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Surface Radiation Survey at the Shepley's Hill Remediation Site, Devens, Massachusetts

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SUMMARY

The Idaho National Laboratory (INL) provided technical support for ongoing environmental remediation activities at the Shepley's Hill remediation site, near Devens, MA. The technical support included the completion of a radiation survey of naturally occurring radioactive materials (NORM) at Shepley's Hill, Shepley's Hill landfill cover, and Red Cove areas. The objective of the radiation survey was to assess the ability of the INL backpack sodium iodide spectroscopy (BaSIS) system to detect elevated levels of NORM that may be associated with radon-222 emanation from near surface and subsurface fractures in the area. It is postulated that these fracture zones provide subsurface conduits for the transport of environmental contaminants. As such, location of these fracture sets will proved EPA Region 1 with the means for completing the development of an accurate site conceptual model. The results of the radiological survey show that some of the radiological anomalies correlate with currently mapped rock outcrops; however, not all of the rock outcrops in the surveyed area have been mapped. As such, it is not conclusive that all of the radiological anomalies correspond with surface rock outcrops. EPA Region 1 intends to perform a more comprehensive correlation of the radiation data collected with the BaSIS system with additional data sets such as detailed bedrock structural mapping, 2-dimensional resistivity profiling, and high-resolution topographic mapping. The results of this effort will be used in consideration of designing a potential follow-on effort for mapping of radon.

ACKNOWLEDGEMENTS

The authors and INL would like to acknowledge EPA Region 1 and its contractors that supported this effort, along with the EPA Technical Support Project.

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ACRONYMS

BaSIS	backpack sodium iodide spectroscopy
CSM	conceptual site model
EPA	Environmental Protection Agency
GIS	geographic information system
GPS	global positioning satellite
INL	Idaho National Laboratory
LiDAR	light detection and ranging
NIST	National Institute for Standards and Technology
NORM	naturally occurring radioactive material
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

SURFACE RADIATION SURVEY AT THE SHEPLEY'S HILL REMEDIATION SITE, DEVENS, MASSACHUSETTS

1. INTRODUCTION

The Idaho National Laboratory (INL) recently provided technical support for ongoing environmental remediation activities at the Shepley's Hill remediation site, near Devens, MA (Figure 1). A formal request was made by the United States Environmental Protection Agency (EPA), Region 1 office in Boston, MA. The technical support was requested for the purposes of conducting radiation surveys using a portable backpack sodium iodide spectroscopy (BaSIS) system with real-time measurement and integrated geographic information system (GIS) capabilities.

