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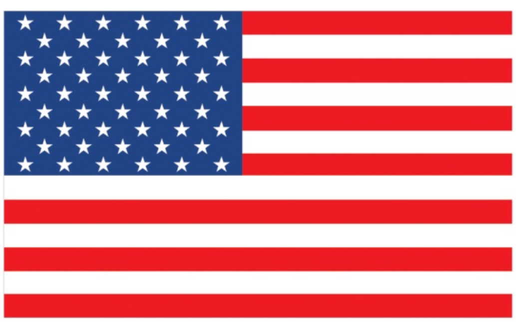
Aerial Measuring System (AMS)
Israel Atomic Energy Commission (IAEC)

JOINT COMPARISON STUDY REPORT

Nevada National Security Site

June 24 –27, 2013



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AERIAL MEASURING SYSTEM (AMS)/ ISRAEL ATOMIC ENERGY COMMISSION (IAEC) JOINT COMPARISON STUDY REPORT

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ABSTRACT

Under the 13th Bilateral Meeting to Combat Nuclear Terrorism conducted on January 8–9, 2013, the committee approved the development of a cost-effective proposal to conduct a Comparison Study of the Aerial Measuring System (AMS) of the U.S. Department of Energy (DOE), National Nuclear Security Administration (NNSA) and Israel Atomic Energy Commission (IAEC). The study was to be held at the Remote Sensing Laboratory (RSL), Nellis Air Force Base, Las Vegas, Nevada, with measurements at the Nevada National Security Site (NNSS). The goal of the AMS and the IAEC joint survey was to compare the responses of the two agencies' aerial radiation detection systems to varied radioactive surface contamination levels and isotopic composition experienced at the NNSS, and the differing data processing techniques utilized by the respective teams. Considering that for the comparison both teams were using custom designed and built systems, the main focus of the short campaign was to investigate the impact of the detector size and data analysis techniques used by both teams. The AMS system, SPectral Advanced Radiological Computer System, Model A (SPARCS-A), designed and built by RSL, incorporates four different size sodium iodide (NaI) crystals: 1″ × 1″, 2″ × 4″ × 4″, 2″ × 4″ ×16″, and an "up-looking" 2″ × 4″ × 4″. The Israel AMS System, Air RAM 2000, was designed by the IAEC Nuclear Research Center – Negev (NRCN) and built commercially by ROTEM Industries (Israel) and incorporates two 2″ diameter × 2″ long NaI crystals. The operational comparison was conducted at RSL-Nellis in Las Vegas, Nevada, during week of June 24–27, 2013. The Israeli system, Air RAM 2000, was shipped to RSL-Nellis and mounted together with the DOE SPARCS on a DOE Bell-412 helicopter for a series of aerial comparison measurements at local test ranges, including the Desert Rock Airport and Area 3 at the NNSS. A 4-person Israeli team from the IAEC NRCN supported the activity together with 11 members of the RSL team, which consisted of pilots, mechanics, scientists, a data analyst, equipment operators, and operation specialists. All planned flight activities followed by scientific discussions on the collected data were completed. For IAEC, the joint survey provided an opportunity to characterize their system's response to extended sources of various fission products at the NNSS. As both systems play an important role in their respective countries' (United States and Israel) 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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Acronyms and Abbreviations

AGL	above ground level
^{241}Am	americium-241
AMS	Aerial Measuring System
ATU	acquisition and telemetry unit
cm	centimeter(s)
^{60}Co	cobalt-60
cps	count(s) per second
^{137}Cs	cesium-137
DC	direct current
DOE	U.S. Department of Energy
^{152}Eu	europium-152
ft	foot (feet)
GIS	Geographic Information System
GPS	Global Positioning System
IAEC	Israel Atomic Energy Commission
IEMC	International Emergency Management and Cooperation
kg	kilogram(s)
km	kilometer(s)
km/h	kilometer(s) per hour
lb	pound(s)
m	meter(s)
mi	mile(s)
MMGC	man-made gross count
μR/hr	microroentgen(s) per hour
NaI:Tl	thallium-doped sodium iodide
NNSA	U.S. Department of Energy, National Nuclear Security Administration
NNSS	Nevada National Security Site
NRCN	Nuclear Research Center – Negev
NSTec	National Security Technologies, LLC
RSL	Remote Sensing Laboratory
SHP	Shape
SPARCS	SPectral Advanced Radiological Computer System

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INTRODUCTION

In support of the U.S. Department of Energy (DOE) International Emergency Management and Cooperation (IEMC/NA-46) Program, the comparison of the U.S. and Israeli Aerial Measuring Systems (AMS) study was proposed and accepted at the January 2013 Bilateral Meeting in Tel Aviv, Israel.

The study, organized by the DOE/National Nuclear Security Administration (NNSA) Remote Sensing Laboratory (RSL), involved the DOE/NNSA Aerial Measuring System Project based at the RSL and operated under a contractor agreement by National Security Technologies, LLC (NSTec), and the Israel Atomic Energy Commission (IAEC) Aerial Measuring System. The operational comparison was conducted at RSL-Nellis in Las Vegas, Nevada, during week of June 24–27, 2013. The Israeli system, Air RAM 2000, was shipped to RSL-Nellis and mounted together with the DOE Spectral Advanced Radiological Computer System, Model A (SPARCS-A) on U.S. DOE Bell-412 helicopter for a series of aerial comparison measurements at local test ranges, including the Desert Rock Airport and Area 3 at the Nevada National Security Site (NNSS). A four-person Israeli team from the IAEC, Nuclear Research Center – Negev (NRCN) supported the activity.

Objectives of this joint comparison study included:

- Using the DOE/RSL Bell-412 helicopter aerial platform, perform the comparison study of measuring techniques and radiation acquisition systems utilized for emergency response by IEAC and NNSA AMS.
- Carry out operational flight activities collecting radiation data from natural background, dispersed radioactivity, and point sources.
- Allow each team (U.S. AMS and IAEC) to observe each other's aerial measuring processes and exchange ideas.
- Compare results obtained with the IAEC and NNSA AMS systems.
- Compare the response of the U.S. and Israeli detectors to radiological anomalies and extended radiation sources.
- Review the mission objectives and parameters used by IAEC and DOE AMS.
- Compare technologies, procedures, and data analysis techniques.
- Recommend the best procedures and processing method.
- Carry out initial SPARCS operation training, so the IAEC can request a SPARCS unit for evaluation.

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 concerning the actual measurements, data analyses, and comparison of results.

MEASURING SYSTEMS

One advantage of acquiring aero-radiometric measurements lies in the high collection rate of data over large areas and rough terrain. Typical aero-radiometric systems record and save gamma-ray spectra, correlated with the Global Positioning System (GPS) derived location information (latitude, longitude, elevation over GPS ellipsoid=GPS altitude) in regular time intervals of 1 to 2 seconds. Such data can be used to locate radiation anomalies on the ground, map ground contamination, or track a radioactive airborne plume. 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.

During the acquisition the flight altitude is kept constant, with typical values recorded between 50 and 985 feet (ft) (15 and 100 meters [m]) above ground level (AGL). The helicopter ground speed is maintained constant, in the case of DOE Bell-412, 70 knots (130 km/h).

For the comparison study, AMS and IAEC used their emergency response radiation detection systems, Israel's Air RAM 2000, and the DOE's SPARCS. For altitude measurements the AirRAM 2000 system uses a barometric altimeter with the range of 0–8000 ft, which is calibrated at 1000 ft by a radar altimeter. The SPARCS system uses radar altimeters for vertical positioning (altitude over the ground) and Differential GPS for location.

Survey Aircraft

The DOE Bell-412 helicopter was used as the airborne platform to carry out the comparison study (Figure 1). The Bell-412 is a twin engine utility helicopter that has been manufactured by Bell Helicopter since 1981. With a standard fuel capacity of 330 gallons, it is capable of flying for up to 3.7 hours, with a maximum range of 356 nautical miles and a cruising speed of 122 knots. However, with the AMS radiation survey configuration of 12 detectors, four crew members (two pilots, a mission scientist, and an equipment operator), with a survey speed of 70 knots (120 ft/sec) at survey altitude of 300 ft AGL, the Bell-412 was capable of 2.5 hours of flight time.

Figure 1. DOE Bell-412 helicopter during survey

Radiation Detection Systems

AMS SPARCS

AMS used a detection system developed by RSL for NNSA AMS applications (Figure 2). The AMS SPARCS is a radiological data acquisition and analysis system designed for the nuclear or radiological emergency response mission. It is used in aircraft to conduct large area radiological surveys for ground contamination resulting from nuclear reactor accidents and radiological dispersals incidents. The system is modular and records the gamma radiation level, spectral data, and GPS coordinates once a second. It is portable, relatively light, and durable enough that it can be readily mounted in almost any vehicle, boat, or aircraft.

The main components of the SPARCS, as shown in Figure 2, are detector pod, acquisition and telemetry unit (ATU), and laptop computer with the "cabin" software installed. SPARCS collects and saves the data once a second.

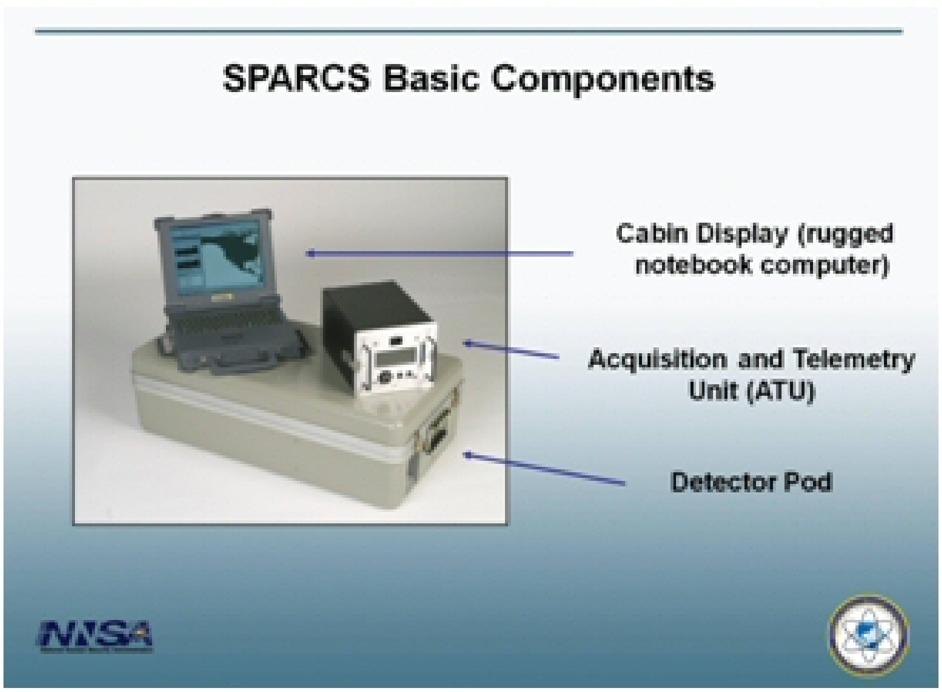


Figure 2. SPARCS main components

The SPARCS-A pod employs a total of four thallium-doped sodium iodide (NaI:Tl) (Figure 3) crystals of the following dimensions:

- 1″ × 1″ (2.5 × 2.5 cm)
- 2″ × 4″ × 4″ (5 × 10 × 10 cm)
- 2″ × 4″ × 16″ (5 × 10 × 40 cm)
- 2″ × 4″ × 4″ (5 × 10 × 10 cm) "up-looking"

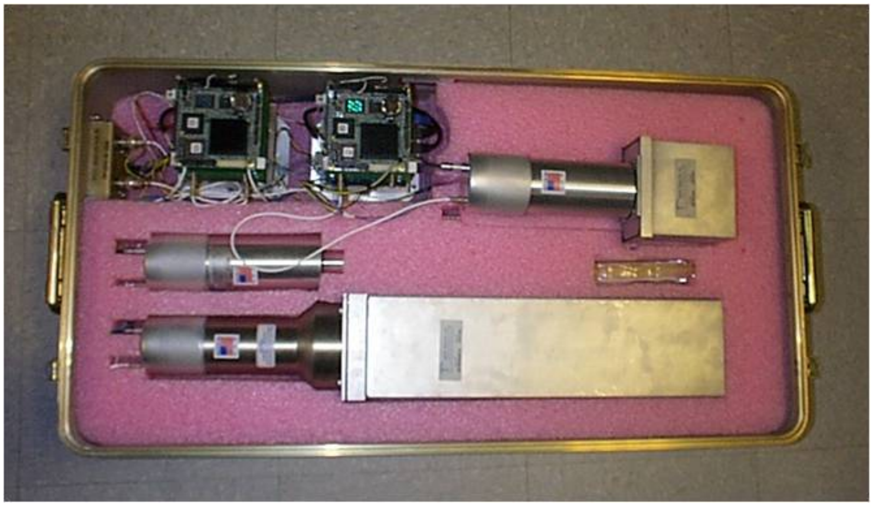


Figure 3. Interior of the SPARCS-A pod

These detectors (Figure 3) are packaged together with their support electronics: high-voltage power supplies, preamplifiers, and multi-channel analyzers in a single pod with the dimensions of 16.5″W × 32.5″D × 10″H (42 × 82 × 25 cm) and weight of 98 lb (44.5 kg). For the technical exchange, the pod was mounted in the cargo compartment in the tail boom of the Bell-412 helicopter.

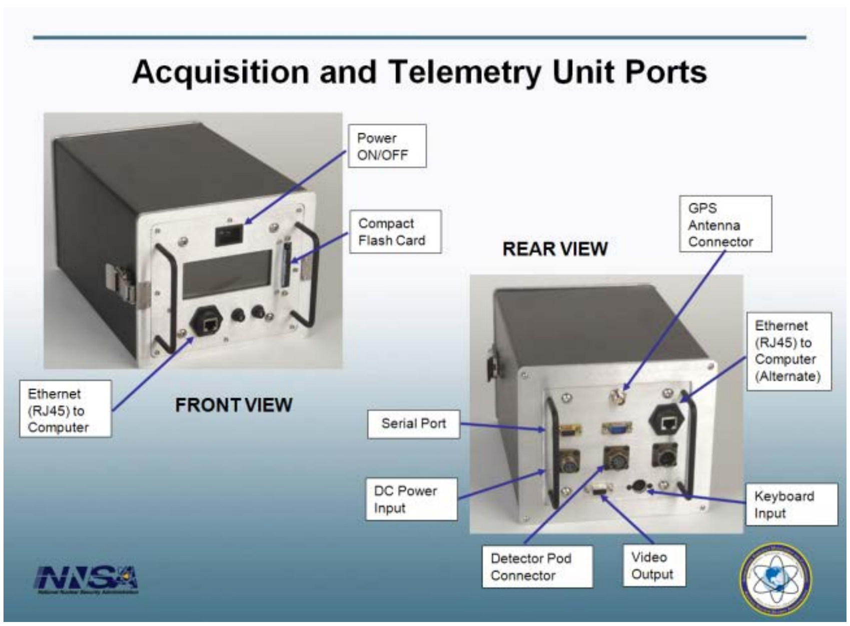


Figure 4. The SPARCS ATU connections

The SPARCS ATU records detector data, records GPS coordinates, stores data on a compact flash card, provides data for laptop display, and provides DC power for the detector pod (Figure 4). Its dimensions are 7.3″W × 11.5″D × 6.2″H (18 × 30 × 16 cm) and weight is 10.5 lb (4.8 kg).

