Innovative Gamma Ray Spectrometer Detection Systems for Conducting Scanning Surveys on Challenging Terrain – 13583

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ABSTRACT

The Santa Susana Field Laboratory located near Simi Valley, California was investigated to determine the nature and extent of gamma radiation anomalies. The primary objective was to conduct gamma scanning surveys over 100 percent of the approximately 1,906,000 square meters (471 acre) project site with the most sensitive detection system possible. The site had challenging topography that was not conducive to traditional gamma scanning detection systems. Terrain slope varied from horizontal to 48 degrees and the ground surface ranged from flat, grassy meadows to steep, rocky hillsides. In addition, the site was home to many protected endangered plant and animal species, and archeologically significant sites that required minimal to no disturbance of the ground surface. Therefore, four innovative and unique gamma ray spectrometer detection systems were designed and constructed to successfully conduct gamma scanning surveys of approximately 1,076,000 square meters (266 acres) of the site.

INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) conducted an extensive radiological characterization of the Santa Susana Field Laboratory (SSFL) from 2009 to 2012 on behalf of the United States Department of Energy (USDOE) in accordance with an interagency agreement. The SSFL is located in southeastern Ventura County, California, approximately 30 miles from downtown Los Angeles and was the site of approximately 40 years of USDOE nuclear reactor research and associated activities in an area known as Area IV. One nuclear reactor, known as the Sodium Reactor Experiment, had a partial melt-down of the core in 1959 with a release of radioactive materials which caused heightened public interest in the SSFL facility. Many years later, during the decommissioning phase, intense public interest and scrutiny demanded the completion of a comprehensive radiological investigation of Area IV and an adjacent property (the Northern Buffer Zone), herein named the Study Area, to determine the extent and nature of radiological contamination in surface and subsurface soil. This investigation was performed to meet the requirements of the State of California’s Senate Bill 990 and subsequently the

Administrative Order on Consent (AOC) for Remedial Action between the State of California's Department of Toxic Substances Control and the USDOE [1], which required cleanup level to background concentrations.

The SSFL occupies a total of 11,530,000 square meters (2,850 acres) of developed and undeveloped land ranging between 573 meters (1,880 feet) and 655 meters (2,150 feet) above mean sea level. The Study Area occupies a total of 1,906,000 square meters (471 acres), in which terrain varies with from horizontal to 48 degrees and the ground surface ranges from flat, grassy meadows to steep, rocky hillsides. In addition, the site is home to many protected plant and animal species, and archeologically significant sites, which required minimal to no disturbance of the ground surface. [2]

The facilities at the SSFL supported many major space programs, from the earliest satellite launches to the Space Shuttle. Nuclear energy related research also took place at the SSFL from the mid-1950s until the mid-1990s. The USDOE and Atomics International operated the Energy Technology Engineering Center (ETEC) in Area IV, which was engaged in the development, fabrication, disassembly, and examination of nuclear reactors, reactor fuel, and other radioactive materials. Nuclear operations at ETEC included 10 nuclear research reactors, seven critical facilities, the Hot Laboratory, the Nuclear Materials Development Facility, the Radioactive Materials Handling Facility, and various test and radioactive material storage areas. [2]

A notable project that took place at the SSFL was the sodium reactor experiment (SRE), built by Southern California Edison and Atomics International. It was considered the first civilian nuclear plant in the United States and the first commercial nuclear power plant to provide electricity to the public by powering the nearby city of Moorpark in 1957. The SRE was also unique in that it used liquid sodium to cool the reactor core rather than traditionally using water-cooling. In 1959, there was a partial melt-down of the core that resulted in a release of radioactive materials to the surrounding environment. [2]

The gamma radiation investigation was conducted in the Study Area to determine the nature and extent of gamma emitting radiological contamination in surface soil, within the detection capabilities of the deployed gamma spectrometers. Data gaps remaining from previous investigations of the Study Area indicated the need for further characterization. The USEPA and USDOE made a commitment to the public and the SSFL Radiological Study Technical Workgroup to conduct gamma radiation scanning surveys over 100 percent of accessible surfaces within the Study Area. [3]

Real-time gamma radiation measurements were collected, and the data evaluated to determine the presence and location of gamma radiation anomalies (GRAYs) in surface and shallow subsurface soil. The gamma radiation results were an essential component of the overall investigation, and with other lines of evidence (previous soil samples results, geophysical anomalies, historical information, etc.), were used to target soil sample locations.

