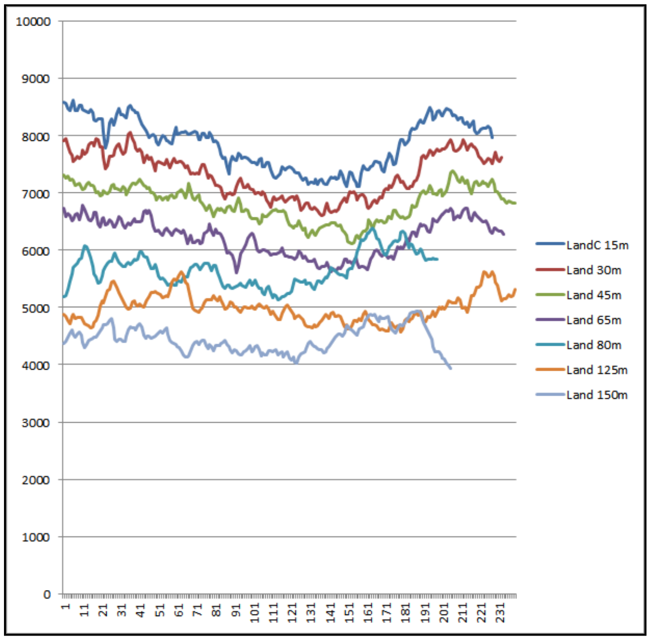

FIGURE 21 **COUNT RATE TIME SERIES OVER THE LAND LINE FOR THE NRCAN SYSTEM. THE X AXIS SHOWS THE TIME ALONG THE SURVEY LINE IN SECONDS. THE LARGER VARIATION IN THE COUNT RATE FROM SAMPLE TO SAMPLE REFLECTS THE SMALLER ACTIVE DETECTOR VOLUME USED FOR THE NRCAN SYSTEM.**

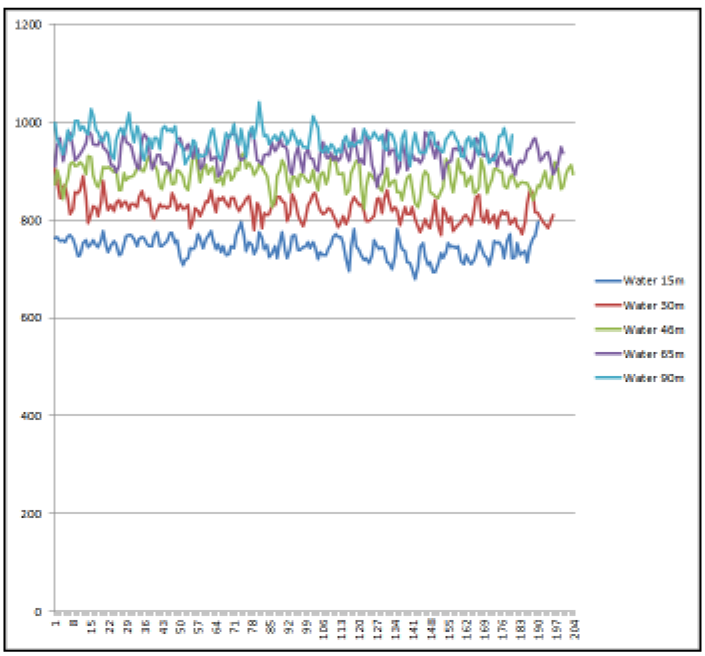

FIGURE 22 **COUNT RATE TIME SERIES OVER THE WATER LINE FOR THE NRCAN SYSTEM. THE X AXIS SHOWS THE TIME ALONG THE SURVEY LINE IN SECONDS.**

TABLE 2 **AVERAGE COUNT RATES FROM AMS AND NRCAN DETECTORS AT THE CALIBRATION LINE.**

Altitude nominal (actual) AMS (feet AGL)	AMS Twelve 2”×4”×16” detectors		Altitude NRCan	NRCan Two 4”×4”×16” detectors	
	Land (cps)	Water (cps)		Land (cps)	Water (cps)
50 (57)	25602± 47	2868 ± 7	15m (45 ft)	7868 ± 20	743 ± 1
150 (144)	22840 ± 35	3191 ± 8	30m (100 ft)	7326 ± 18	821 ± 1
300 (256)	19662 ± 68	3568 ± 8	45m (150 ft)	6813 ± 14	887 ± 1
500 (475)	14958 ± 79	3853 ± 9	65m (215 ft)	6221 ± 15	934 ± 1
1000 (957)	8567 ± 17	4093 ± 10	80m (260 ft)	5673 ± 11	962 ± 1
1500 (1515)	5330 ± 30	3821 ± 9	125 m (410 ft)	5014 ± 11	1038 ± 1
3000 (n/a)	2916 ± 11	2934 ± 8	150 m (490 ft)	4448 ± 11	NA

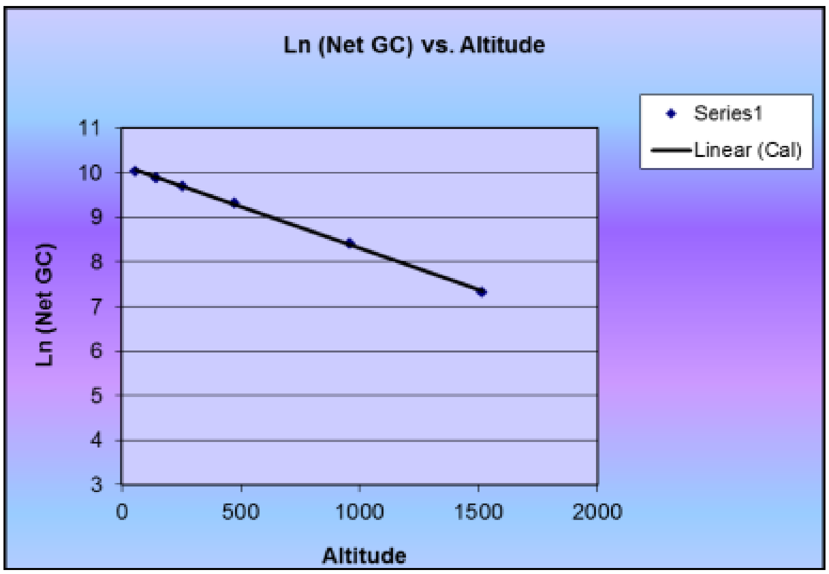

FIGURE 23 **AMS RESULTS OF ALTITUDE SPIRAL OVER LAKE MOHAVE CALIBRATION RANGE. PLOTTED AS LOG OF NET GC.**

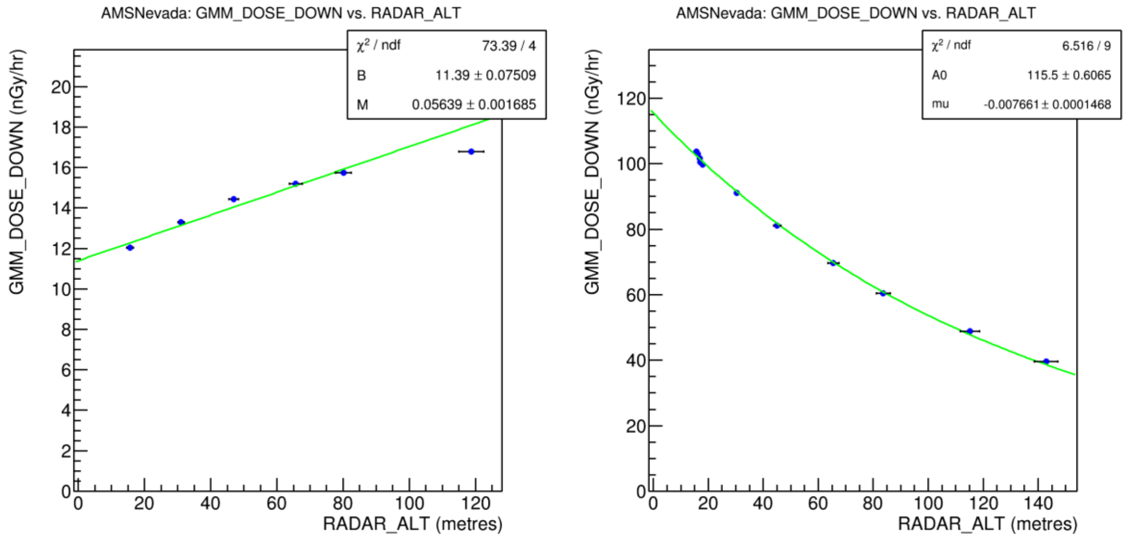

FIGURE 24 **NRCAN RESULTS OF ALTITUDE SPIRAL OVER LAKE MOHAVE CALIBRATION RANGE. LEFT PLOT SHOWS DATA ACQUIRED OVER WATER, RIGHT PLOT DATA ACQUIRED OVER LAND. PLOTTED AS GC (LINEAR SCALE)**

From the average count rates recorded for the approximately 60-second flight over the calibration line, the AMS 12-log system count rate shows (Table 2 and Figure 23) an exponential dependence on altitude consistent with the empirical model of (Equation 1). The 3 parameter iterative χ^2 fit to the net count data yielded local height attenuation coefficient of 0.00175 ft^{-1} (0.00574 m^{-1}).