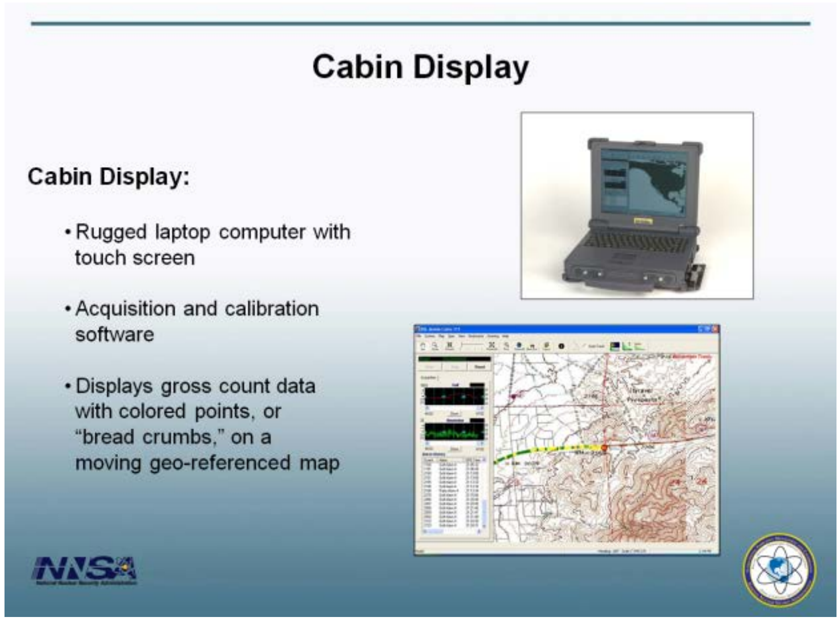


Figure 5. SPARCS cabin display

The cabin display (Figure 5) is an RSL-developed software package for the operator interface to the system. The software runs on a rugged laptop computer, with a touch screen, and controls both data acquisition and spectral calibration. The software primary screen (Figure 6) displays gross count data with colored points, or "bread crumbs," on a moving geo-referenced map. For field operations the background map is a geo-referenced image: an aerial photo or street map of the area of interest. The display (Figure 6) shows the survey map with "bread crumb" flight path and count rate data (left), the strip chart count rate data for the four detectors (upper right), the GPS longitude and latitude, and speed and altitude (bottom right). Note that the altitude is the GPS altitude and not the aircraft above ground altitude. The SPARCS does not record the actual aircraft altitude, so it is important to maintain a constant altitude throughout the mission in order to process the data. At the end of the flight the software creates the two output files:

- Geographic Information System (GIS) shape (SHP) file that can be imported to ESRI ArcGIS or Google Earth Pro, containing the location information and the count rate breadcrumb data
- SPARCS proprietary mps binary file containing full spectral information that can be opened with the RSL SpecTool software package

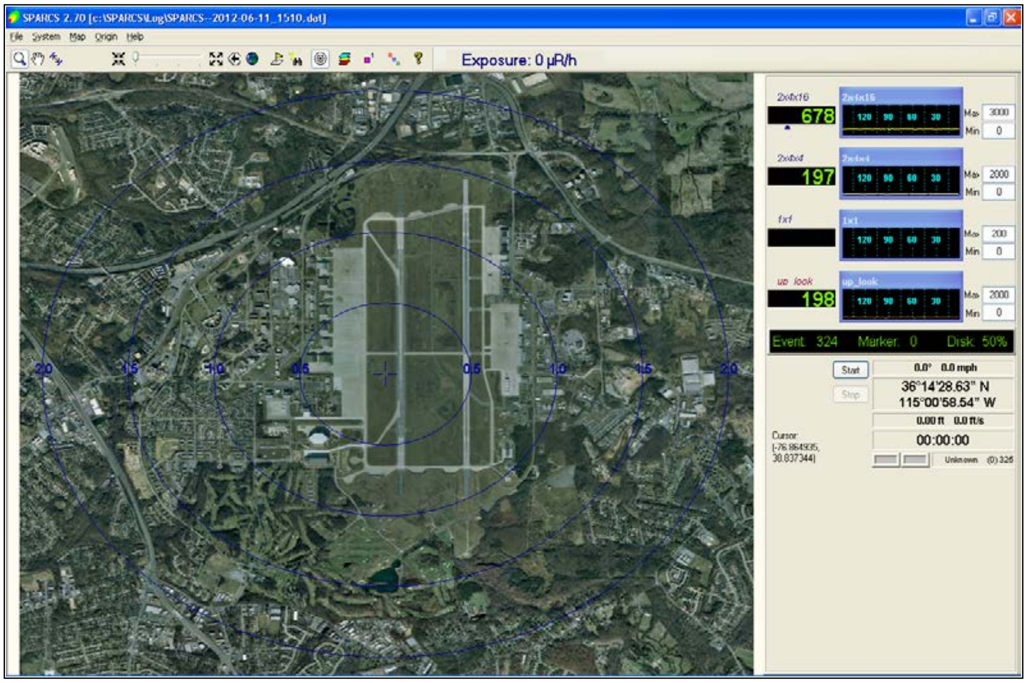


Figure 6. SPARCS-A Cabin Display laptop screen

For the technical exchange flights, the SPARCS was mounted inside the Bell-412 cargo compartment in the tail boom with the detector box equipment secured by cargo straps and cables fed through the compartment's front bulkhead to the main cabin (Figure 7).

Figure 7. SPARCS inside Bell-412 cargo compartment

IAEC AirRAM 2000

For the joint survey, the IAEC used the AirRAM 2000 radiation monitoring system presented schematically in Figure 8.

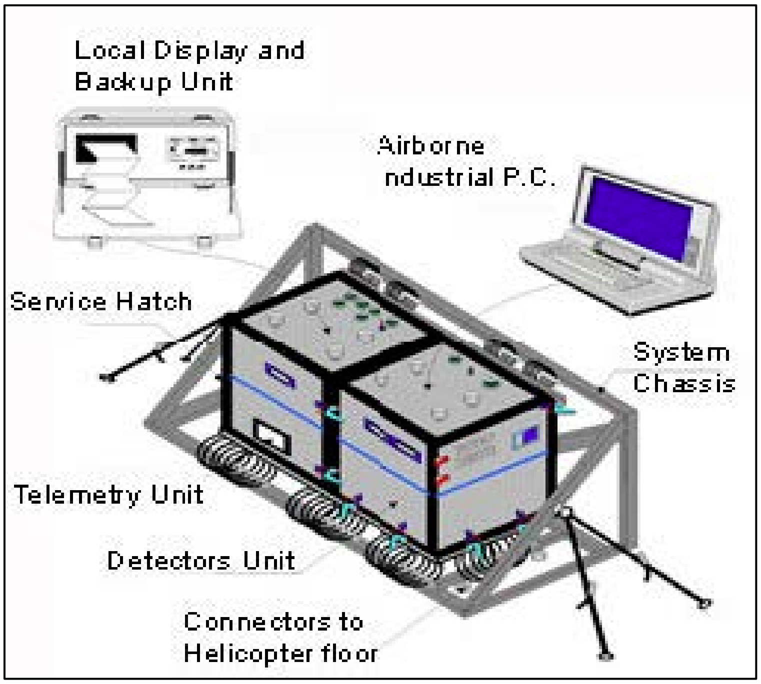


Figure 8. Schematic diagram of the IAEC aerial detection system

Figure 9. AirRAM 2000 aerial radiation detection system

The Israeli AMS System was designed by the IAEC NRCN and built commercially by ROTEM Industries (Israel). The system is designed to be used inside the main cabin on an aircraft (originally a Bell-212) and is currently flown on a UH-60 Blackhawk. It was designed to track radioactive plumes, measure ground deposition, and identify radioisotopes. The AirRAM 2000 contains two 2″ diameter × 2″ long sodium iodide (NaI) detectors (one down-looking and one up-looking) with a 3 cm lead layer between, and a Geiger–Müller counter to monitor dose rate for crew safety (Figures 8 and 9). The AirRAM 2000 collects and saves data every 2 seconds. In the design special attention was given to ensure that no detector saturation will occur, so the flights can be flown at low altitude flights with high spatial resolutions. During plume tracking missions, the safety precautions are to fly above the clouds and maintain the exposure below the 100X natural background. During the flight, every 2 seconds, the count rate from detectors (up-looking, down-looking, and safety) are transmitted along with the chopper’s position and system’s status to the ground. The continuous data link includes the collected data, upload commands, and a free text chat. Beside real-time data telemetry, the onboard computer is used for data backup. In case of computer failure or GPS malfunction, navigation can be performed by map, and selected results will be transmitted to the ground by the radio system.

The system’s main mission objective is real-time monitoring of radioactive clouds, including positive cloud detection, cloud shape definition and propagation direction, and cloud height. The cloud height is determined by the difference between the two detectors’ values while losing altitude.

For the joint survey, the NaI detector configuration was changed to side-by-side, and their signals were summed. The unit with the NaI detectors was mounted towards the side door of the helicopter (right unit in Figures 8 and 9). Inside the helicopter cabin, the detector unit and the second unit containing radio equipment for telemetry were connected and mounted in the ROTEM Equipment Mounting Rack (Figure 10). The rack holds the two boxes together and allows for secure attachment to the helicopter floor. The rack also functions as a vibration isolator (MARBEK isolated system) to protect the electronics from the major UH-60 Blackhawk vibration frequency of 17 Hz.

Figure 10. AirRAM 2000 ROTEM Equipment Mounting Rack

The total weight of the system is 440 lb/200 kg (330 lb/150 kg AirRAM radiation detection system and 110 lb/50 kg Equipment Mounting Rack). The system is designed to use aircraft electrical power of 28 volt DC. The GPS antenna is typically mounted on a glass panel above the pilot when flown on a UH-60 Blackhawk. During the joint survey, both AMS and IAEC systems used the common Differential GPS provided by Trimble antenna and receiver. Due to a security restriction on using radio frequency during some of the flights, the data telemetry capability was not used in the study. For the joint survey flights, the AirRAM and rack were shipped to RSL and mounted on the floor of the DOE Bell-412 helicopter as cargo. The IEAC system's gross weight of 440 lb/200 kg prevented the use of cargo straps to secure it, and a special mounting plate (Figure 11) was manufactured by RSL.

Figure 11. Custom mounting plate on the floor of Bell-412

The opening in the plate was positioned over the Bell-412 600 mm wide flight control tunnel to prevent the attenuation of incoming radiation by the fuel cells under the helicopter floor, so the gamma rays were attenuated only by the fuselage body of the helicopter. The schematics of the Bell-412's forward fuel cells and flight control tunnel are presented in Figure 12. The fuel cell shape follows the frame of the Bell-412 with an average height of 300 mm. For data acquisition and data analysis, the IAEC uses in-house developed software described later.

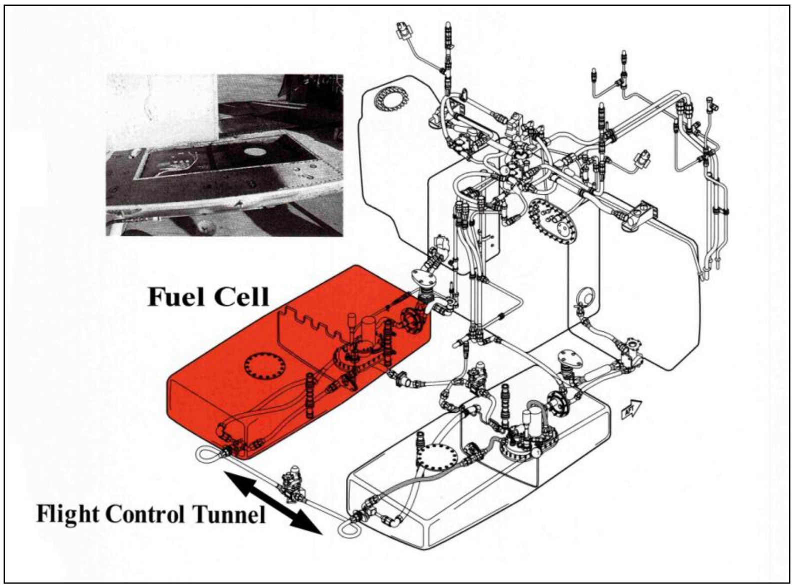


Figure 12. Location of the forward fuel cells and flight control tunnel in Bell-412

The fully assembled and mounted AirRAM system inside the Bell-412 is presented in Figure 13.

Figure 13. The AirRAM 2000 inside the DOE Bell-412 helicopter

DATA EVALUATION METHODS

AMS

AMS uses a dedicated in-house developed data processing methodology and software PC Radiation and Environmental Data Analyzing Computer (REDAC). The collected spectral data are processed in several steps, starting with the correction of the gross counts to the nominal flight altitude, correcting for all background components (radon, cosmic, helicopter), deriving terrestrial exposure rate, extracting man-made activity and finally individual isotopes. All data are then presented as contour maps using commercial ArcGIS software.

Gross Count

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

$$C_{GC} = \left(\frac{1}{t_{Live}} \sum_{E=38}^{3028} c(E) - C_N \right) \times e^{\mu \times (H - H_0)}$$

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 non-terrestrial sources (cps)
H = actual aircraft (radar measured) altitude (ft or m above ground level),
H_0 = nominal flight altitude (ft or m),
μ = gamma-ray air attenuation coefficient (ft^{-1} or m^{-1}).