In the design of a typical gamma radiation scanning investigation, select radionuclides of concern are prioritized and targeted for detection at pre-defined concentrations. For this investigation pre-defined detection concentrations were not established and instead detection criteria were to achieve as low as possible detection limits in the field with commercially available detection systems. Therefore, gamma spectroscopy data was collected with large volume sodium iodide (thallium) (NaI(Tl)) detectors at low scanning velocities in close proximity to the ground surface. In addition, In Situ high purity germanium (HPGe) based static gamma spectroscopy measurements were collected for verification of potential gamma radiation anomalies (GRAYs).

DESCRIPTION

Four innovative and unique gamma radiation detection systems were designed and constructed to overcome the challenging terrain encountered at the SSFL, and to achieve the greatest detection sensitivity and ground surface coverage within project scope, budget and safety requirements. The detection systems were primarily fabricated from available commercially components. However, some custom-made components were specifically designed and constructed from conceptual plans to meet the unique project requirements. Each detection system varied by transportation mechanism but contained the same essential components: one to eight Radiation Solutions Inc. (RSI) 4-liter NaI(Tl) scintillation detector(s) each with a 1024-channel multi-channel analyzer, a lead shield, a Global Positioning System (GPS), a data acquisition and storage module, and a field computer with wireless communication. The RSI proprietary computer program RadAssist® was utilized to communicate with the detection systems and for data processing.

Transportation mechanisms included off-road telehandlers (similar to a forklift) with extension booms for flat areas, modified gasoline-powered, rubber track carriers for steep areas, and mules (Equus mulus) with a modified saddle and harness for rough terrain, and biologically and archeologically sensitive areas not accessible by other detection systems.

Most detectors were shielded with lead on all sides and on the top while the bottom had a 0.25-inch polycarbonate sheet “window.” The shield reduced background subsequently increasing the detector’s sensitivity and reducing shine from extraneous gamma rays from surrounding soil surfaces, objects, and the atmosphere.

The data storage console integrated gamma ray data collected by the RSI detectors and the GPS signal. Trimble® Model SPS852 GPS receivers with Zephyr™ II antennas, accurate to 10 centimeters or less (using a RTK base station), replaced less accurate GPS receivers initially deployed with the detection systems. Data was transmitted via wireless router to Panasonic Toughbook® (Model CF-30 or CF-19) field computers that operated RSI's RadAssist® and ESRI's ArcPad® software programs. These programs, along with detailed georeferenced aerial maps, survey areas, and up-to-date gamma scanning coverage maps, allowed the operator to simultaneously view real-time scanning information and monitor coverage progress while actively conducting surveys.

After the detection systems were constructed, sensitivity tests were performed to determine optimal operating parameters. Systems were tested for field of view (FOV), operating height, and maximum operating velocity. These parameters were maintained as constant as possible during field operations to ensure measurements were accurate, representative, and reproducible.

Enhanced Radiation Ground Scanner II

The Enhanced Radiation Ground Scanner II (ERGS II) design was based on the USEPA's preexisting Enhanced Radiation Ground Scanner I (ERGS I) detection system. The purpose of the ERGS I was to conduct ground surveys at select radioactive waste sites and during emergency responses. The ERGS II was very similar to the ERGS I and consisted of eight NaI(Tl) scintillation detectors enclosed in a lead and stainless steel shield. The shield was designed with forklift inserts allowing it to mount onto an industrial off-road telehandler equipped with all terrain wheels (Figure 1). A telehandler is similar to a forklift, but with an extension boom with forks, wider chassis, off-road wheels, hydrostatic transmission, and other features to increase maneuverability on variable terrain and soil conditions.

Figure 1: An ERGS II operator testing for proper scanning velocity before conducting surveys.

Due to the offset center of gravity, weight, and large turning radius of the telehandler, the ERGS II was operated primarily in open, flat or moderately sloping terrain. It was the preferred detection system because of its wide field of view (FOV), mobility, and high detection sensitivity.