For the NRCan data (**Figure 24**) nonterrestrial background (NTB) is determined by a linear fit to the data acquired over water. To then calculate the effective air attenuation factor, the NTB is subtracted point by point from the data acquired over land, and the resulting data points fit to a decreasing exponential function.

Effective air attenuation coefficient calculated from the NRCan data was 0.006±0.001 m^{-1}. This compares very well with the AMS measured value of 0.00175 ft^{-1}, i.e., 0.00574 m^{-1}.

Scaling Factor

The count rate is mainly directed by the system sensitivity. As indicated in **Table 2**, the AMS system records more counts per second (higher sensitivity) than NRCan does. As the AMS and NRCan flew at different altitudes over the lake Mohave calibration line, only in two cases was the direct ratio between count rates derived. These can be seen in **Table 3**.

TABLE 3 **SENSITIVITY DIFFERENCE BETWEEN AMS AND NRCAN DETECTORS AT THE CALIBRATION LINE.**

Altitude	AMS Net Counts	NRCan Net Counts	Count Ratio
150 ft	19649	5926	3.3
50 ft	22734	7125	3.2

The “theoretical” count rate ratio of three derived from the difference in the systems’ volumes (1536 cubic inches for AMS and 512 cubic inches for NRCan) is very close to the counts ratios measured at Lake Mohave.

Source Overfly at Desert Rock Airport

AMS RESULTS

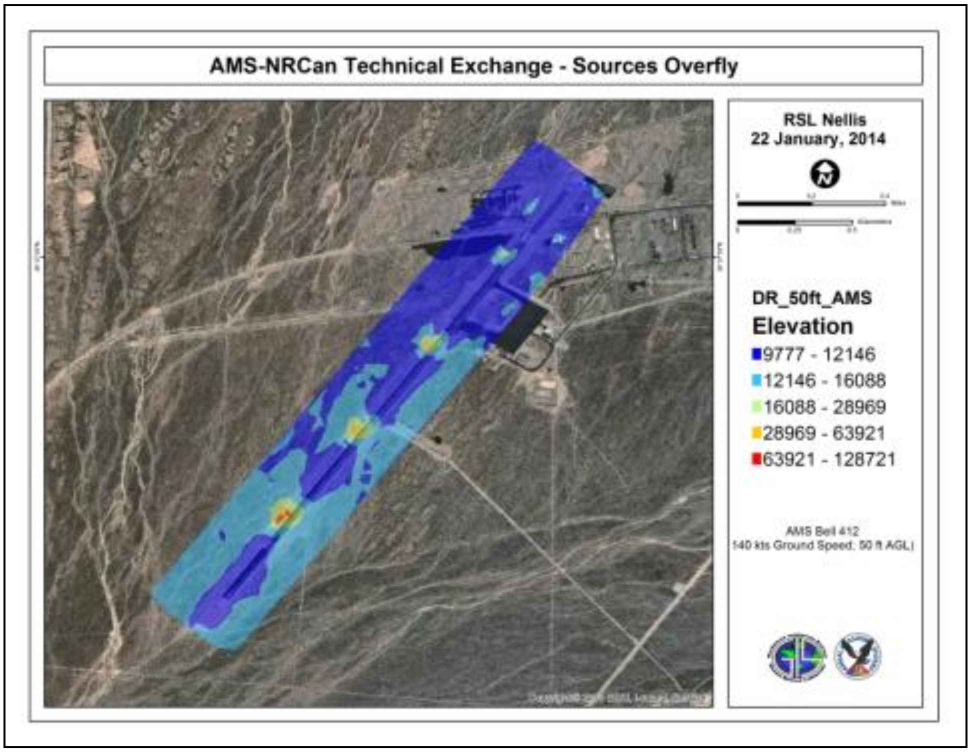

FIGURE 25 **AMS RESULTS OF SOURCES OVERFLY AT DESERT ROCK AIRPORT AT 50 FT AGL.**

The four sources listed in **Table 1**, and placed every 1500 ft (460 m) along the runway of the Desert Rock Airport, were overflown at 50 ft (15 m) AGL, 100 ft (30 m) AGL, and 150 ft (46 m) AGL with the line spacing of 100 ft (30 m). The AMS 12-log system detected all sources at 50 ft (15 m) AGL; however, only ^{137}Cs, ^{60}Co, and ^{133}Ba were detected at 100 and 150 ft (30 and 46 m) AGL. The results of the source overfly will be used by each team to confirm their respective minimum detectable activity.