The non-terrestrial background count rate, C_N, is determined initially from the test line altitude profile and is adjusted on a flight-by-flight basis; it has contributions from cosmic rays, the aircraft system, and airborne radon. The air attenuation coefficient, μ, is also determined from the test line data.

Terrestrial Exposure Rate

The terrestrial exposure rate is derived from the integrated counting rate in the gamma energy spectrum range between 38 and 3028 keV. Strictly, this can only be performed by a detailed analysis of the gamma-ray spectrum and by using models that relate exposure rate to each gamma-ray energy in the spectrum. This count rate, measured in counts per second (cps) at survey altitude, is converted to exposure rate (*ER*) in μR/h at 3 ft (1 m) AGL using the following equation:

$$ER = \frac{C_{GC}}{F}$$

where,

C_{GC} = gross count rate at survey altitude (cps)
F = experimentally derived conversion factor (cps/μR h^{-1})

The conversion factor *F* was determined from documented calibration line located at Lake Mohave in Clark County, Nevada. The calibration range has been used to relate the count rate observed at different altitudes with different detector arrays to the exposure rate measured at 3 ft (1 m) AGL using pressurized ionization chambers. The conversion factor assumes a uniformly distributed radiation source (1) covering an area that is a large when compared to the field of view of the detector system (a circle with a diameter roughly twice the altitude of the aircraft), and (2) having a gamma-ray energy distribution similar to that of the natural background of the calibration line.

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 the 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, since significant variations can result from geological fluctuations or changes in the ground coverage (e.g., river, dense vegetation, buildings).

A 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):

$$C_{MM} = \sum_{E=38}^{1394} C(E) - K_{MM} \sum_{E=1394}^{3028} C(E)$$

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)

$$K_{MM} = \frac{\sum_{E=38}^{1394} C_{ref}(E)}{\sum_{E=1394}^{3028} C_{ref}(E)}$$

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. $C_{ref}(E)$ represents the count rate in the reference gamma-ray energy spectrum at the energy E(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.

Isotope Extraction: General Three Window

The three-window extraction algorithm is a linear Compton tail removal technique. The algorithm uses two relatively narrow windows on each side of the photo peak of interest (third window) (Figure 14).

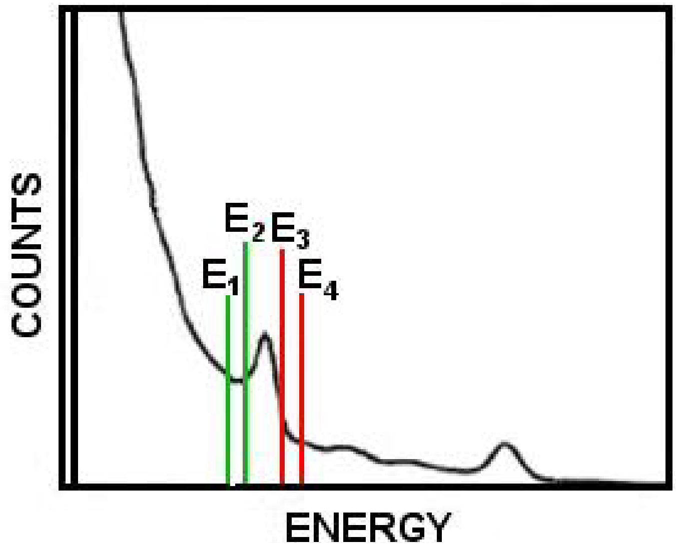


Figure 14. Three-window algorithm applied to a typical spectrum

The Compton contribution, assumed to be in the central window, is interpolated from the outside window contributions. The actual ratio of background central counts to the sum of the outside counts is derived from measured flight data as with other extractions. A three-window algorithm is used by AMS to extract ^{137}Cs when looking at an unknown accident area where there might be fission product activity. The three-window algorithm used was:

$$C_{3-window} = \sum_{E=E_2}^{E_3} C(E) - K_3 \left(\sum_{E=E_1}^{E_2} C(E) + \sum_{E=E_3}^{E_4} C(E) \right)$$

with,

$$K_3 = \frac{\sum_{E=E_2}^{E_3} C_{ref}(E)}{\sum_{E=E_1}^{E_2} C_{ref}(E) + \sum_{E=E_3}^{E_4} C_{ref}(E)}$$

where,

$C_{3\text{-}window}$ = count rate from the three-window algorithm

E_n = limiting energies of the windows (E1<E2<E3<E4)

K_3 = ratio of the counts in the primary window to the counts in the two background windows in a reference region of the survey area

The three-window algorithm is also very useful in extracting low-energy photopeak counts where the shape of the Compton-scatter contributions from other isotopes is changing significantly. This is the algorithm used for calculating the ^{137}Cs contour plots presented later.

IEAC

The IEAC relies on in-house developed software for data acquisition and analysis, including spectral extraction and contouring. During the real-time acquisition, the AirRAM 2000 monitoring is done by displaying the gross count rate integrated from the 1024-channel spectrum covering the energy range of 50–4000 keV, and not by specific energy window. The system is optimized for real-time measurements, namely reactor accidents and major events resulting with radioactive contamination of the ground. The primary data product is the exposure rate on the ground. The conversion coefficients from the recorded count rate to exposure rate are derived from altitude profile mission, and each data point is corrected for natural background, including cosmic contribution. For radioactive ground deposition estimates, the IAEC analysis assumes that the ground surface is flat and that all the radioactive material is on the ground surface.

ORGANIZATION OF THE CAMPAIGN

Description of Survey Sites

Government Wash

Government Wash site is located 10 miles north of RSL and is characterized by varied geology. AMS has been using it for evaluation of responses of aerial acquisition systems to varied natural background (Figure 15). The actual setup with flight lines over Government Wash is presented in Figure 16.

During the exchange, the Government Wash was flown at an altitude of 150 ft (46 m) with 300 ft (91 m) line spacing,

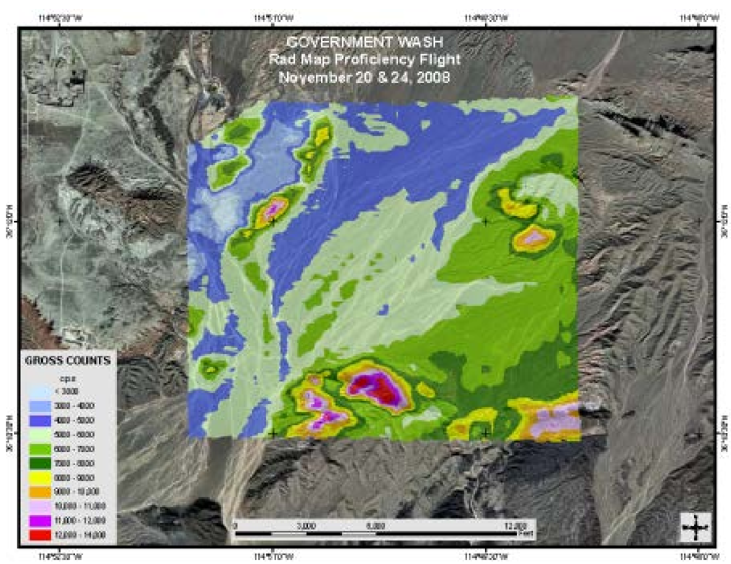


Figure 15. Radiation gross counts contour map of natural background at Government Wash Site from earlier survey data

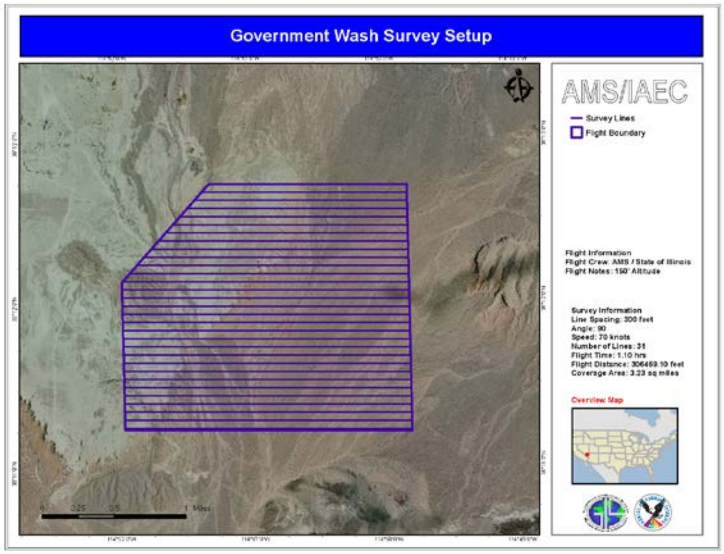


Figure 16. Government Wash Site survey lines setup

Lake Mohave Calibration Line

To derive conversion coefficients from count rate at survey altitudes expressed in counts per second (cps) to the terrestrial exposure rate at 3 ft (1 m) above ground in microroentgen per hour (µR/hr), AMS established a calibration line approximately 2 mi (3 km) long at Lake Mohave, approximately 60 mi (97 km) south of Las Vegas (Figure 17). The location of the calibration line was based on very uniform geology along the shore line of Lake Mohave and proximity to a large body of water. The standard AMS flight profile over the Lake Mohave calibration line is the altitude spiral. The altitude spiral allows for an estimate of the average attenuation coefficient of gamma rays in air and the cosmic ray component of the spectrum and the system inherent background that can be determined by flying the same path over water and land at various altitudes. The standard AMS altitude spiral performed at Lake Mohave includes flying water and land line at altitudes of 50, 150, 300, 500, 1000, and 3000 ft. In addition, the land line in that area has been measured by ground-based instruments, and the terrestrial exposure rate at 3 ft (1 m) AGL is known to be 8.5 µR/h, a useful absolute calibration point for both AMS and IAEC systems.

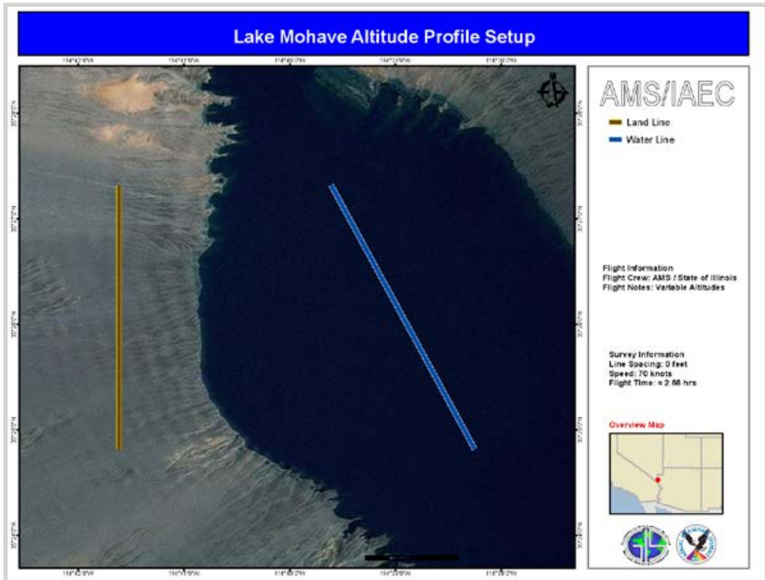


Figure 17. Lake Mohave calibration line

NNSS Area 3

Since January 1951 the NNSS (formerly known as Nevada Test Site) has been the primary United States site for testing nuclear weapons and for studying their effects on structures and military equipment. The NNSS is located approximately 65 mi (105 km) northwest of Las Vegas. It covers an area of approximately 1,350 mi^2 (3500 km^2). The elevation above mean sea level ranges from ~2690 ft (~809 m) to ~7680 ft (~2340 m).

For the AMS/IAEC technical exchange, the NNSS Area 3 was flown. Area 3 was the site of several nuclear tests carried out in the 1950s and 1960s. The isotopes identified during the AMS 1994 survey included ^{60}Co, ^{137}Cs, ^{152}Eu, and ^{241}Am. The area of interest planned for the survey is presented in Figure 18.

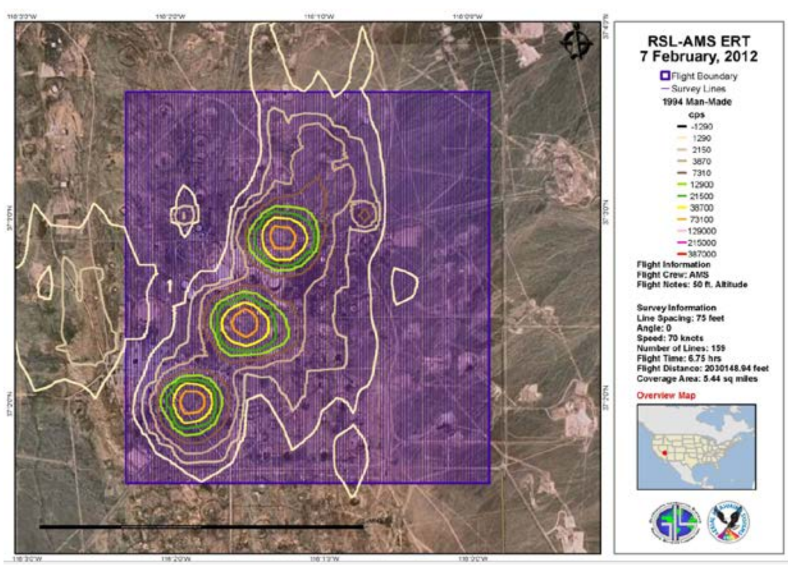


Figure 18. Contour map of NNSS Area 3 man-made contaminations

The contours in Figure 18 were derived from the aerial survey of the carried out by AMS previously, in this case in 2012, as part of the training exercise.