The ERGS II consisted of two RSI RSX-4 detector units. Each RSX-4 contained a set of four 4-liter NaI(Tl) detectors housed in a carbon fiber casing. The two carbon fiber cases were enclosed in a lead and stainless steel shield designed by USEPA and constructed by Radiation Shielding, Inc. The electronic components were housed separately, on top of the shield. Both RSX-4 units were connected to an RSI RS-501 data storage console, which was also connected to GPS. Spectral and GPS data was transmitted via wireless router to a laptop mounted in the operator's cab of the telehandler, providing display of real-time data.

The detector was positioned so it was parallel to the ground at a height of 15 inches by adjusting the forks and boom of the telehander. Plastic guide chains were affixed to the ERGS II shield and provided a visual aid to the operator to ensure the proper height was maintained during scanning surveys. The operator viewed the ends of the chains touching the ground and received assistance by radio or hand gestures from an assistant prompting adjustments as necessary. To ensure that 100% of the accessible ground surface was scanned, a transect width of 72 inches was selected, which was approximately 85% of the calculated 86 inch FOV. Thus, an overlap of the FOV was obtained when scanning adjacent transects ensuring complete surface coverage. The operator maintained a maximum scanning velocity of 2 feet per second by monitoring the velocity through ArcPad®, which was modified to display velocity. Additional velocity control mechanisms were used depending on the specific telehandler in use; e.g., an adjustable rheostat for the throttle.

Dual Detector Track Mounted Gamma Scanner

The Dual Detector Track Mounted Gamma Scanner (TMGS) consisted of two RSI RSX-1 NaI(Tl) scintillation detectors in an individual carbon fiber casing partially enclosed (rear of detector case that contained only electronics was not shielded to reduce weight) in separate lead and stainless steel, copper-lined shields (Figure 2). The copper attenuated the 59 KeV gamma ray created from the interaction of higher energy gamma rays with the stainless steel and lead. The detectors were mounted on a modified CanyCom Model BP419, off-road, dual rubber-track carrier. The TMGS replaced the Wheel-Mounted Gamma Scanner (WMGS), not presented in this article, that caused excessive operator fatigue and did not perform efficiently on rough surfaces. The TMGS was capable of safely scanning significantly steeper slopes than the other detection systems, excluding the Single Detector Track Mounted Gamma Scanner (STGS).

Figure 2: TMGS operator conducting a gamma scanning survey on a steep gradient.

The TMGS was powered by a gasoline engine and featured hand controls for starting, stopping, steering, and changing gears. The detectors were mounted to the CanyCom body on an aluminum frame custom designed by the USEPA. The detectors on the TMGS were mounted parallel at a distance of 18.5 inches apart, as measured from the centerline of the detectors. A mounting bracket acted like a hinge to allow the detectors to move vertically for increased maneuverability on uneven terrain. A swivel wheel was installed on the front end of the carrier for maneuverability. Two modifications were made to enhance the durability of the TMGS in rough terrain; first, the solid rubber tracks were upgraded to the rubber integrated with forged steel to prevent the tracks from ripping, tearing, and stretching, and second, the stock yokes were upgraded to forged steel.

The TMGS electronics were contained in a metal case affixed to the vehicle. The case protected the contents from sudden inclement weather, damage if the vehicle rolled over, and airborne dust. Both detectors were connected to an RSI RS-701 data storage console, which was also connected to GPS. Spectral and GPS data was transmitted via wireless router to a laptop mounted on the CanyCom, providing display of real-time data.

The detectors were positioned parallel to the ground at a fixed height of 15 inches, requiring no adjustments by the operator as the hinged detector platform maintained the detectors at proper height. To ensure that 100% of the accessible ground surface was scanned, a transect width of 56 inches was used which was approximately 85% of the calculated 48 inch FOV. Thus, an overlap of the FOV was obtained when scanning adjacent transects ensuring complete surface coverage. A velocity test determined that the vehicle should not exceed full throttle in fourth gear to maintain a maximum scanning velocity of two feet per second. Reverse low was used while backing up. In conformance with project health and safety standards, the TMGS was operated on slopes up to 25 degrees. However, the vehicle was capable of accessing steeper gradients.