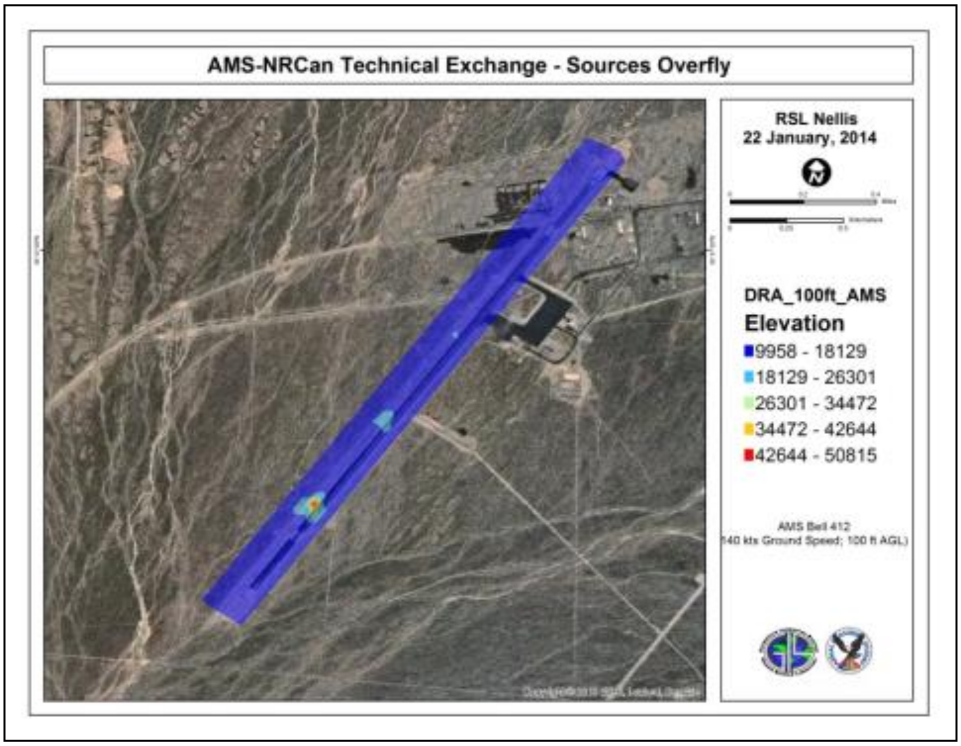

FIGURE 26 **AMS RESULTS OF SOURCES OVERFLY AT DESERT ROCK AIRPORT AT 100 FT AGL.**

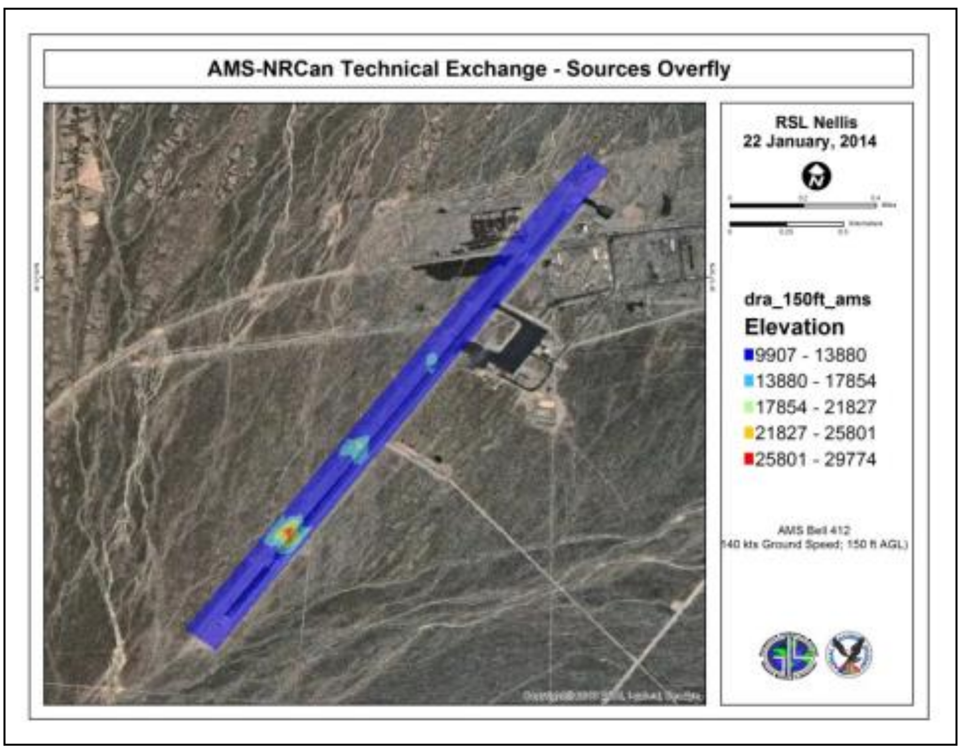

FIGURE 27 **AMS RESULTS OF SOURCES OVERFLY AT DESERT ROCK AIRPORT AT 150 FT AGL.**

NRCan Results

The NRCan 2-log system detected all sources at 50 ft (15 m) AGL; however, only ^{137}Cs, ^{60}Co, and ^{133}Ba were detected at 100 and 150 ft (30 and 46 m) AGL. These results qualitatively indicated a reasonable level of sensitivity with respect to the 12-log AMS system. NRCan results are shown as a "breadcrumb" trail from a single pass rather than a gridded result.

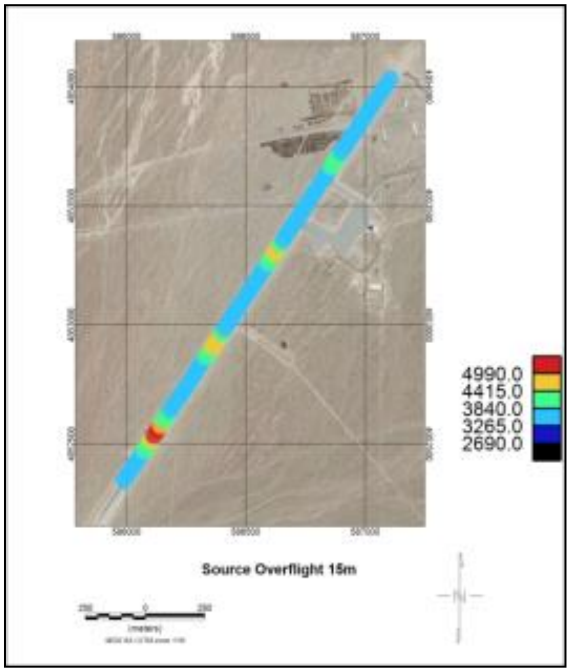

FIGURE 28 **NRCAN GROSS-COUNT RESULT FOR THE 15 M (~50 FT) OVERFLIGHT.**

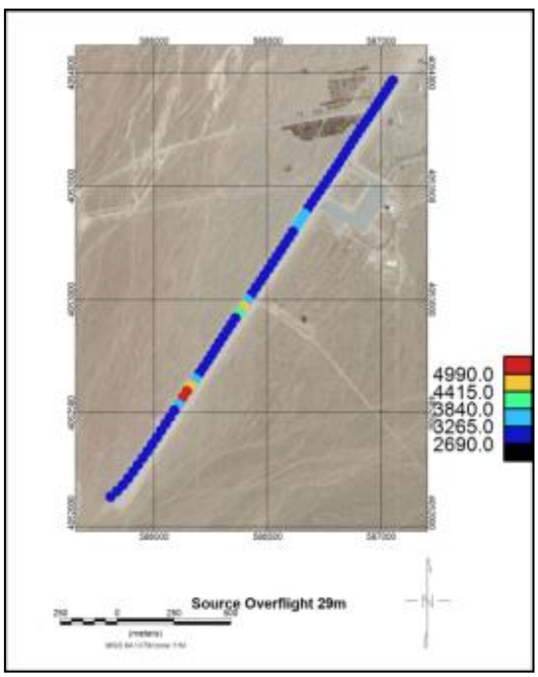

FIGURE 29 **GROSS-COUNT RESULT FOR THE 30 M (~100FT) OVERFLIGHT.**

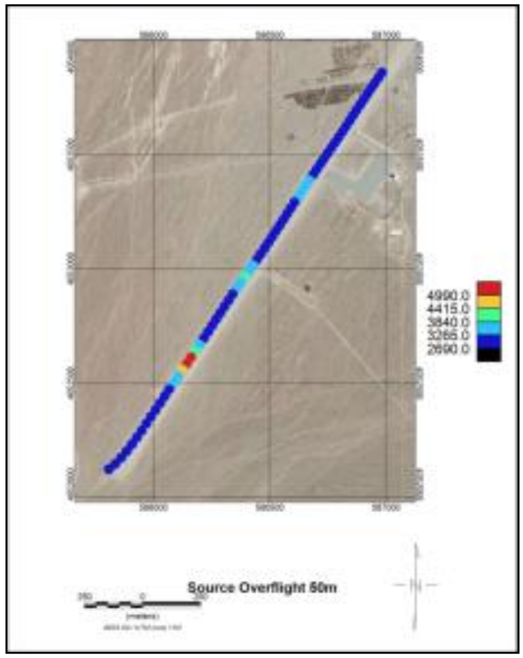

FIGURE 30 **TOTAL COUNT RESULT FOR THE 50M (~150FT) OVERFLIGHT.**

CONTOURS

NATURAL BACKGROUND CONTOURS

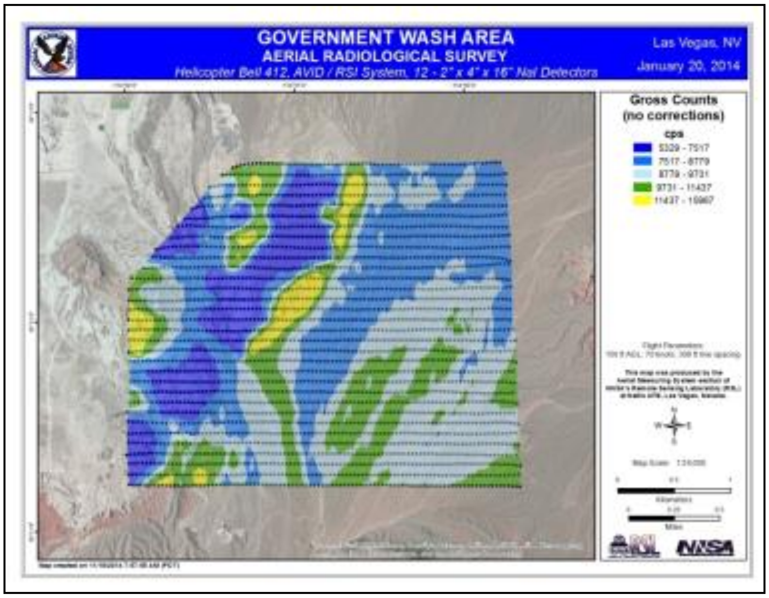

FIGURE 31 **GROSS-COUNT CONTOUR OF THE NATURAL BACKGROUND AREA (GOVERNMENT WASH) CREATED USING THE AMS DETECTION SYSTEM AND AMS PROCESSING TECHNIQUES (2014-01-20 PM).**

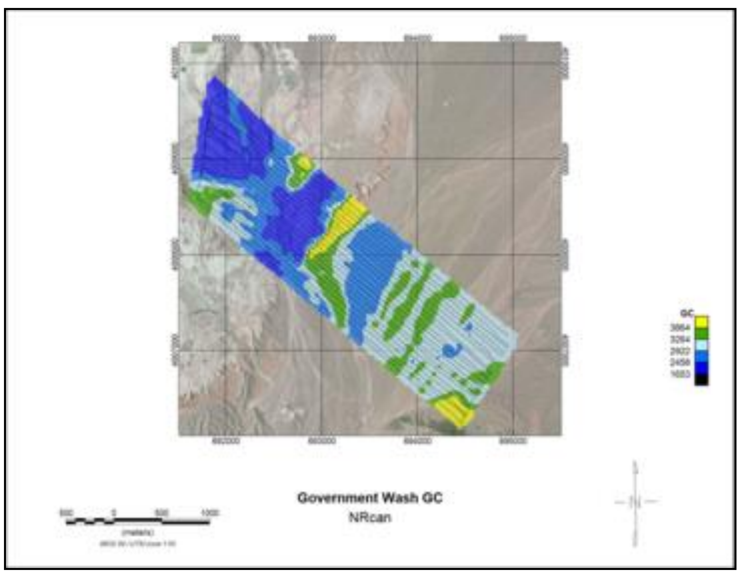

FIGURE 32 **GROSS-COUNT CONTOUR OF THE NATURAL BACKGROUND AREA (GOVERNMENT WASH) CREATED USING NRCAN DETECTION SYSTEM, FLIGHT PARAMETERS, AND NRCAN DATA PROCESSING TECHNIQUES (2014-01-20 AM).**

The NRCan survey was conducted with a 24 m altitude (versus 46 m AMS), 50 m/s speed, and 50 m line spacing. With these parameters it was possible only to cover a smaller area in the time available. Comparison of the two maps shows very similar relative response.