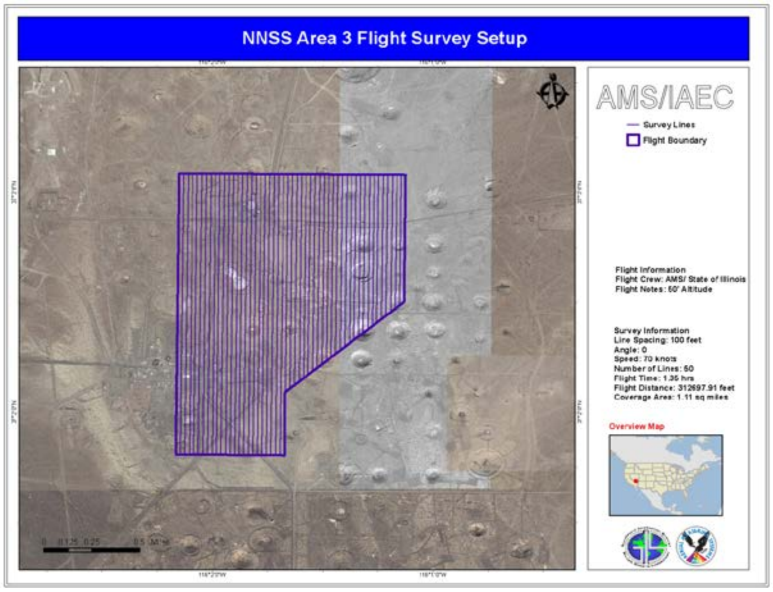


Figure 19. Survey setup for the NNSS Area 3

To complete the survey, as shown in Figure 19, in a flight time of approximately 2.5 hr, a subset of lines covering the three bull's-eyes was flown. Survey parameters were 50 ft (15 m) AGL altitude, with 100 ft (30 m) line spacing at 36 m/sec (70 knots) helicopter ground speed.

Historical operations in this area resulted in contamination consistent with that of a nuclear/ radiological accident/incident with different types and amounts of dispersed radioactive materials.

Desert Rock Airport

To observe the system response to point radiation anomalies, ^{137}Cs and ^{60}Co sources were placed along the 7500 ft long runway, 1500 ft (450 m) apart, at the Desert Rock Airport adjacent to the NNSS (Figure 20).

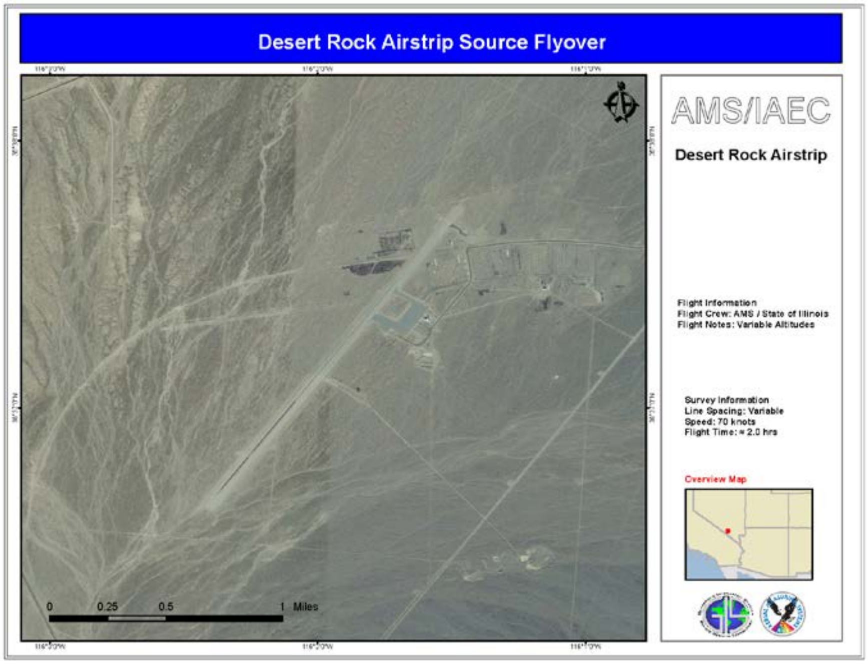


Figure 20. Desert Rock Airport

Desert Rock Airport is a private-use airport located 3 miles (5 km) southwest of the central business district of Mercury, in Nye County, Nevada, United States. The airport is located on the NNSS and is owned by the DOE.

Desert Rock Airport covers 100 acres (40 ha) and has one asphalt runway 7515 ft long × 100 ft wide (2291 × 30 m). The placement and activity of the sources used in the overfly test are listed in Table 1.

Table 1. Activity and location of the radioactive sources used in the study

	Activity (mCi)	Longitude	Latitude
^{137}Cs	20.6	−116.028505	36.624740
^{60}Co	3.6	−116.031402	36.621293
^{60}Co	1.7	−116.034129	36.617998

TECHNICAL EXCHANGE AGENDA

Due to NNSS operations and severe flight restrictions, the joint survey was conducted under time restraint conditions. The detailed activity plan for the survey week is presented below.

Date	Day	Activity
June 20, 2013	Thursday	IAEC equipment at RSL Israeli delegation arrives in Las Vegas
June 24	Monday	08:00 Badging 09:00 Operational Briefing at RSL General Introductions Security and General Safety Briefings 10:00 IAEC equipment installation in the Bell-412 Unpacking Installation Preflight testing 11:30–13:00 Lunch 13:00 SPARCS operation training 16:30 End of day
June 25	Tuesday	08:30 Mission briefing for Lake Mohave flight 09:00 Altitude spiral at Lake Mohave (2.5 hr) 11:30 Helicopter refueling, lunch 13:00 Mission briefing for Government Wash flight 13:30 Government Wash survey flight (2.5 hr) 16:00 Return to Nellis Air Force Base 16:30 End of day
June 26	Wednesday	08:00 Arrive to Desert Rock Airport 08:30 Mission briefing for Area 3 survey 10:00-12:30 Area 3 survey (2.5 hr) 12:30-13:30 Refueling, lunch 13:30 Source overfly at Desert Rock Airport 16:00 Return to Nellis Air Force Base 16:30 End of day
June 27	Thursday	0:900 Meeting at the North Las Vegas Airport 09:30–12:00 initial data processing 12:00–13:00 Lunch 13:00–16:00 Post-mission debriefing/discussions 16:30 End of day/mission/project Israeli delegation departs

RESULTS

Attenuation and Sensitivity

Lake Mohave Calibration Line

The altitude spiral flight over the Lake Mohave Calibration Line was used to derive the local effective air attenuation coefficient, obtain the sensitivity of both acquisition systems, and estimate their inherent background. The altitude spiral consists of passes between two waypoints programmed into helicopter navigation system over the land calibration line and water line at several different altitudes. During the exchange, the altitudes were 50, 100, 200, 300, 750, 1500, and 3000 ft AGL. The path plots of the altitude spiral flight plotted independently by both groups are presented in Figure 21.

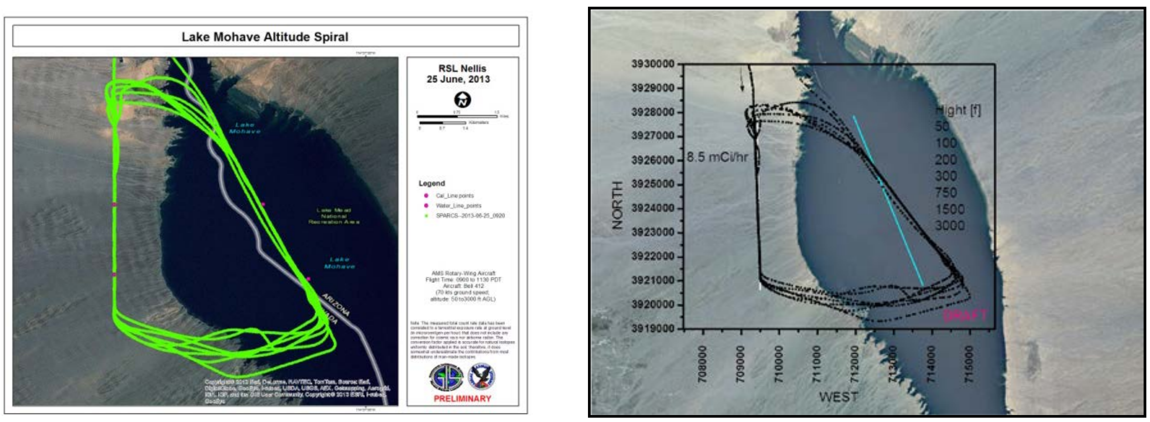


Figure 21. Path plot of the altitude spiral over Lake Mohave processed by AMS (left) and IAEC (right)

The count rate ratio of the SPARCS single 2″ × 4″ ×16″ NaI detector to the AirRAM 2000 two 2″ × 2″ inch detectors of about 18 (Table 2) compares very well with the ratio of volumes between systems of 16 [128 inch^3 (2″ × 4″ × 16″)/8 inch^3 (2″ × 2″ × 2″)].

From the altitude spiral, the effective air attenuation coefficient and sensitivity of the detectors can be derived by plotting each altitude flight's net gross counts versus altitude on a semi-log plot (Figure 22) and exponentially fitting the gross counts expression:

$$C_{alt} = C_{GC} \times e^{\mu_{air} \times (H - H_{avg})}$$

where

- C_{alt} = gross counts normalized to the averaged survey altitude, (cps).
- C_{GC} = total terrestrial count rate or gross counts, (cps).
- μ_{air} = gamma ray air attenuation coefficient, ft^{-1}.
- H, H_{avg} = average radar altitude, ft AGL.

Then, a value of the effective gamma ray air attenuation coefficient, μ_{air}, and the system sensitivity was deduced empirically from the altitude profile data for each flight over the Lake Mohave calibration line. From the analysis of the SPARCS data by AMS (Figures 22, 23, and 24), the air attenuation coefficient was 0.001662 ft^{-1}; from AirRAM data, the air attenuation coefficient was 0.001856 ft^{-1}. The independent analysis of AirRAM data by IAEC yielded an attenuation coefficient of 1/485=0.00206 ft^{-1}. The sensitivities of the systems were derived by dividing the CR_{GC} by the ground terrestrial exposure rate at the calibration line of 8.5 μR hr^{-1}. Estimated SPARCS sensitivity was 325 cps/μR hr^{-1}; AirRAM sensitivity was 19 cps/μR hr^{-1}. The IAEC estimated independently their sensitivity in terms of net counts as 163/8.5 μR hr^{-1} = 19 cps/μR hr^{-1}.

Table 2. Average count rate from different detectors at the calibration line

Altitude (ft)	Count rate (cps)					
	Land Line			Water Line		
	SPARCS NaI 2″×4″×16″	AirRAM two NaI 2″×2″	Count Ratio	SPARCS NaI 2″×4″×16″	AirRAM two NaI 2″×2″	Count Ratio
50	2620	151	17	159	11	14
100	2450	141	17	155	10	16
200	2139	118	18	165	11	15
300	1887	102	18	172	10	17
750	993	53	19	190	12	16
1500	405	22	18	173	11	16
3000	223	13	17	196	12	16

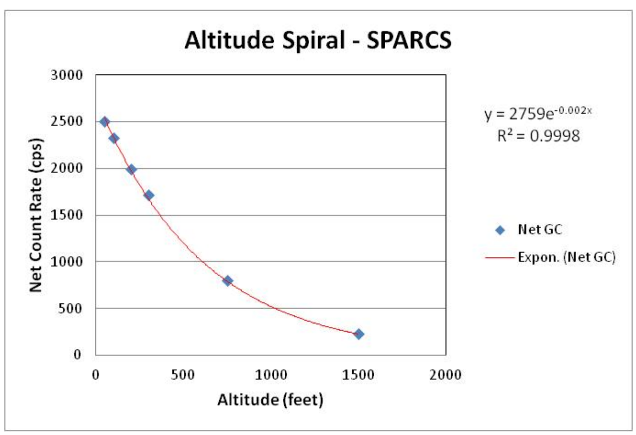


Figure 22. Results of the curve fit into altitude spiral data acquired with SPARCS and analyzed by AMS

AMS typically does the fit on the lognormal scale, resulting in the straight line fit to the data (Figures 23 and 24).

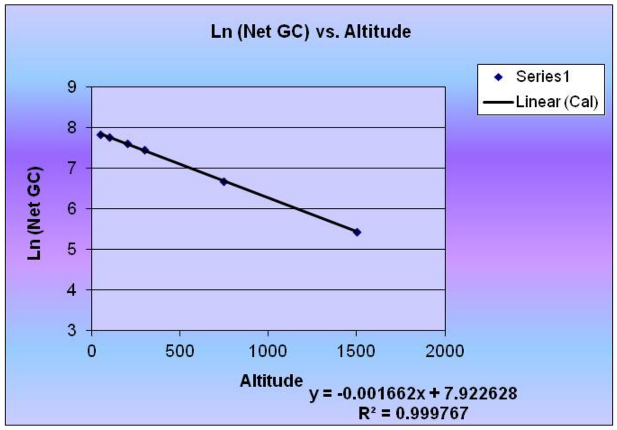


Figure 23. Altitude profile data fit on the lognormal scale on SPARCS results

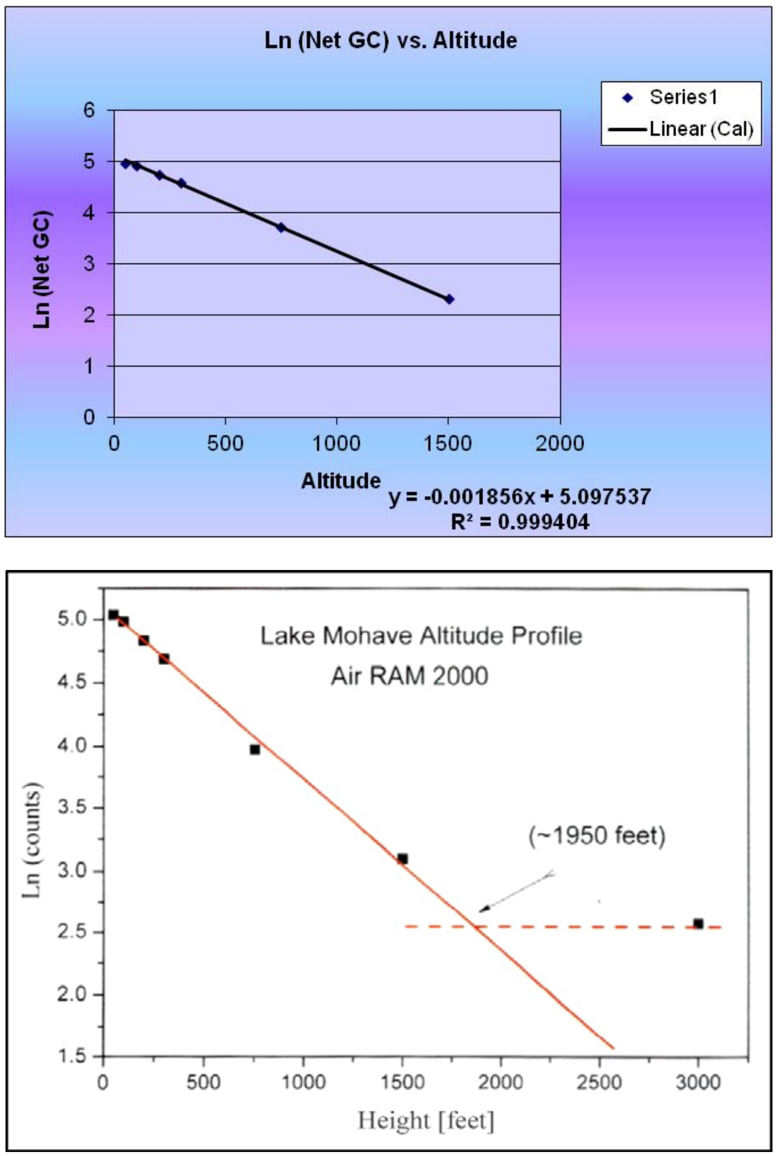


Figure 24. Results of the curve fit of the altitude spiral data collected with AirRAM and analyzed by IAEC (top) and AMS (bottom)

Desert Rock Airport Sources Overfly

Three radioactive sources listed in Table 1 were placed approximately 1500 ft (450 m) apart along the runway at the Desert Rock Airport (Figure 25). Using the visual flight rules, several passes directly over the sources (marked with orange cones) were executed. To study the response of the SPARCS and AirRAM, the flight altitude and speed were varied from 50 to 150 ft AGL and from 35 to 150 knots. The results of the source flyover are presented in Figures 26–32. The SPARCS data (gross counts from the 2″ × 4″ × 16″ NaI crystal) show an elevated count rate at any combination of flight altitude and speed tested, from 50 ft AGL at 50 knots to 150 ft AGL at 100 knots. The AirRAM, due to much lower detector volume, failed to detect the smaller ^{60}Co source at 100 ft and both ^{60}Co sources at 150 ft AGL. A higher flight speed of 100 knots, combined with lower sampling frequency (sample every 2 seconds) affected the AirRAM capability to spatially locate the sources (Figures 28, 31, and 32).