Single Detector Track Mounted Gamma Scanner

The STGS had the same design and features as the TMGS, except the detector mounting platform was designed for a single RSI RSX-1 detector (Figure 3). The STGS was more maneuverable than the TMGS but with a lower detection capability. Like the TMGS, the detector was positioned parallel to the ground at a fixed height of 15 inches. To ensure that 100% of the accessible ground surface was scanned, a transect width of 36 inches was used, which was approximately 85% of the calculated 30 inch FOV. Thus, an overlap of the FOV was obtained when scanning adjacent transects ensuring complete surface coverage. The STGS had a maximum two foot per second velocity and 25 degree slope gradient requirement like the TMGS.

Figure 3: STGS operator conducting a gamma scanning survey on a steep gradient.

Mule Mounted Gamma Scanner

The Mule Mounted Gamma Scanner (MMGS) system consisted of two RSI RSX-1 NaI(Tl) scintillation detectors in an individual carbon fiber housing partially enclosed (rear of detector case that contained only electronics was not shielded to reduce weight) in separate lead and stainless steel, copper-lined shields and the mule provided additional shielding on the inner sides of the detector. The detectors were attached to a metal frame with outriggers on each side of a modified mule saddle and harness, called the mule rig (Figure 4). The mule rig was mounted onto a mule (*Equus mulus*) guided by an experienced mule handler while a field technician provided additional guidance and technical support. The MMGS was developed and employed for its maneuverability and ability to scan steep, rough, and vegetated terrain. It was also selected to scan in archeologically and biologically protected sites for its low impact and minimal ground disturbance where mechanized vehicles were not allowed to operate.

Figure 4: A mule handler leads the MMGS while conducting a gamma scanning survey on rough terrain.

Several mules were trained and deployed. Thus, the mule rig and outriggers were adjustable to maintain a constant detector-to-ground height and to allow for modest adjustments when different animals were deployed (the size and leg length of each mule varied). The mule rig was upgraded from steel to a primarily aluminum to reduce the weight and mule fatigue. All electronics were contained in a weatherproof, electronics housing affixed to a platform attached to the top of the mule rig.

Both detectors were connected to an RSI RS-701 data storage console, which was also connected to GPS. Spectral and GPS data was transmitted via wireless router to a laptop carried by a field technician, providing display of real-time data.

The detector height was set at 35 inches. The height of the detectors oscillated slightly as a natural consequence of the mule's gait. Periodically the mule rig needed adjusting and repositioning to maintain the correct height and to secure the rig to the mule. To ensure that 100% of the accessible ground surface was scanned, a transect width of 90 inches was used, which was approximately 85% of the calculated 104 inch FOV. Thus, an overlap of the FOV was obtained when scanning adjacent transects ensuring complete surface coverage. In addition, the field technician viewed the scanned surface coverage and followed behind or ahead of the MMGS and marked the ground with environmentally safe spray paint as a guide to the mule handler.

The mules were extensively trained to respond to commands given by the handler. They were taught to walk slowly, a challenging objective, in an attempt to maintain a maximum velocity of 3 feet per second. Occasional excursions beyond the maximum velocity were deemed acceptable as controlling a mule at all times was not possible or feasible. However, mainly due to the operating height, the MMGS was not as sensitive to variances in scanning velocity as the other detection systems.

DISCUSSION

A primary project objective was to collect gamma ray measurements with the most sensitive detection system possible. Therefore, the ERGS II was the preferred gamma scanning detection system due to its greater sensitivity and larger FOV. The ERGS II was used to survey areas of gentle to moderately sloping gradients with minimal presence of obstacles or ground disturbance. The gross weight of the telehandler and detector required caution on loose or loosely compacted soil and near obstacles; e.g., gas pipes, cables, fencing, boulders, low hanging tree limbs, etc.

The TMGS or STGS were utilized in areas inaccessible to the ERGS II. The TMGS and STGS were capable of surveying slopes of up to 25 degrees and over semi-rocky conditions. In addition, the narrow width and high maneuverability enabled these detection systems to operate around and over small obstacles. The STGS replaced the TMGS on steeper and more technically difficult terrain due to the lighter weight and smaller profile (single detector protruding from the front). Before the TMGS and STGS were developed and became operational, the MMGS had been deployed to conduct surveys where the ERGS II or WMGS were not capable of accessing. After the TMGS and STGS were operational, the MMGS was deployed in inaccessible area to the other three detection systems. The MMGS was often used to survey with minimal ground disturbance in protected habitat for endangered plants and animals, and archeologically (Native American) significant sites. The mules could step over small obstacles that allowed access to surfaces where mechanized equipment did not have adequate ground clearance.