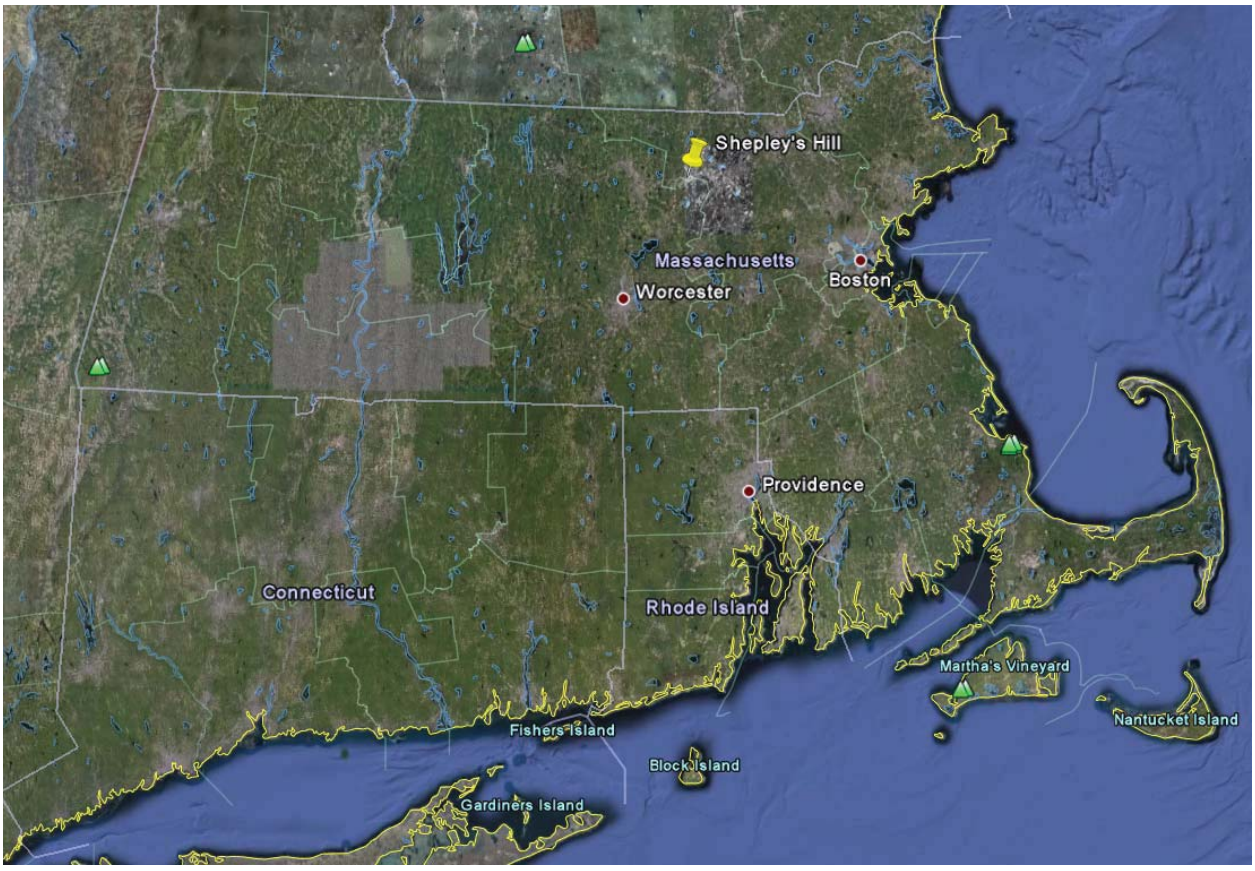

Figure 1. Location of Shepley's Hill site, near Devens, Massachusetts.

2. SHEPLEY'S HILL SITE DESCRIPTION AND OBJECTIVE

The current application involves using the BaSIS system to support an ongoing bedrock mapping project at an approximately 100-acre granitic bedrock upland area adjacent to the Shepley's Hill landfill. A detailed survey of this area was completed using the BaSIS system, including detailed maps indicating areas of elevated radiation, and contour plots of radiation intensity.

The fracture networks in the bedrock that underlie Shepley's Hill and the adjacent landfill are conduits for subsurface contaminant transport. As such, the EPA, Region 1 is conducting a detailed bedrock structural mapping program to identify the locations of the subsurface fracture zones. This study has included 2-dimensional resistivity profiling, high-resolution topographic mapping, and borehole geophysics.

In a search for non-invasive methods of identifying bedrock fractures, it was hypothesized that naturally occurring radioactive material (NORM); specifically radon gas, preferentially follows the bedrock fractures. As such, it is expected that radon concentrations, and subsequently the radioactive decay products, occur in higher concentrations above these fractures. The decay products of radon (specifically Rn-222) include several gamma-ray emitting radionuclides. The radium-226 (Ra-226) radioactive decay chain is shown in Figure 2. These decay products emit gamma-rays that can be detected with the NaI detector in the BaSIS. Therefore, the primary objective of the radiation measurements at Shepley's Hill was to determine whether or not the locations of bedrock fractures could be identified based on the relative concentrations of radon daughter products. Additionally, measurements of other naturally occurring radionuclides, K-40 and Th-232, were performed to evaluate whether or not their concentrations could be correlated to bedrock fracture sets.

The data and information presented in this report will be correlated with other data sets currently being collected by EPA Region 1, including detailed bedrock structural mapping, 2-dimensional resistivity profiling, and high-resolution topographic mapping such as light detection and ranging (LiDAR). It is expected that discrete areas of elevated radiation may correlate with bedrock fracture zones, mapped or unmapped. Additionally, EPA Region 1 intends to perform a more comprehensive correlation of the radiation data collected with the BaSIS system with additional data sets (e.g., bedrock structural data, high resolution topographic mapping, geophysical data, etc.). The results of this effort will be communicated to INL in consideration of designing a potential follow-on effort. The information will provide critical input toward developing a conceptual site model (CSM) for bedrock ground water flow at the site.