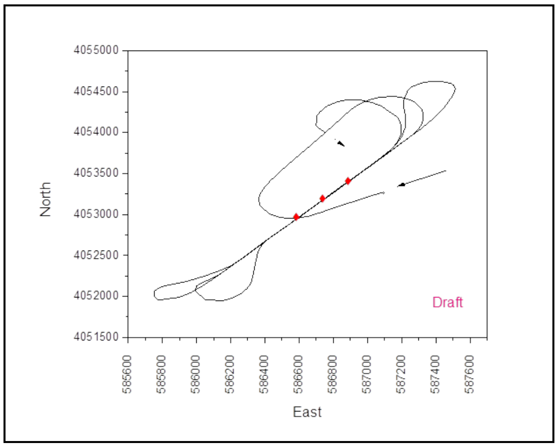


Figure 25. Locations of the sources at Desert Rock Airport as viewed by the IAEC team

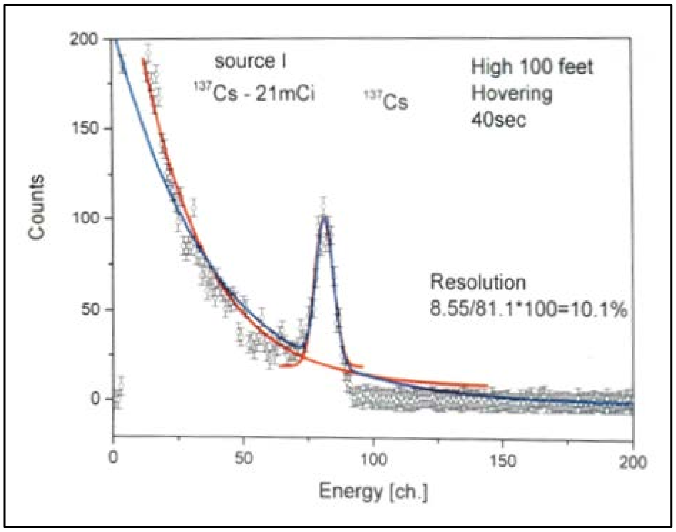


Figure 26. Spectrum of ^{137}Cs source collected by AirRAM 2000 by hovering over the source

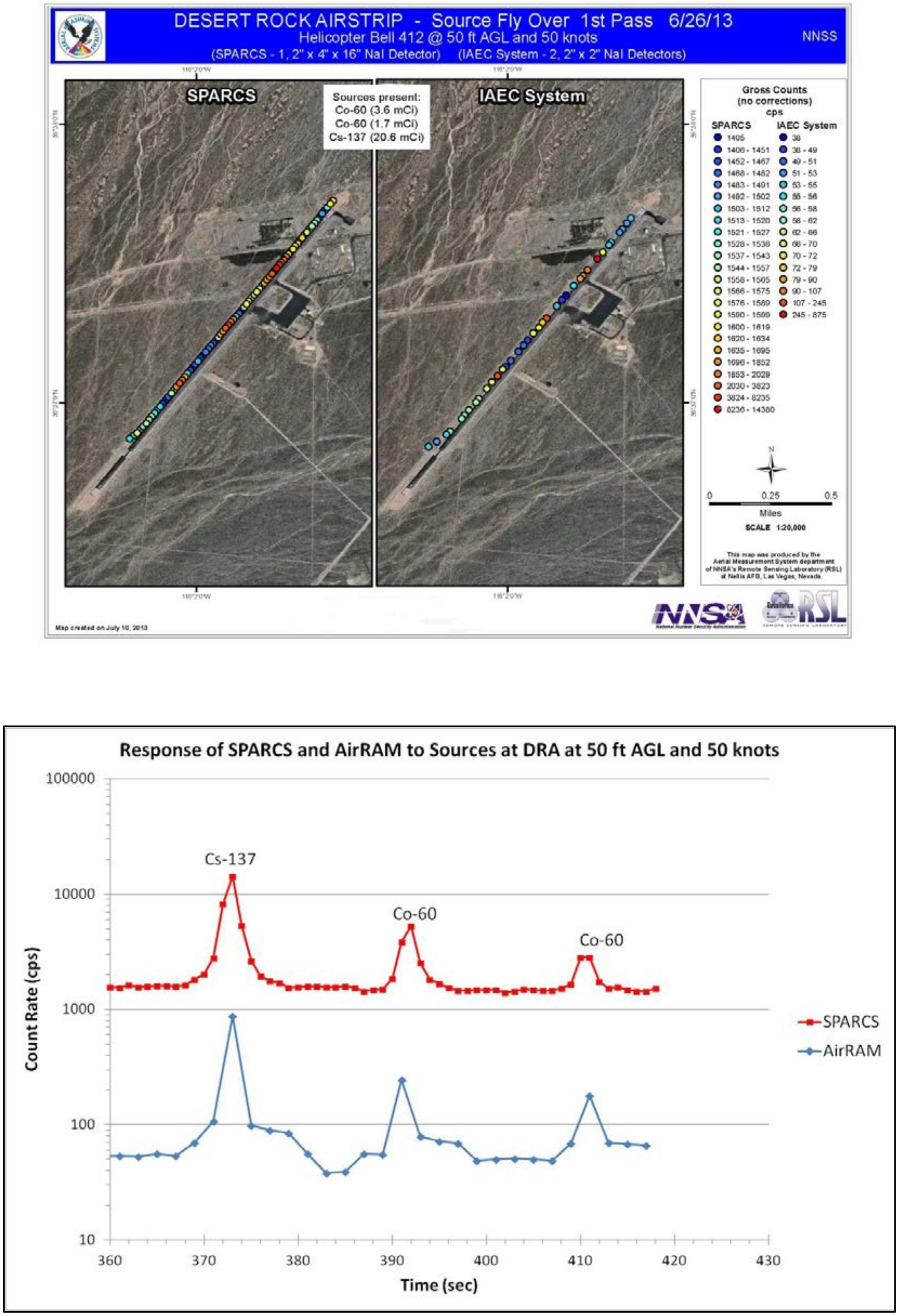


Figure 27. Source flyover at Desert Rock Airport at 50 ft AGL altitude at 50 knots ground speed presented spatially (top) and as time series (bottom)

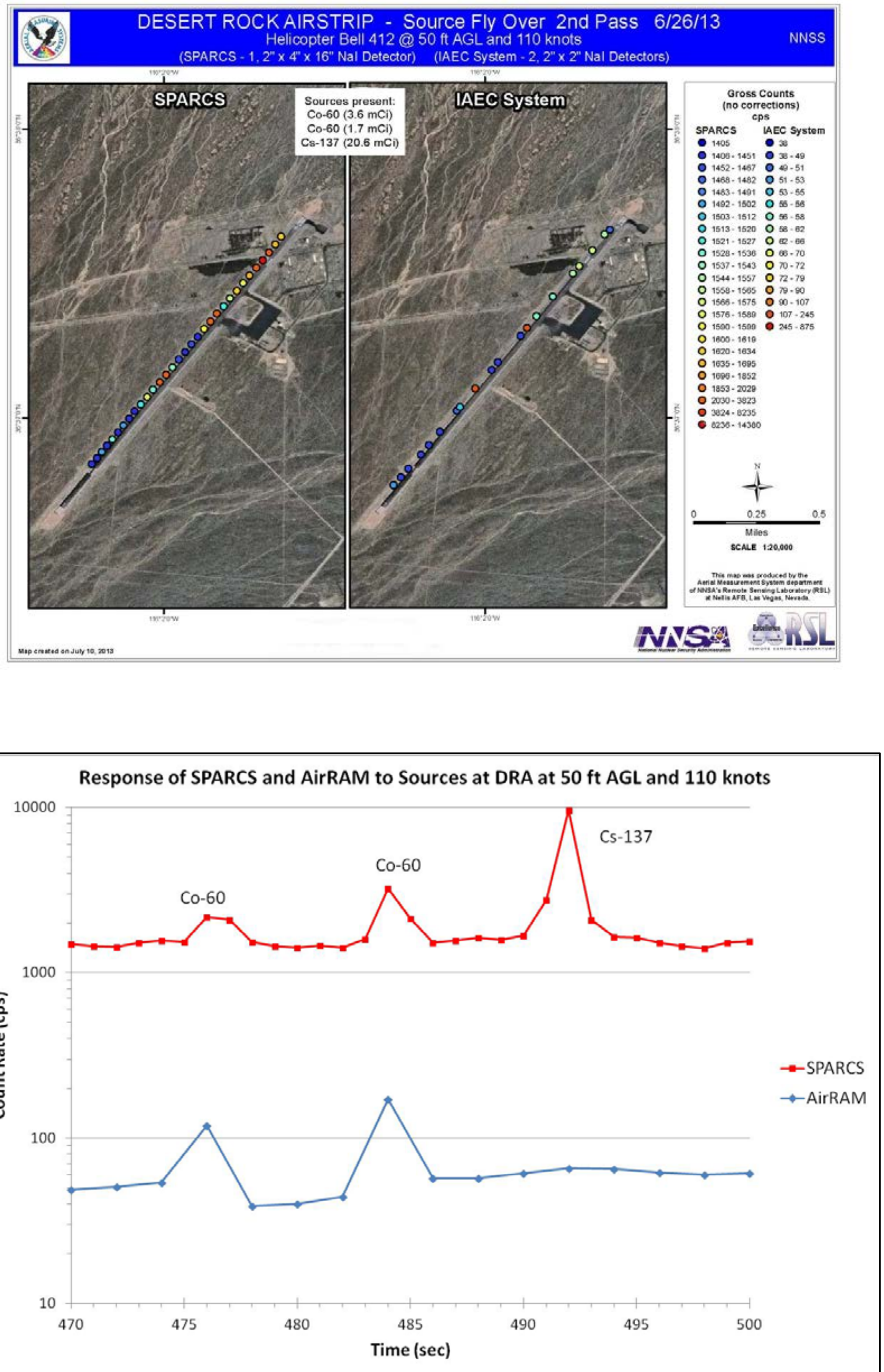
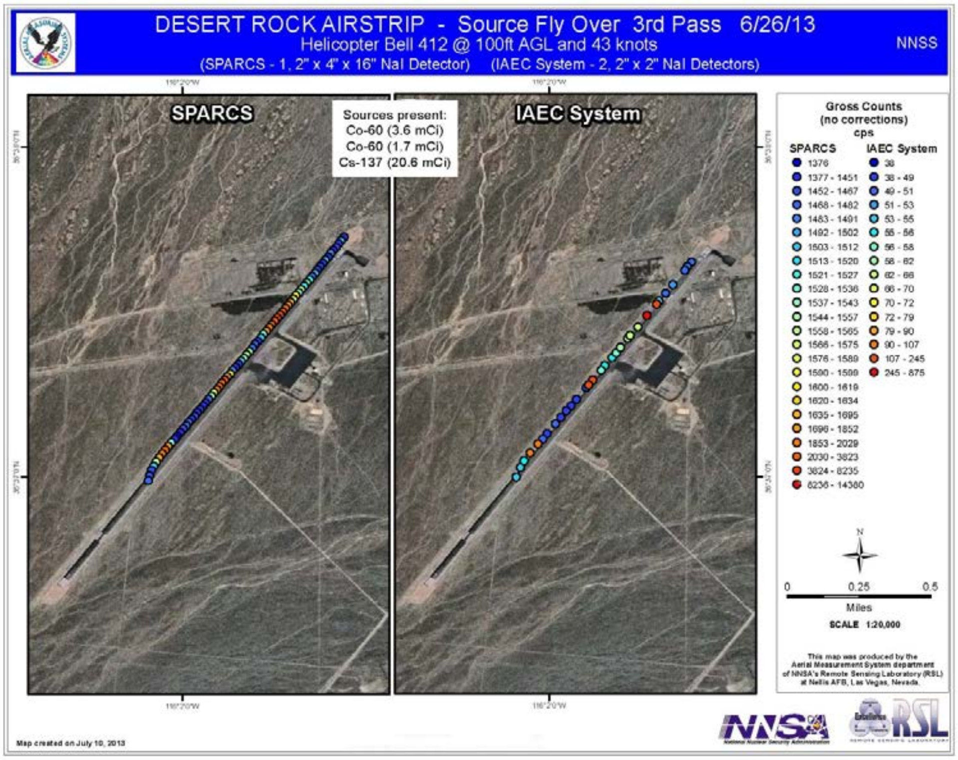


Figure 28. Source flyover at Desert Rock Airport at 50 ft AGL altitude at 110 knots ground speed presented spatially (top) and as time series (bottom)