CONTOURS FROM NNSS Area 3

NNSS Area 3 is contaminated with mixed fission products (^{137}Cs, ^{60}Co, ^{152}Eu). Contours were created using the man-made region-of-interest (ROI) algorithm described earlier.

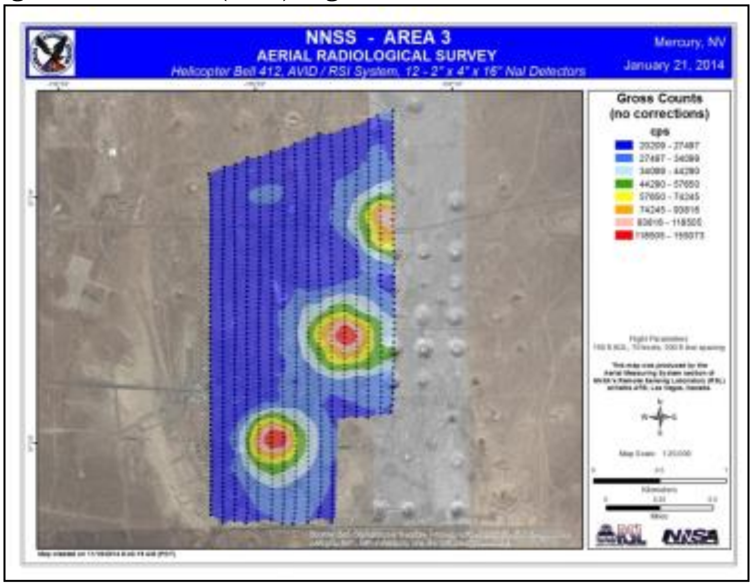

FIGURE 33 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 3 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES. FLIGHT LINES ARE SUPERIMPOSED ON THIS PICTURE. (2014-01-21 PM).**

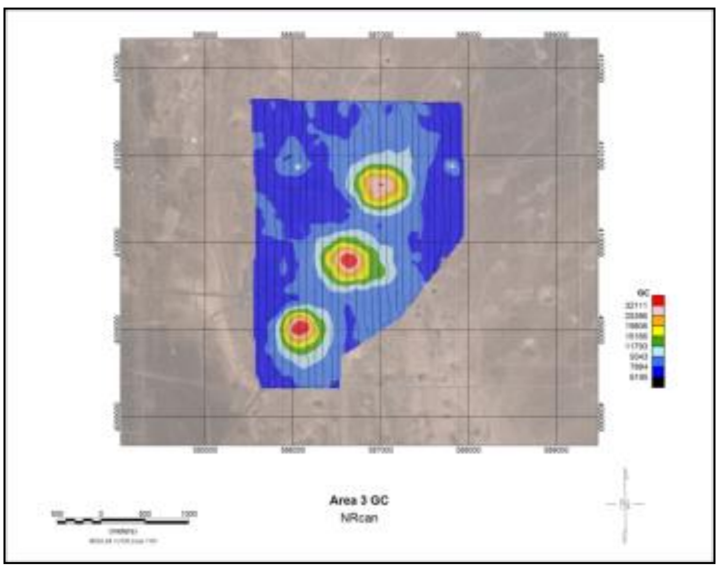

FIGURE 34 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 3 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES. FLIGHT LINES ARE SUPERIMPOSED ON THIS PICTURE. (2014-01-21 AM)**

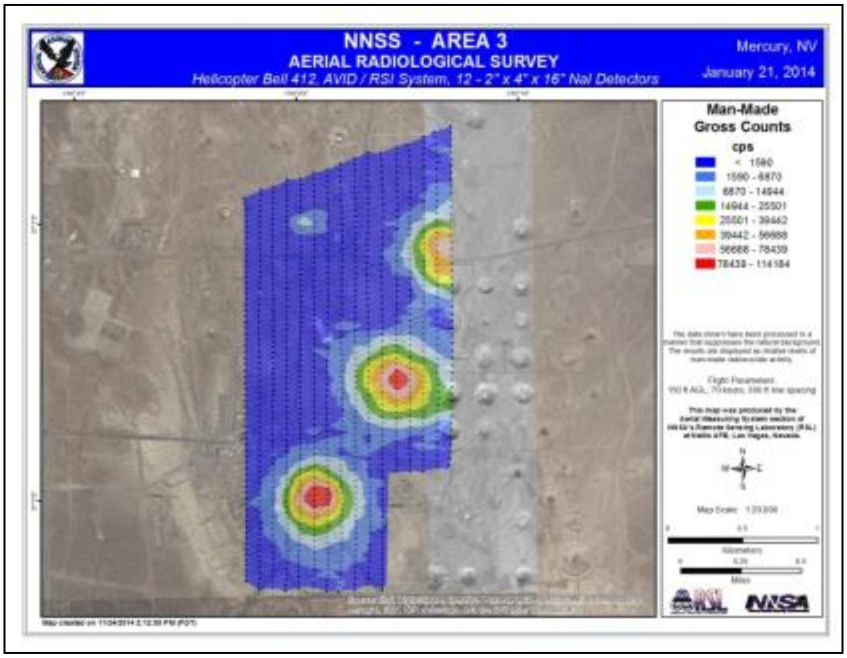

FIGURE 35 **CONTOUR OF MAN-MADE ACTIVITY FROM AREA 3 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES.**

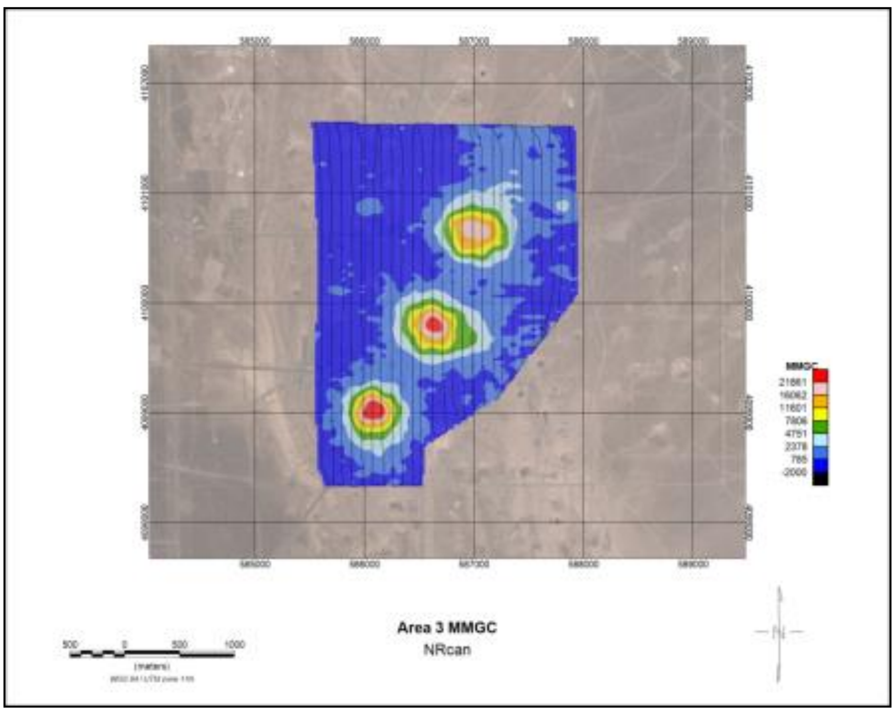

FIGURE 36 **CONTOUR OF MAN-MADE ACTIVITY FROM NNSS AREA 3 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES**

Actual acquisition parameters for the NRCan survey were mean altitude 48 m, mean speed 21 m/s and line spacing 50 m. Differences in available flight time resulted in the difference in coverage between the AMS and NRCan data.