Prior to scanning activities, the height of vegetation, such as grass and small bushes, was reduced to less than 6 inches by a landscaping crew. This allowed the detectors easier access and reduced potential attenuation of gamma rays. In addition, while conducting surveys, technicians could see surface obstacles and hazards that were previously hidden by the heavy vegetation.

Operation of each detection system required two field personnel: one operator (or mule handler) and one field technician who provided safety and technical assistance. During scanning, transects were overlapped to ensure complete 100% coverage of accessible surfaces. As previously discussed, transects were set at approximately 85% of the calculated FOV for each detection system to ensuring proper coverage.

Two survey patterns were employed, either linear transects or diminishing circles. The operator traversed a predefined transect, turned the detection system around and returned on the adjacent transect following the track or wheel marks or painted markings from the previous transect. On steep and rugged terrain, where turning safely was not possible, the detection system was backed down the slope adjacent to the previous transect. Diminishing circles were executed by scanning the outer boundary of a survey area, then continuing to survey in consecutively smaller circles or a spiral pattern while following the boundary of the previous circle until 100 percent of the accessible surface was scanned. In general, this approach increased efficiency and allowed for easier maneuverability. The visual map feature in RadAssist® or ArcPad® guided the operator during scanning to ensure 100% coverage.

Daily quality control (background and source response) and equipment inspections were conducted on all detection systems. Maintenance was performed periodically on a prescribed schedule and as needed, as the detectors, electronics, and transportation mechanisms underwent considerable stress from the elements and rough terrain.

Spectral and GPS data were downloaded daily and evaluated for statistical outliers, which were removed from the datasets. Two statistical data analyses were performed for each of the 10 predefined geographical areas; one comparing gross count rate measurements to a mean background count rate and one comparing radionuclide-specific gamma peak regions of interest to the total gamma spectrum. Colored coded maps were produced to display these statistical datasets for review and evaluation to identify Potential GRAYs (PGRAYs).

Statistical thresholds, based on a specific number of standard deviations above a mean, were calculated for various geographical areas and each statistical analysis. Results exceeding the threshold were flagged as PGRAYs, then further investigated. Static measurements with count times of 20 minutes were collected with an appropriate gamma scanning detection system at all PGRAYs to determine if the anomaly was due to naturally occurring radioactive materials

(NORM) or site-related contamination. If site-related contamination was suspected or results were inconclusive then a 20 minute static measurement with an HPGe detection system was collected. An evaluation of all data was performed to classify the PGRAY as a Confirmed GRAY or Not a GRAY.

A total of 217 PGRAYs were identified, of which 70 were classified as Confirmed GRAYs and 147 as Not a GRAY. Surface, and if warranted, subsurface soil samples were collected at all locations classified as a GRAY, but not at locations classified as Not a GRAY. Subsequently, radiochemical analyses of the soil samples were preformed, with specific analyses selected based on field gamma spectral data results and historical site assessment data. In general, soil sample results confirmed the presence of suspected site-related contamination. However, a rigorous correlation analysis is beyond the scope of this paper. [4]

CONCLUSION

Four innovative, custom designed gamma ray scanning detection systems were successful in collecting spectroscopic data on challenging terrain not possible by conventional, commercially available detection systems. The survey met the project objective to scan 100 percent of accessible surfaces with the most sensitive detection system possible. Approximately 1,072,000 square meters (265 acres) or 56.5% of a 1,906,000 square meters (471 acres) Study Area were surveyed. The remaining 829,600 square meters (205 acres) were classified as inaccessible.

Gamma ray spectral data was digitally mapped using high-resolution, geo-referenced databases to provide visual representations of results. Evaluation of results identified 217 PGRAYs, which were further investigated with in situ gamma spectroscopic techniques to classify 70 PGRAYs as Confirmed GRAYs and 147 PGRAYs as Not a GRAY. Subsequent soil sampling of each Confirmed GRAY with radiochemical analyses generally correlated with the initial assessments of these anomalies.

These unique and rugged detection systems are applicable to a wide range of investigation and remediation projects requiring radiological contamination assessment for gamma emitting radionuclides over large areas of ground surface. In addition, these detection systems can successfully survey areas with challenging terrain, including terrain previously considered inaccessible by traditional methods and equipment.

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