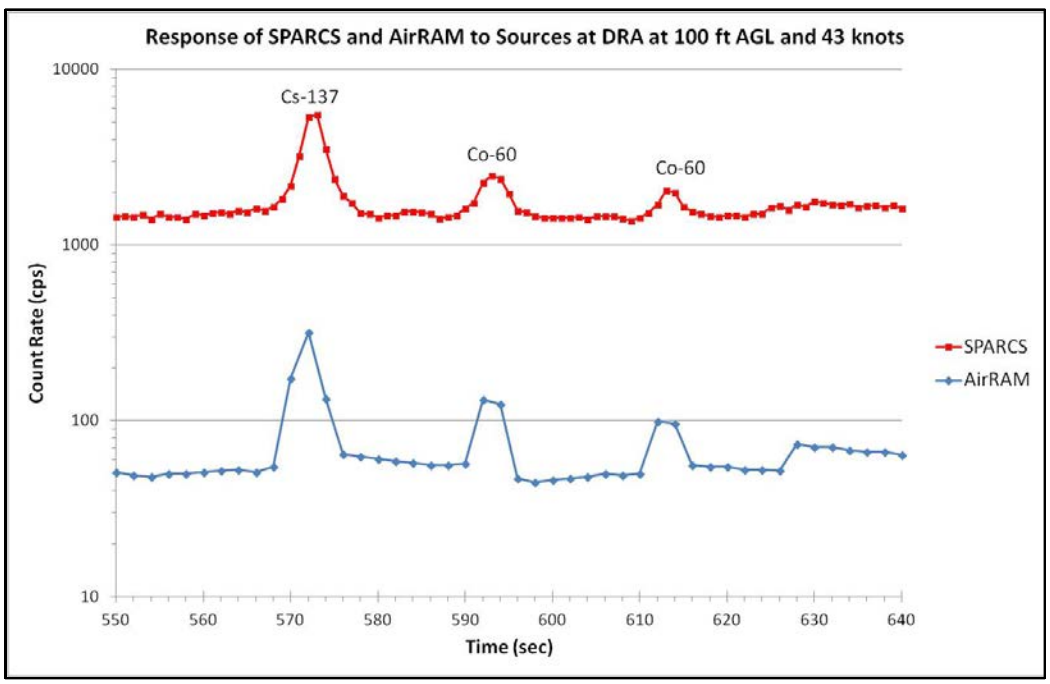
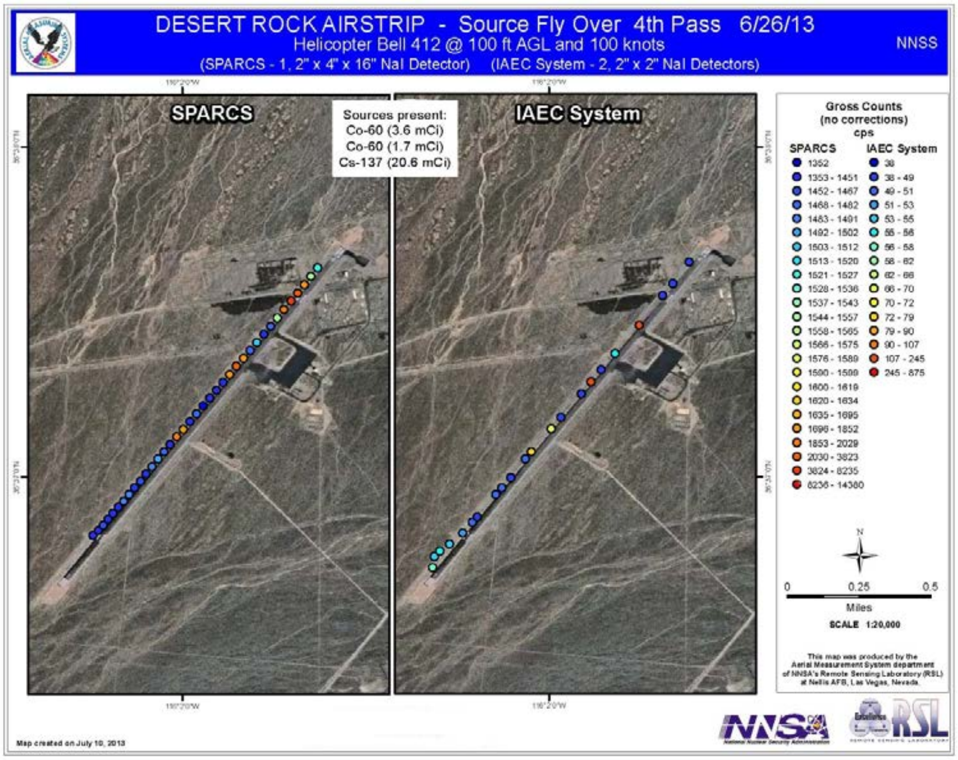


Figure 29. Source flyover at Desert Rock Airport at 100 ft AGL altitude at 43 knots ground speed presented spatially (top) and as time series (bottom)



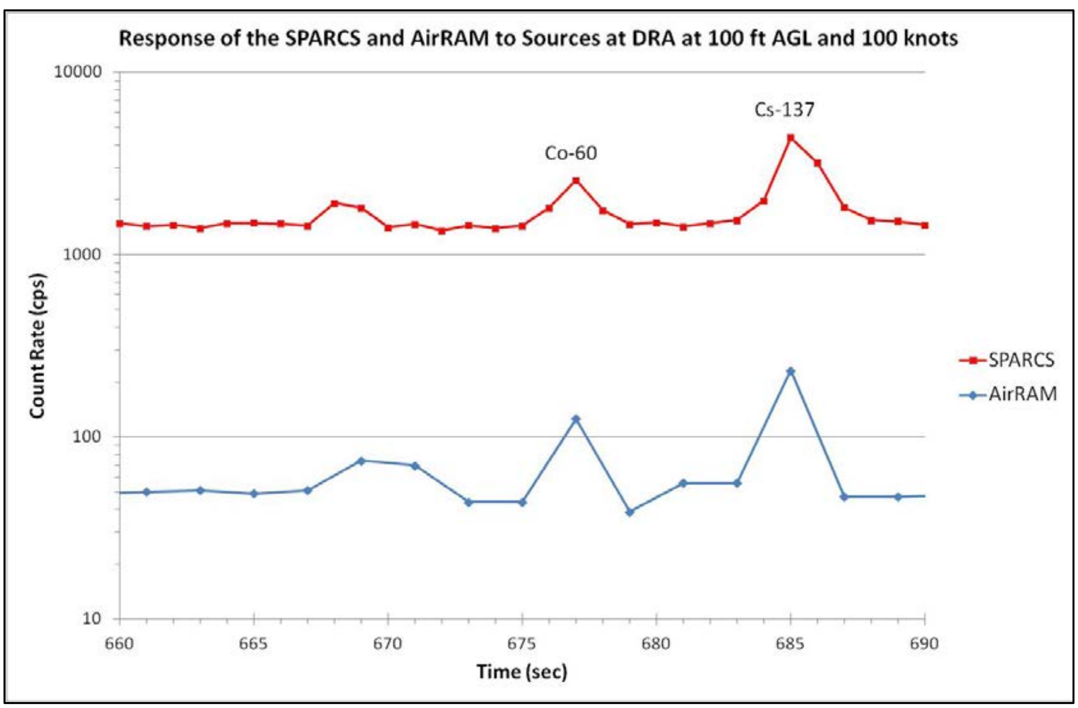


Figure 30. Source flyover at Desert Rock Airport at 100 ft AGL altitude at 100 knots ground speed presented spatially (top) and as time series (bottom)

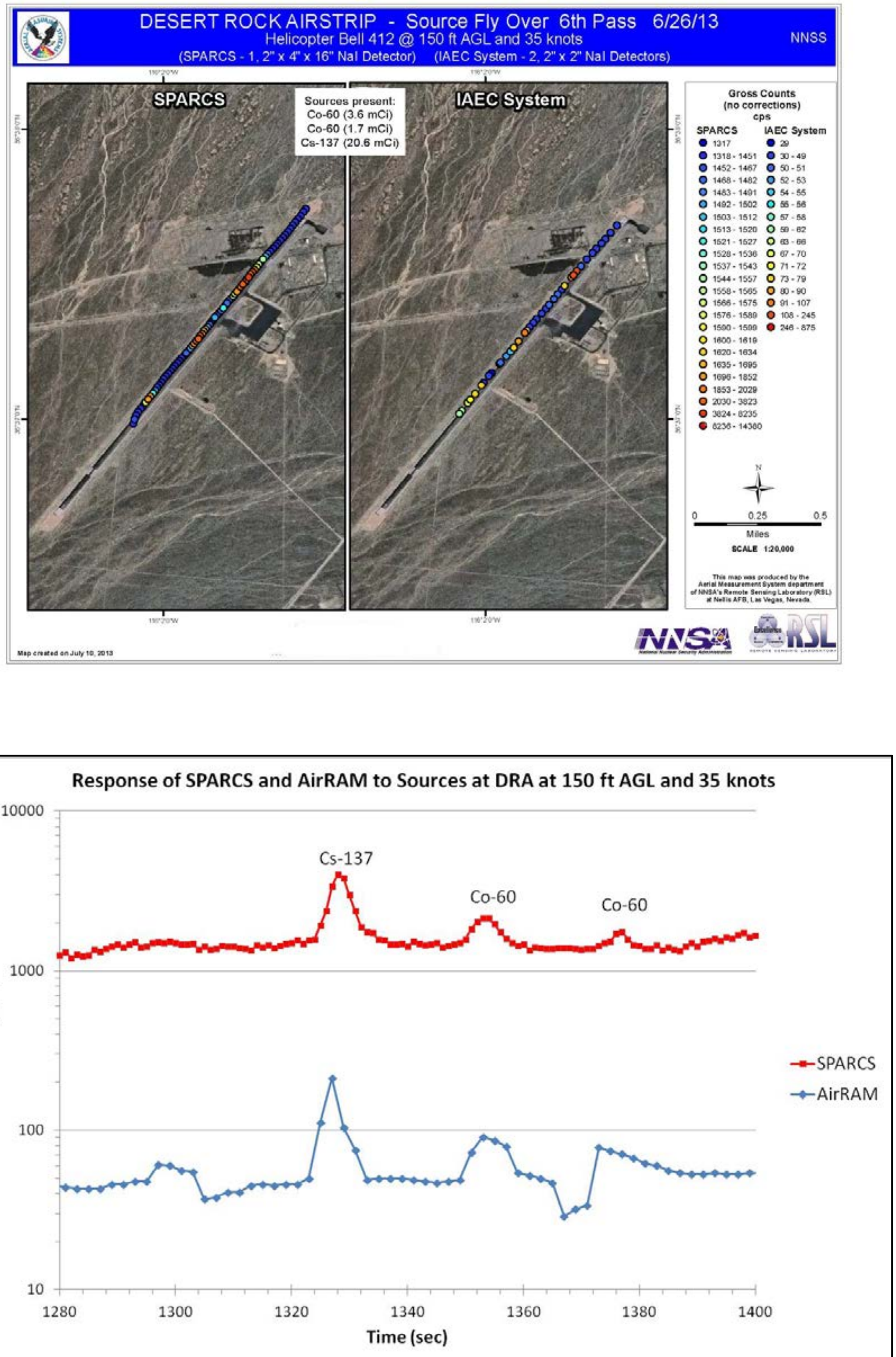


Figure 31. Source flyover at Desert Rock Airport at 150 ft AGL altitude at 35 knots ground speed presented spatially (top) and as time series (bottom)

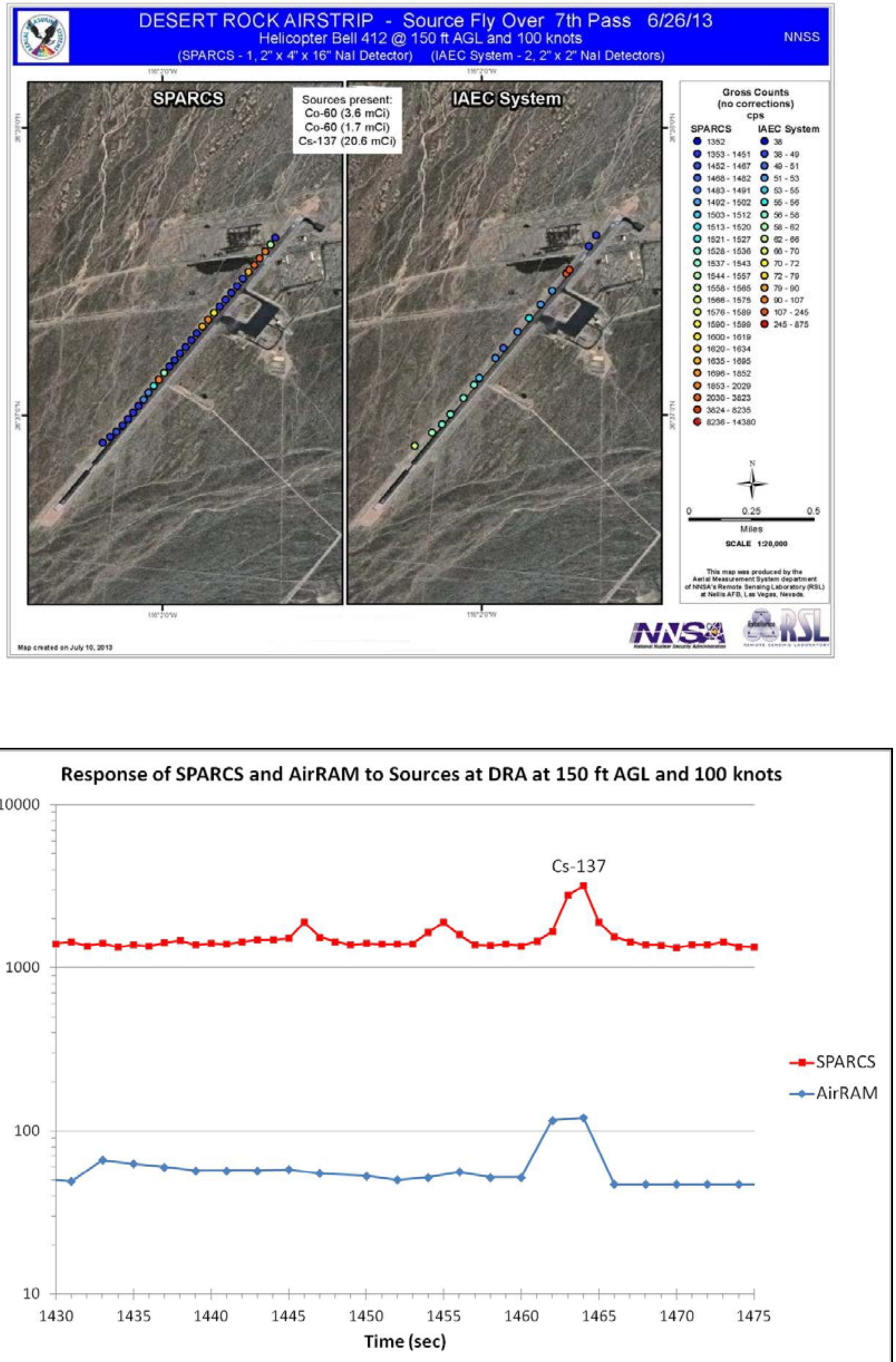


Figure 32. Source flyover at Desert Rock Airport at 150 ft AGL altitude at 100 knots ground speed presented spatially (top) and as time series (bottom)

Contours

Natural Background

To compare responses of the SPARCS and AirRAM to variable natural radiation background, the AMS test/evaluation area (Government Wash) was surveyed using standard AMS techniques of flying uniformly spaced parallel lines over survey area. The actual flight lines flown during the exchange are shown in Figure 33.