CONTOURS FROM NNSS AREA 8

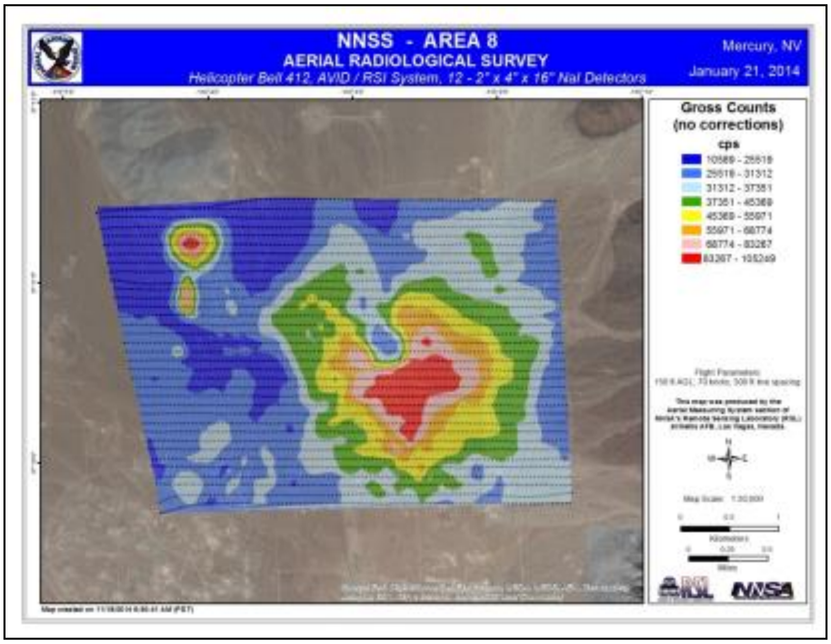

FIGURE 37 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 8 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES (2014-01-21 AM)**

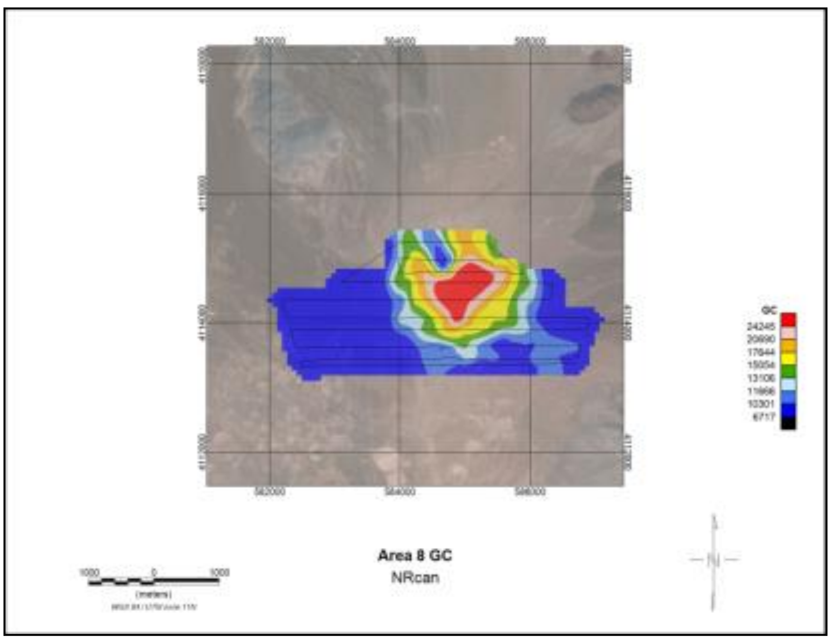

FIGURE 38 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 8 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES (2014-01-21 PM)**

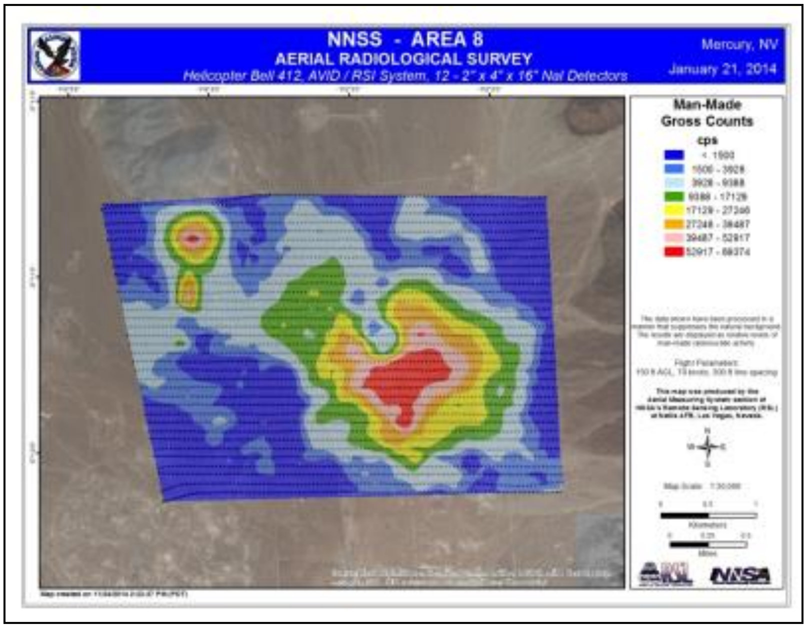

FIGURE 39 **CONTOUR OF MAN-MADE ACTIVITY FROM NNSS AREA 8 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES.**

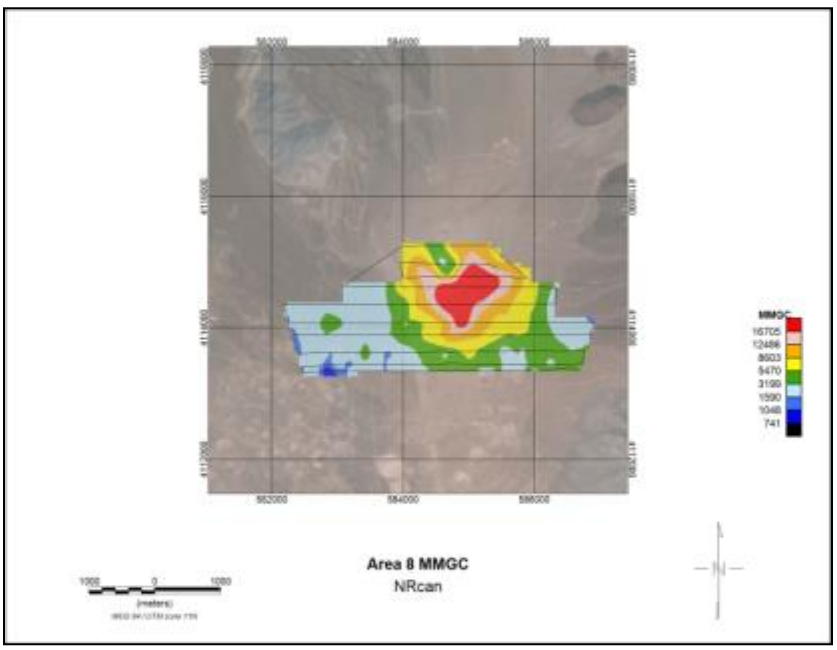

FIGURE 40 **CONTOUR OF MAN-MADE ACTIVITY FROM NNSS AREA 8 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES.**

Limited time was available for the NRCan survey of Area 8 (this time slot corresponded to AMS's flight over Area 3) resulting in differences in coverage compared with the AMS survey. Acquisition parameters were altered on the fly to ensure coverage of some of the interesting areas. Actual acquisition parameters for the NRCan survey were mean altitude 50 m, mean speed 27 m/s, and line spacing 200 m.

CONTOURS FROM NNSS AREA 11

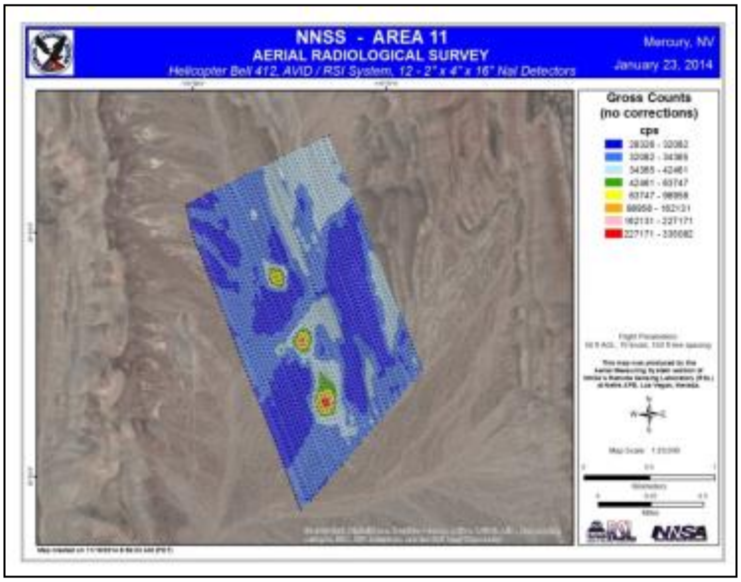

FIGURE 41 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 11 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES. (2014-01-22 PM)**

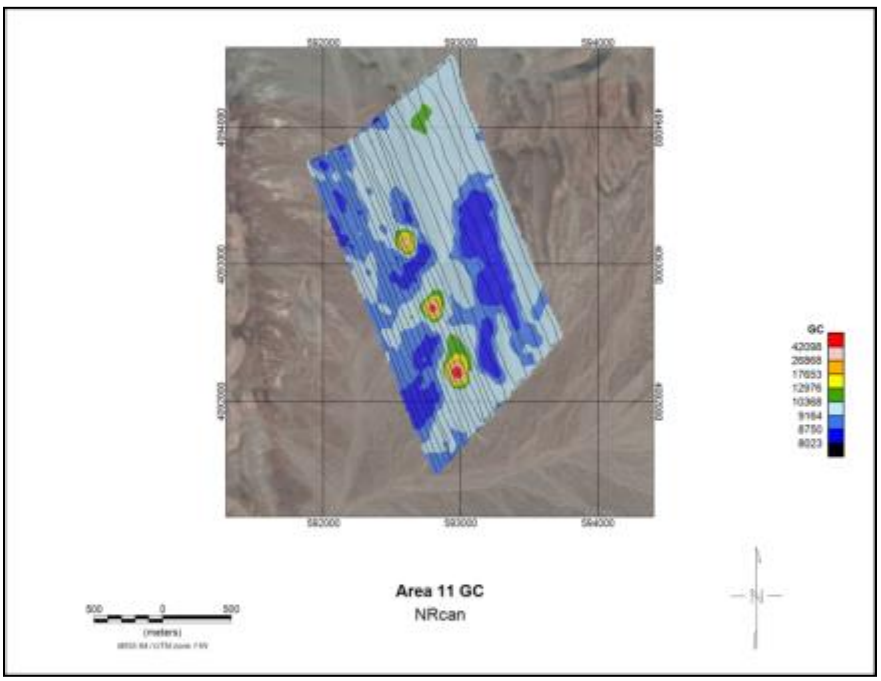

FIGURE 42 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 11 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES. (2014-01-23 AM)**

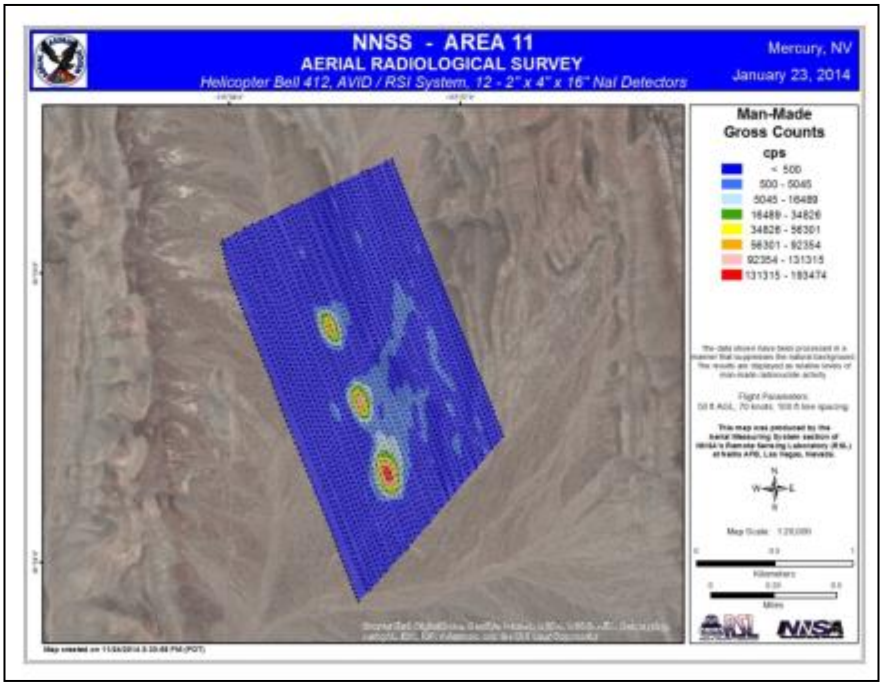

FIGURE 43 **CONTOUR OF MAN-MADE ACTIVITY FROM NNSS AREA 11 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES.**

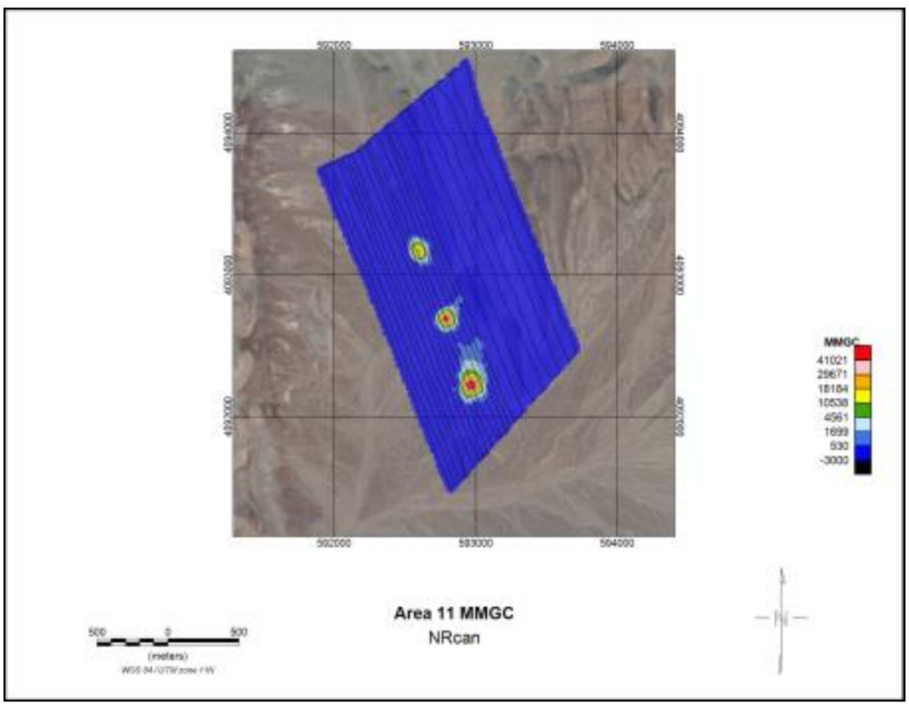

FIGURE 44 **CONTOUR OF MAN-MADE ATIVITY ACTIVITY FROM NNSS AREA 11 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES.**

Some differences can be noted in low count regions. This may be due to energy dependent sensitivity differences between the systems as a result of the thicker crystals in the NRCan system.

CONTOURS FROM NNSS AREA 30

Area 30 is contaminated with mixed fission products (^{137}Cs, ^{60}Co). Contours were created using the man-made ROI algorithm described earlier.