The data collected during the flight over Government Wash were processed in three different ways:

- AMS processed data collected with SPARCS
- AMS processed data collected with AirRAM
- IAEC processed data collected with AirRAM

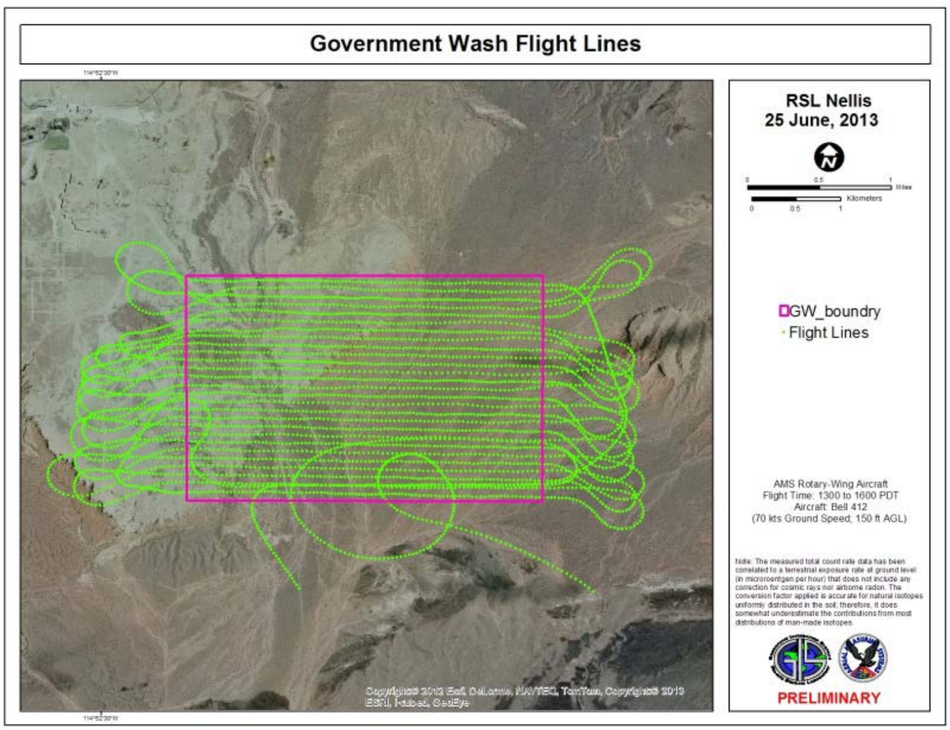


Figure 33. Flight lines of the Government Wash survey

Resulting contour plots of the gross counts derived from data collected by SPARCS and AirRAM, and processed with AMS and IAEC methodology, are presented in Figures 34, 35, and 36.

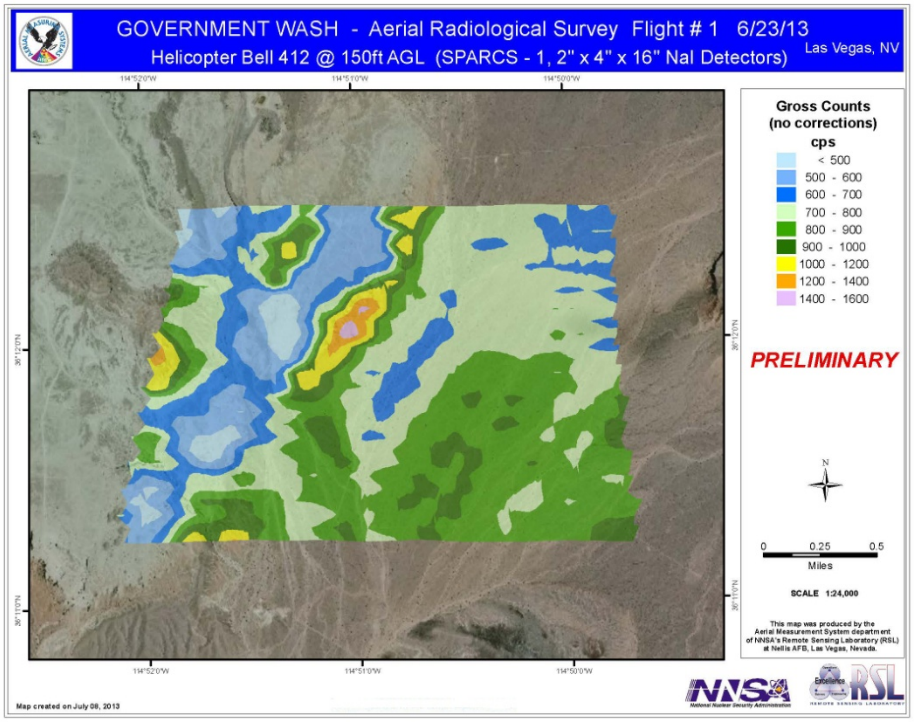


Figure 34. Gross-count contour of the natural background area (Government Wash) created using the AMS detection system SPARCS and AMS processing techniques

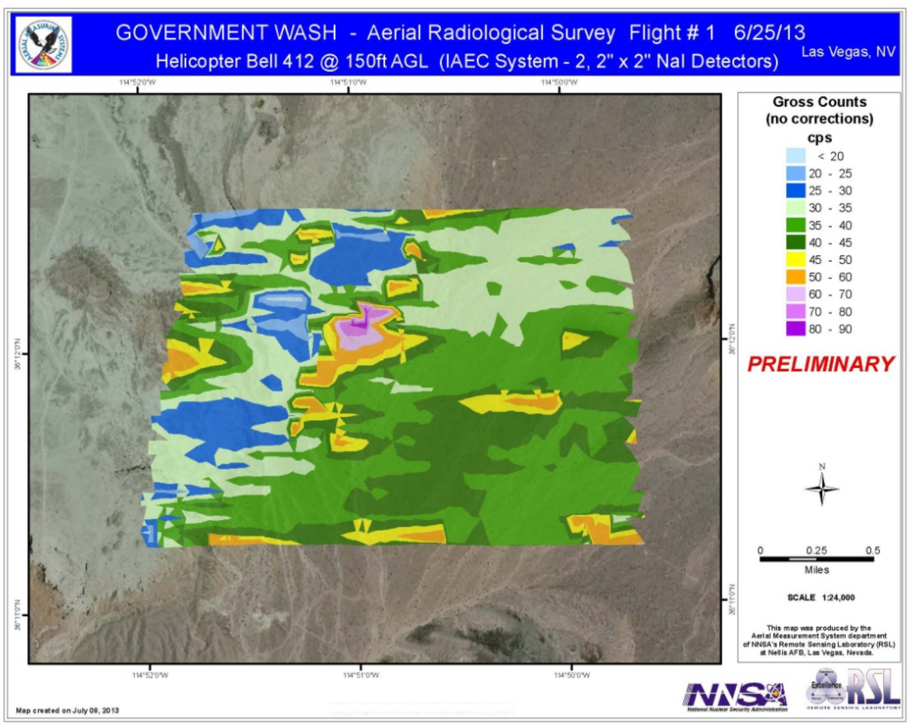


Figure 35. Gross-count contour of the natural background area (Government Wash) created using IAEC AirRAM detection system and AMS data processing techniques

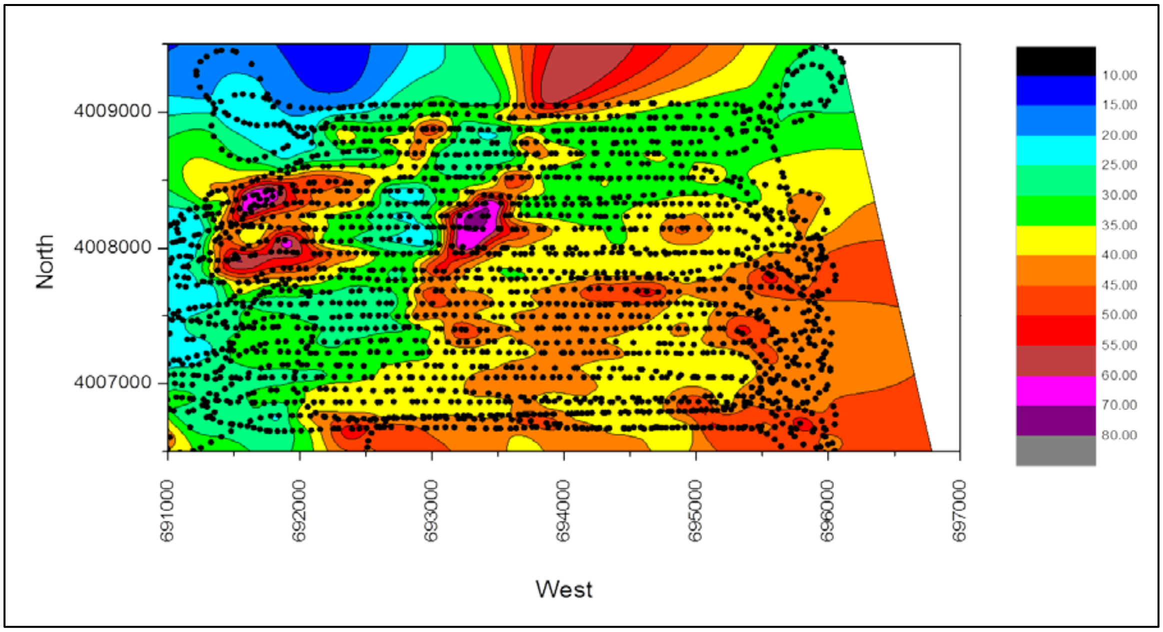


Figure 36 Gross-count contour of the natural background area (Government Wash) created using the IAEC AirRAM detection system and IAEC data processing techniques

Despite the difference in count rates (SPARCS in hundreds of cps and AirRAM in tens of cps), break values, and color scales, the major contour features are visible on all three plots. Again, the lower sampling frequency (measurement every 2 seconds) used by AirRAM affects the spatial quality of the data. At the typical aircraft survey speed of 70 knots, the aircraft covers 120 ft (36 m) every second, and 240 ft (72 m) every 2 seconds. At an altitude of 50 ft, the detector field of view is about 100 ft (30 m) diameter, so the lower sampling frequency results in missing coverage. Comparing the data treatment and contouring methodology used by AMS and IAEC, the main difference is the inclusion of the turns and transition between survey lines into the final IAEC contours. AMS rejects all the data outside the defined survey boundaries (purple rectangle in Figure 33). The aircraft turns are typically associated in the change of altitude as well as the aircraft pitch and roll, which changes the field of view of the detection system.

NNSS Area 3

Area 3 of the NNSS is contaminated with mixed fission products (^{137}Cs, ^{60}Co), as a result of three nuclear tests carried out in close proximity to each other. The survey area was therefore defined in the radiologically most interesting part of the Area 3 (purple polygon in Figure 37). The flight lines presented in Figure 37 are the results of GPS receiver malfunction during flight and frequent GPS dropouts.

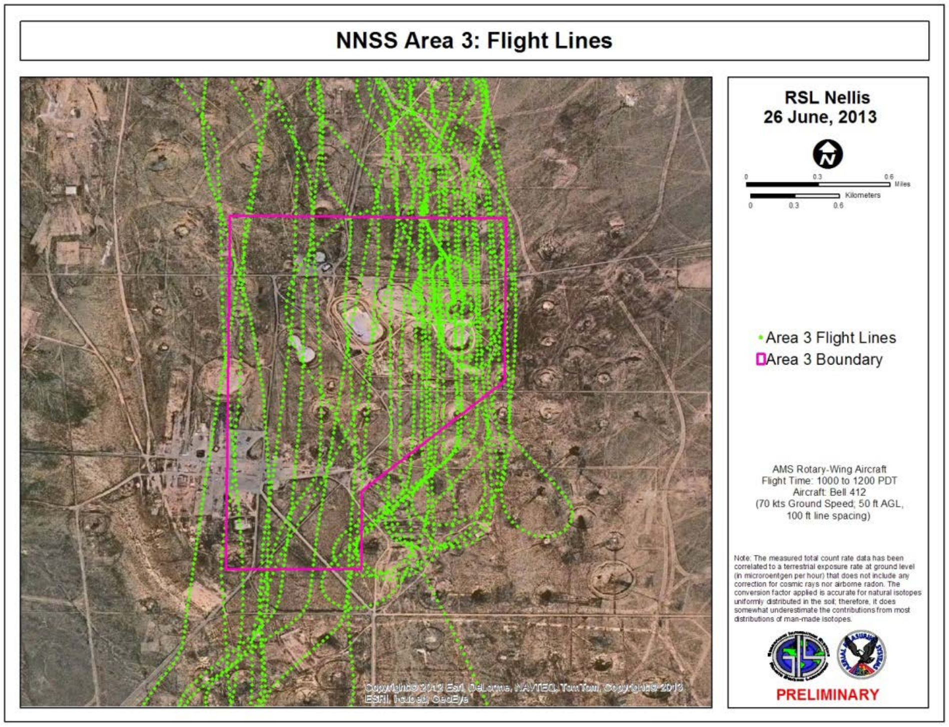


Figure 37. Flight lines of the Area 3 survey

In regards to data analysis, an approach similar to the Government Wash survey was used:

- AMS processed data collected with SPARCS
- AMS processed data collected with AirRAM
- IAEC processed data collected with AirRAM

Resulting contour plots are presented in Figures 38, 39, and 40.