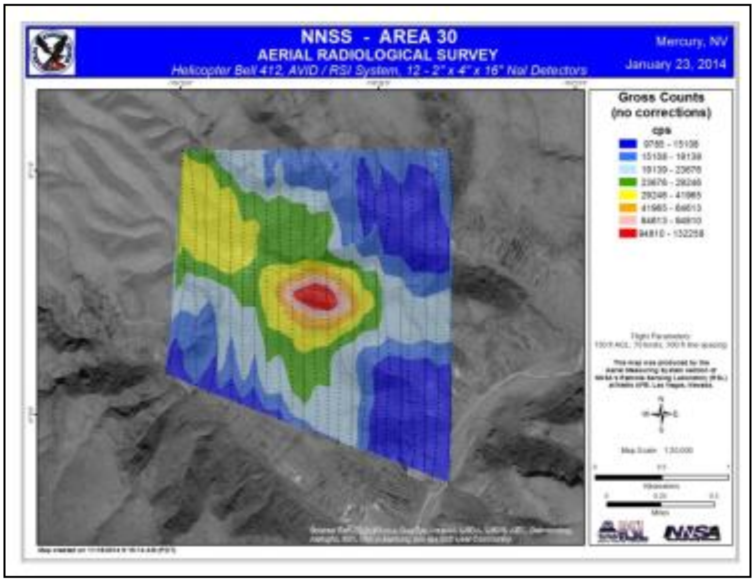

FIGURE 45 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 30 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES. (2014-01-23 AM)**

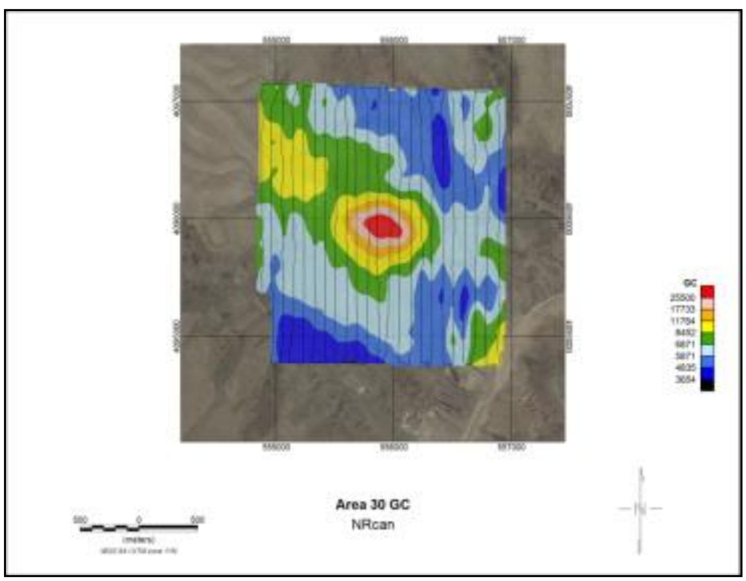

FIGURE 46 **CONTOUR OF GROSS ACTIVITY FROM NNSS AREA 30 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES. (2014-01-22 PM)**

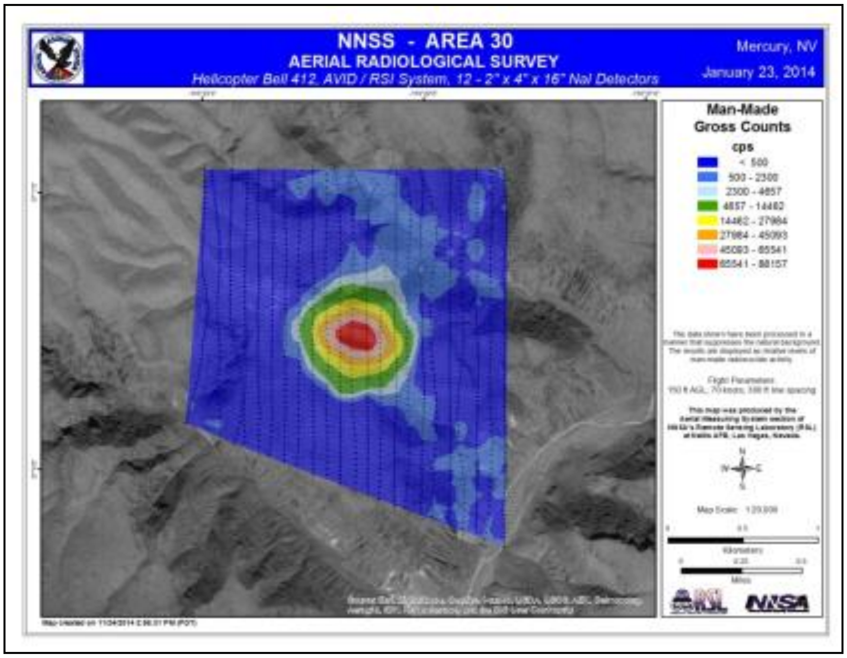

FIGURE 47 **CONTOUR OF MAN-MADE ACTIVITY FROM NNSS AREA 30 CREATED USING AMS DETECTION SYSTEM AND AMS DATA PROCESSING TECHNIQUES.**

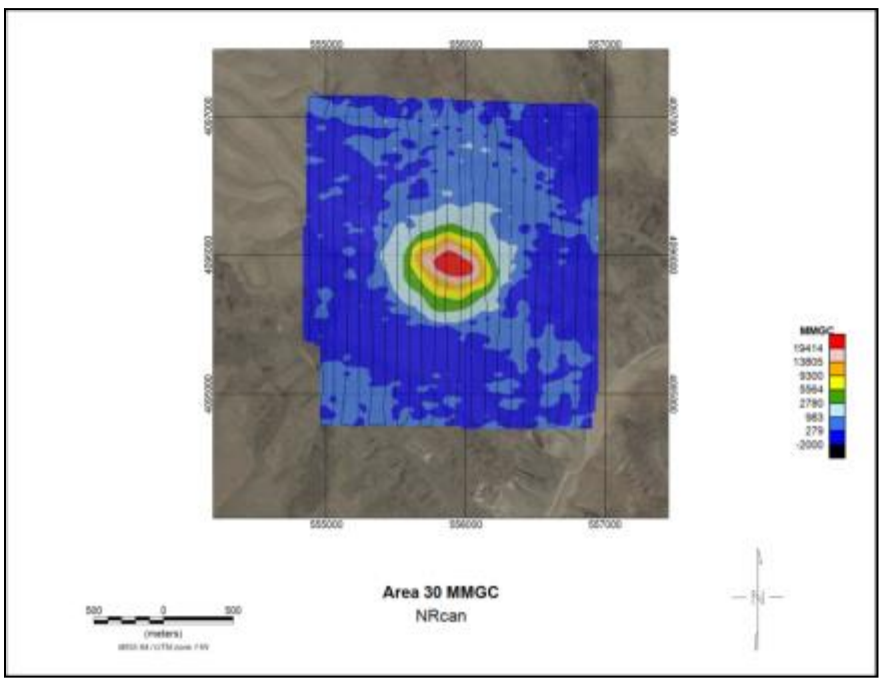

FIGURE 48 **CONTOUR OF MAN-MADE ACTIVITY FROM NNSS AREA 30 CREATED USING NRCAN DETECTION SYSTEM AND NRCAN DATA PROCESSING TECHNIQUES.**

Actual acquisition parameters for the NRCan survey were mean altitude 84 m, mean speed 20 m/s and line spacing 50 m. The high mean altitude results from the limited ability to contour the rapidly changing topography this site.

CONCLUSIONS

The ability to compare the aerial measuring techniques utilized by different groups involved in radiological emergency response has been part of NNSA efforts in recent years. In January 2014, a group from Natural Resources Canada (NRCan) flew their aerial acquisition system together with the U.S. Aerial Measurement Systems (AMS) over designated natural background test ranges and technical areas at the Nevada National Security Site (NNSS). Both the U.S. and Canadian systems are based on units manufactured by Radiation Solutions, Inc. The similarity of the systems allowed for comparison of the units' performance, depending on the geometry of the radiation detectors. Twelve U.S. AMS detectors were mounted in the external pods on a dedicated helicopter, versus the Canadian system (two detectors) mounted in a commercial external basket on the left side of chartered Eurocopter AS350. This configuration was similar to a setup that could be used by NRCan for aerial response to radiological emergencies. Each team used their standard data processing techniques to generate the preliminary data products. An upcoming further report will include a discussion of methods for evaluation of exposure/dose rate at ground level and its uncertainty, measurements of isotope concentrations, and a comparison of laser and radar altimetry for altitude correction.

Height attenuation is determined by both groups using similar methods. Quantitative comparison of the effective air attenuation constant between the two systems shows excellent agreement.

The typical way of presenting extended sources (surface contamination) is by color-filled contours. The AMS contouring technique was applied to the AMS data. The NRCan contouring was done using the Minimum Curvature algorithm. Qualitative comparison of contours shows very good agreement across all of the sites both for gross count and man-made gross count maps. Results of further investigations will be incorporated into the final report.

All of the initial objectives of the aerial campaign were reached. Both teams learned a great deal and important technical exchanges were conducted to ensure that both teams would be able to work together in the future.

ACKNOWLEDGEMENTS

The Canadian team would like to express their thanks to the U. S. Department of Energy for providing the opportunity to conduct these surveys, and in particular to Piotr Wasiolek and other members of the Aerial Measuring System team for their work in organizing the visit and his hospitality. We look forward to further ongoing collaboration. This work was funded in part by Defense Research and Development Canada's Centre for Security Science, project CSSP-2013-CD-1129.

BIBLIOGRAPHY

Briggs, I. (1974, February). Machine Contouring Using Minimum Curvature. *Geophysics, 39*(1), pp. 39-48.

Bristow, Q. (1978). Application of Airborne Gamma-Ray Spectrometry in the Search for Radioactive Debris from the Russian Satellite Cosmos 954 (Operation "Morning Light"). *Current Research Part B Geological Survey of Canada Paper, 78-1B*, p. 151.

Hendricks, T. J., & Riedhauser, S. R. (1999). *AN AERIAL RADIOLOGICAL SURVEY OF THE NEVADA TEST SITE.* Las Vegas: Bechtel Nevada Report DOE/NV/11718--324.

Kogan, R. e. (1971). *Gamma Spectrometry of the Natural Environments and Formations.* Jerusalem: Israel Program for Scientific Translations.

U.S. DOE Nevada Operations Office. (1978). *Operation Morning Light, A Non-Technical Summary of U.S. Participation.* Las Vegas: U.S. DOE Report NV-198.

Appendix A: Personnel

Name	Position
Piotr Wasiolek	AMS Task Lead
Rusty Malchow	AMS Scientist
Leslie Winfield	Federal AMS Manager
Karen McCall	AMS Project Manager
Ray Arsenault	Pilot
Manuel Avaro	Pilot
Ed Zachman	Helicopter Mechanic
Tom Schaus	Sundance Pilot
Jezabel Stampahar	AMS Data Analyst
Mike Lukens	AMS Electronic Technician
Tom Stampahar	AMS Electronic Technician
Jadus Hay	AMS Operation Specialist
Brad Harvey	NRCan Scientist
Richard Fortin	NRCan Scientist
Henry Seywerd	NRCan Scientist
Laurel Sinclair	NRCan Scientist

Appendix B: Activity Plan for the Surveys

AMS – NRCan Technical Exchange
Las Vegas, NV
January 20-24, 2014

Participants

Natural Resources Canada (NRCan)

AMS

IMPORTANT NOTE: Laptops, Cell phones (or ANY recording devices), Portable data storage devices, Firearms, Alcohol, Controlled Substances, and Cameras are strictly Prohibited in the limited areas of NNSS.

- Photo Identification is required at time of badging. Please bring your passport.
- Badges will be returned at the end of each day and reissued the following morning.
- A group photo will be taken at the Sundance Helicopters on Monday morning.
- Smoking is only permitted in designated areas, so please refrain from smoking unless in a designated area.
- Cell phones are prohibited inside each facility (as noted above), so if someone needs to reach you please have them call (702) 295-8001 and leave a message with the person answering the phone. The message will be passed directly to your escort.

Sunday, January 19, 2014 – Sundance Helicopters

15:00 – 18:00	Installation of the NRCan acquisition system on Sundance Helicopters Eurocopter AS 350 – Sundance mechanics and NRCan crew, AMS source support

Monday, January 20, 2014 – Sundance Helicopters

07:30-08:00	Welcome, Introductory Comments
08:00-09:00	OCC Briefing (NSTec OCC)
09:00-10:00	Mission/Flights Overview (Lake Mohave – spiral; Government Wash, Area 3, 8, 11, Desert Rock – sources): maps, setups (AMS)
05:30-17:00	**Ground truth measurements – NRCan and UNLV – Government Wash**
10:00-12:30	**Flight 1-AMS: Altitude Spiral Lake Mohave – DOE Bell 412 –AMS operator**
10:00-12:30	**Flight 1-NRCan: Government Wash Survey – Sundance AS 350 – NRCan operator**
12:30	Return to Base - Sundance Helicopters
12:30-13:30	Lunch – everybody-location TBD
13:30-16:00	**Flight 2-AMS: Government Wash Survey - DOE Bell 412–AMS operator**
13:30-16:00	**Flight 2-NRCan: Altitude Spiral Lake Mohave – Sundance AS 350 - NRCan operator**
16:00	Return to Base – Sundance Helicopters – refueling – DOE Bell 412 departs to Nellis
17:00	End of Day 1

Tuesday, January 21, 2014 – Desert Rock Airport (DRA)

NOTE: Personal Laptops, Firearms, Alcohol, and Cameras are Strictly Prohibited.

07:30-09:00	NRCan Visitors Badging Process - Mercury Badge Office – Bldg. 1000
08:00	Sundance AS 350 and DOE Bell 412 landing at DRA - pilots
09:00-09:30	Preflight checks and Mission Briefings – pilots and operators
09:30-11:45	**Flight 3 - AMS: Area 8 Survey (on line 10:00-11:30) – DOE Bell 412–AMS operator/escort, NRCan observer**
09:30-11:45	**Flight 3 - NRCan: Area 3 Survey (on line 10:00-11:30) – Sundance AS 350 – NRCan operator, AMS observer/escort**
11:45-12:15	AMS and NRCan Flights return to DRA/refueling
12:15-14:30	**Flight 4 - AMS: Area 3 Survey (on line 12:30-14:00) – DOE Bell 412–AMS operator/escort, NRCan observer**
12:15-14:30	**Flight 4 - NRCan: Area 8 Survey (on line 12:30-14:00) – Sundance AS 350 – NRCan operator, AMS observer/escort**
14:30-15:00	Flights return to DRA/refueling
15:00-16:00	Afternoon Missions Debriefing
16:00	Helicopters depart to Nellis and Sundance - EOD

<u>Wednesday, January 22, 2014 – Desert Rock Airport (DRA)</u>

NOTE: Personal Laptops. Firearms, Alcohol, and Cameras are Strictly Prohibited.

08:00	Sundance AS 350 and DOE Bell 412 landing at DRA - pilots
8:00-8:30	Preflight Checks and Mission Briefings – pilots and operators
8:30	Radioactive Sources placement at DRA
09:30-12:30	**Flight 5 - AMS: Area 11 Survey (on line 10:00-12:30) – DOE Bell 412 –AMS operator/escort, NRCan observer**
09:00-11:00	**Flight 5 - NRCan: Sources Overfly – Sundance AS 350 – NRCan operator, AMS observer/escort**
11:00-12:00	**NRCan Refueling at DRA/lunch**
12:30-15:30	**Flight 6 - NRCan: Area 30 Survey (on line 13:00-15:00) – Sundance AS 350 – NRCan operator, AMS observer/escort**
13:00-14:00	**AMS Flights Return to DRA/refueling/lunch**
14:00-15:30	**Flight 6 - AMS: Sources Overfly – DOE Bell 412 –AMS operator/escort, NRCan observer**
15:30	**AMS and NRCan Flights Return to DRA/refuling**
15:30-16:00	Missions Debriefing
16:00	Helicopters depart to Nellis and Sundance – EOD

Thursday, January 23, 2014 – Desert Rock Airport (DRA)

NOTE: Personal Laptops. Firearms, Alcohol, and Cameras are Strictly Prohibited.

08:00	Sundance AS 350 and DOE Bell 412 landing at DRA - pilots
8:00-8:30	Preflight Checks and Mission Briefings – pilots and operators
08:30-13:00	**Flight 7-AMS: Area 30 Survey (on line 09:00-11:30) – DOE Bell 412 – AMS operator/escort, NRCan observer**
09:30-13:00	**Flight 7-NRCan: Area 11 Survey (on line 10:00-12:30) – Sundance AS 350 – NRCan operator, AMS observer/escort**
12:00-13:30	Flights Return to DRA/refueling/lunch
13:00-15:30	Missions Debriefing
15:30	Helicopters depart to Nellis and Sundance – EOD
16:00-18:00	NRCan and Sundance equipment de-installation – Sundance Helicopters

<u>Friday, January 24 – UNLV Science and Engineering Building Room 3265</u>

08:00	AMS Overview (AMS)
08:30	NRCan Aerial Mission Overview (NRCan)
08:30-09:30	AVID Presentation (AMS)
09:30-12:00	AMS and NRCan Data Analysis Process – free discussion on following topics:

Data processing 1

- 1st level product generation (uncorrected gross count points)
- Radiation anomaly detection
- Use of commercial data acquisition software for data processing
- Commercial post-processing software (ArcGIS, Google Earth)

12:00-13:30 Lunch TBD

Data processing 2

- 2nd level product generation (background and altitude corrected gross count point data)
- Background (system, radon, cosmic ray, terrestrial)
- Altitude above ground level (AGL)
- **Radar versus laser altimeter**
- GPS and digital elevation map (DEM)
- Water line and Test line altitude profile (background, radon and cosmic ray contribution)
- Exposure rate calibration (calibration line)

13:30-16:00 Data processing 3

- 3rd level product generation (raster/contour)
- Interpolation
- Herring bone (direction of travel)
- Global conversion (exposure rate scaling)
- Man-made isotope extraction (2-window analysis)
- Isotope spectral extraction (3-window analysis)

16:00-16:30 **Project report assignments and plans for the future.**

16:30 END of Exchange