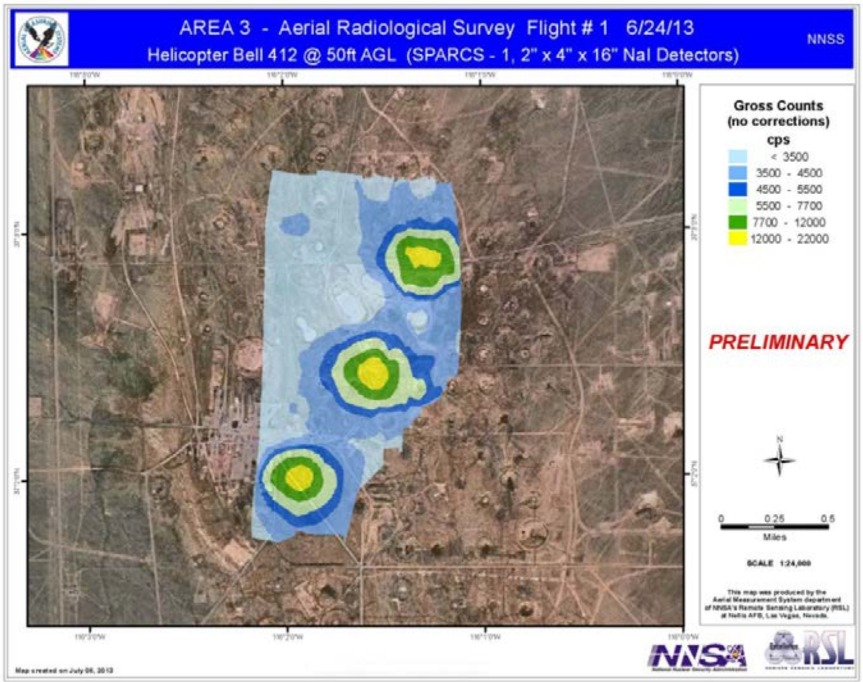


Figure 38. Contour of gross counts activity from Area 3 created using AMS SPARCS detection system and AMS data processing techniques

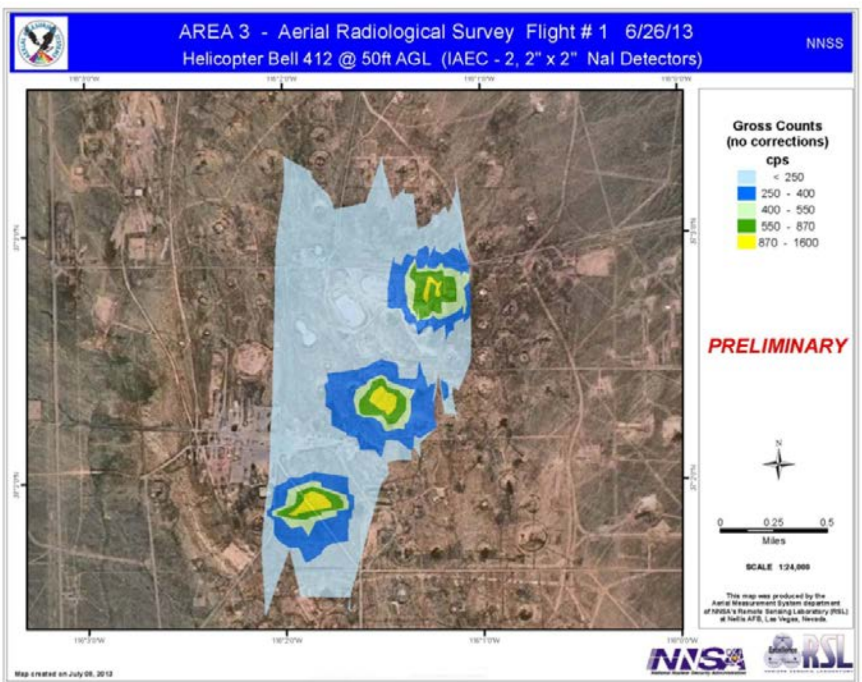


Figure 39. Contour of gross count activity from Area 3 created using IAEC AirRAM detection system and AMS data processing techniques

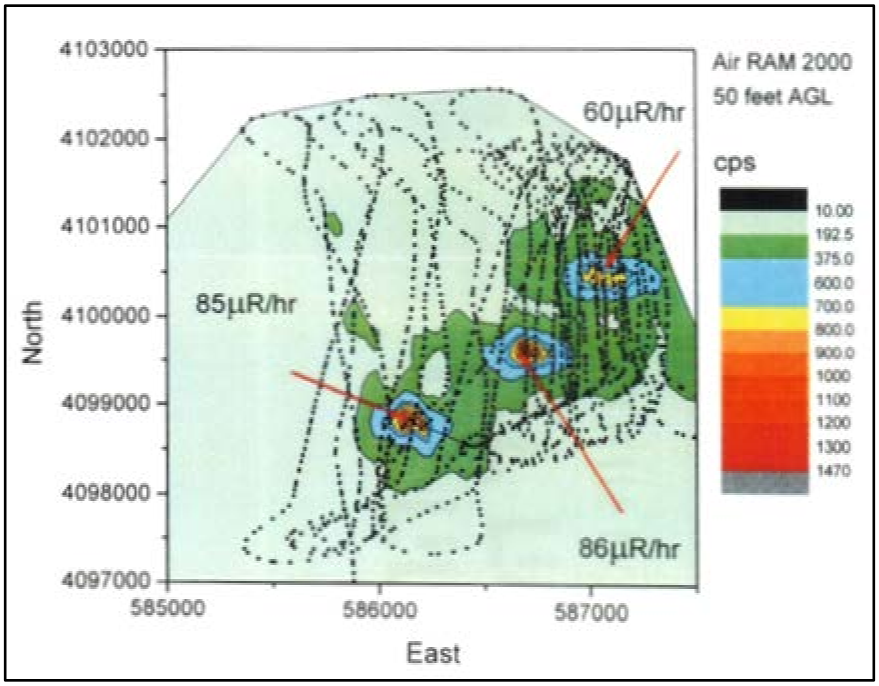


Figure 40. Contour of the gross count activity from Area 3 created using IAEC AirRAM detection system and IAEC data processing techniques

Again, as was the case of the Government Wash, all three gross-count contour maps show similar main features at the three bull's-eyes. Here as well the counting statistics are significantly different (SPARCS in thousands cps, AirRAM in hundreds cps). The interpolation method used by the IAEC software produces smoother contour isolines than the triangulation methods ("tins") used by AMS. The IAEC does not use commercial mapping software and relies on a custom in-house developed software package for data processing. AMS has an obligation to produce products for wide distribution; therefore, all AMS map products are made using the commercial ESRI ArcGIS software.

AMS carried out additional analysis on the SPARCS data: man-made and spectral extraction. The methodology is described in the Data Evaluation section of this report. These two additional ways of handling spectral data and resulting contour plots is an example of the standard products that AMS provides during emergencies (Figures 41 and 42). An example of spectral analysis by IAEC is presented in Figure 43, showing the integrated spectrum from one of the Area 3 bull's-eyes.

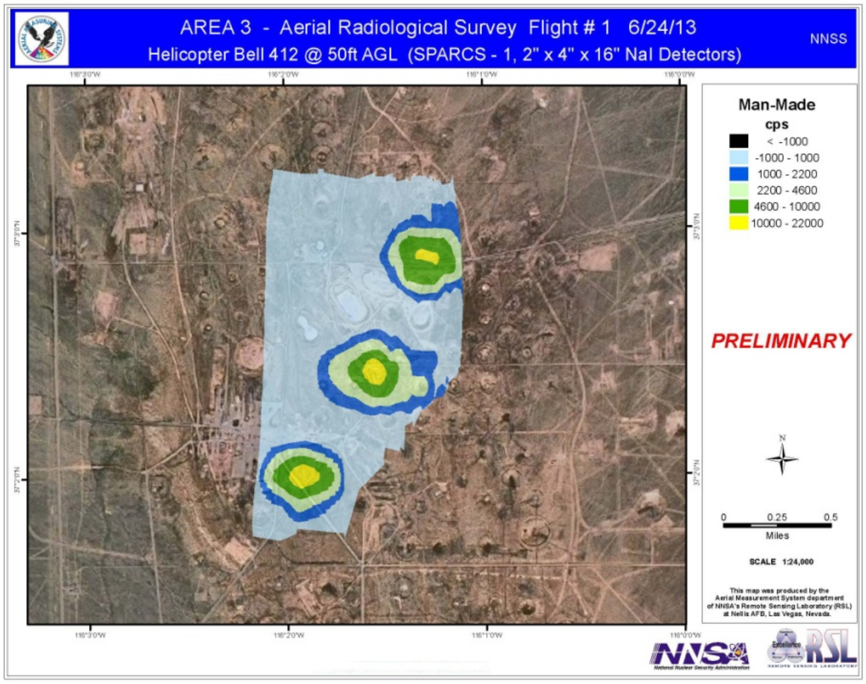


Figure 41. Area 3 man-made count rate extraction from the SPARCS data

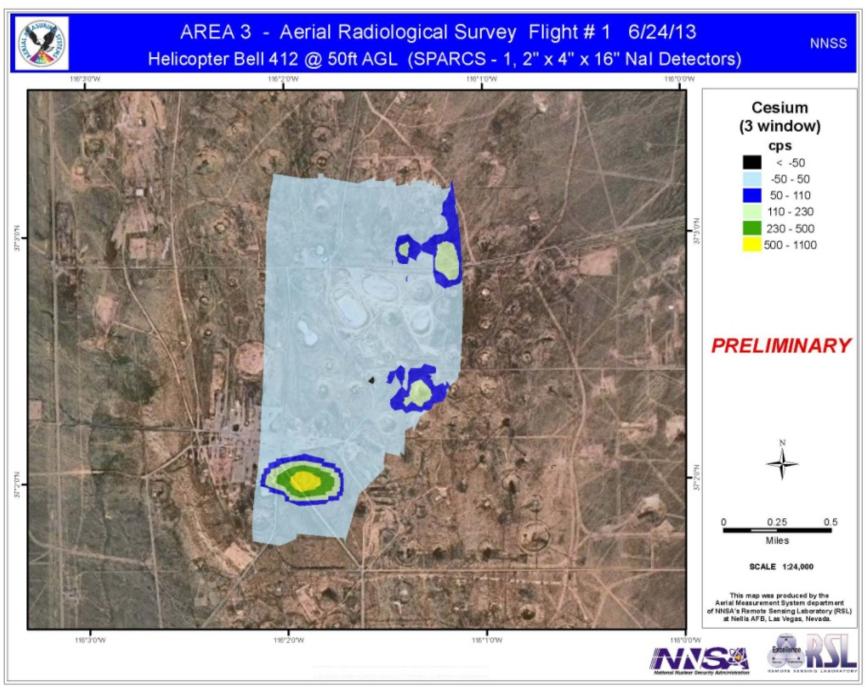


Figure 42. Area 3 ^{137}Cs spectral extraction from the SPARCS data

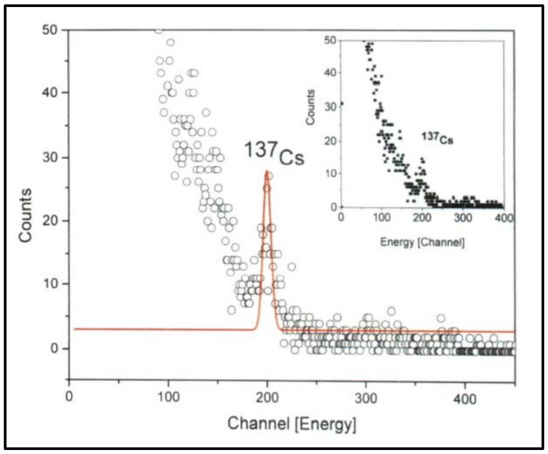


Figure 43. Typical spectrum collected by IAEC AirRAM, in this case during the Area 3 flyover

CONCLUSIONS

The ability to compare the aerial measuring techniques used by different groups involved in radiological emergency response is part of the DOE/NNSA's effort in recent years. In June of 2013, a group from IAEC flew their aerial acquisition system together with the U.S. AMS at natural background areas and over designated areas at the NNSS. AMS provided a Bell-412 helicopter and their radiation detection system for comparison. By coincidence both the U.S. and IAEC systems are custom designed units manufactured in their respective facilities. The similarity of the systems, with the exception of the NaI crystals sizes, allowed for comparison of the units' performance. For the study both systems were mounted as internal cargo. This is a similar configuration flown by AMS on other agency aircrafts, and the standard configuration for IAEC. The typical way of presenting extended sources (surface contamination) data is by color-filled contours. The AMS contouring technique was applied to the AMS and IAEC data showing very good agreement. The IAEC data were processed and contoured using the methodology and software developed by IAEC. All of the initial objectives of the 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.

In summary:

- All four missions (Government Wash, Lake Mohave, Desert Rock Airport, and Area 3) of the DOE AMS-IAEC Comparison Study were completed.
- The IAEC AirRAM 2000 can operate world-wide after some adaptation.
- The IAEC AirRAM 2000 and DOE SPARCS can collect radiation data during significant radiological incidents/accidents and get similar results.
- SPARCS offers higher sampling frequency of one measurement per second versus AirRAM's one measurement every 2 seconds, resulting in better spatial resolution.
- SPARCS has a significant advantage in terms of system sensitivity.
- AMS uses the dedicated steering instrument, helping pilots in precise flying of the pre-programmed survey lines.
- Further comparison between the two teams can improve the methodology and quality of the radiation surveys.

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APPENDIX A: PERSONNEL

Name	**Position**
Piotr Wasiolek	AMS Section Manager
Rusty Malchow	AMS Scientist
Leslie Winfield	Federal AMS Manager
Karen McCall	AMS Project Manager
Emanuele Avaro	Pilot
Ray Arsenault	Pilot
Jez Stampahar	Data Analyst
Mike Lukens	Electronic Technician
Tom Stampahar	Electronic Technician
Ken Braithwaite	Electronic Engineer
Jadus Hay	Operations Specialist
Shalom Shay Dadon	IAEC
Itzhak Halevy	IAEC
Matityahu Sheinfeld	IAEC
Shachar Rofe	**IAEC**

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National Nuclear Security Administration

Nevada National Security Site

Aerial Measuring Systems

Israel Atomic Energy Commission
הוועדה לאנרגיה אטומית