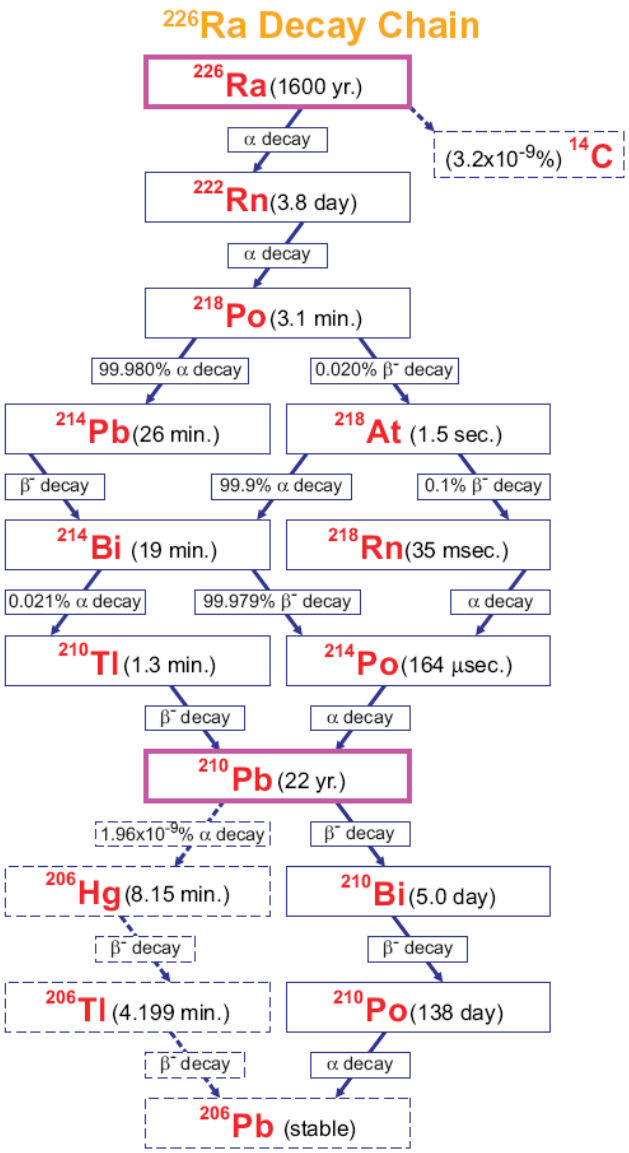

Figure 2**.** Radon-222 decay chain, starting with Ra-226.

3. EQUIPMENT DESCRIPTION

The BaSIS technology was developed at the INL for use at radiologically contaminated Cold War era legacy sites. These sites included the Fernald facility (Fernald, OH); Mound (Miamisburg, OH); East Tennessee Technology Park (Oak Ridge, TN). The system architecture has also been fully integrated into the soil remediation activities that are ongoing at the INL as part of the Idaho Cleanup Project.

The BaSIS system is comprised of commercial off-the-shelf equipment including a 3 in. × 5 in. sodium iodide (NaI) radiation detector, multichannel analyzer, real-time differential corrected global positioning system, a control computer and wireless display. Figure 3 shows the BaSIS system and operator in the field at the Shepley's Hill site. The radiation signatures measured by the NaI detector and the position data received by the Global Positioning Satellite (GPS) system are integrated in the control computer through software written by the INL. The wireless display provides the user interface to the BaSIS software controls.

Figure 3. BaSIS system and operator conducting radiation survey at Shepley's Hill site. Note: The radiation detector is to the left of operator.

The BaSIS software is customizable, and was configured specifically for deployment at the Shepley's Hill site. Figure 4 shows the main BaSIS control screen as configured for the work at Shepley's Hill. As seen on the main screen, the operator has an indication of the operational condition of the radiation measurement system and the GPS. From the main screen, the operator has the option to

collect background data prior to beginning a survey, as well as select the radiation survey mode (i.e., scan or point-and-shoot).

In the field, the BaSIS is generally used to provide 100% coverage of the surveyed area. Typically, the BaSIS is carried over the ground in a fashion similar to mowing the lawn, where there is a small amount of overlap in the field of view from one transect/path to the next. When the BaSIS is operated in *scan* mode, the system continuously collects both radiological and position data every 10-seconds, or other short time interval as specified by the user. As the user traverses the area, data are collected and stored until the survey is terminated. This allows large areas to be surveyed in a minimal amount of time. As shown in Figure 5, the BaSIS display provides the user with a graphic display of the surveyed area, with a "breadcrumb" dropped at the center of each measurement location. The typical survey rate is 1.5 ft/s. With a detector field-of-view of 20 ft., and a count time of 10 seconds, the pixel size for a single data point is approximately 20 ft. wide by 35 ft. long. When the BaSIS is operated in *point-and-shoot* mode, the system is held stationary for a preset time while a single gamma-ray spectrum is collected. This longer count time provides a higher degree of sensitivity, accuracy and precision in the radiological measurement than the 10-second scan measurements. *Point-and-shoot* mode is used to investigate anomalies identified during the large area survey. The pixel size of the *point-and-shoot* data point is a 20-ft. diameter circle, nominally, the field of view of the detector. The real time differentially corrected GPS provides geographic positioning data with sub-meter accuracy.

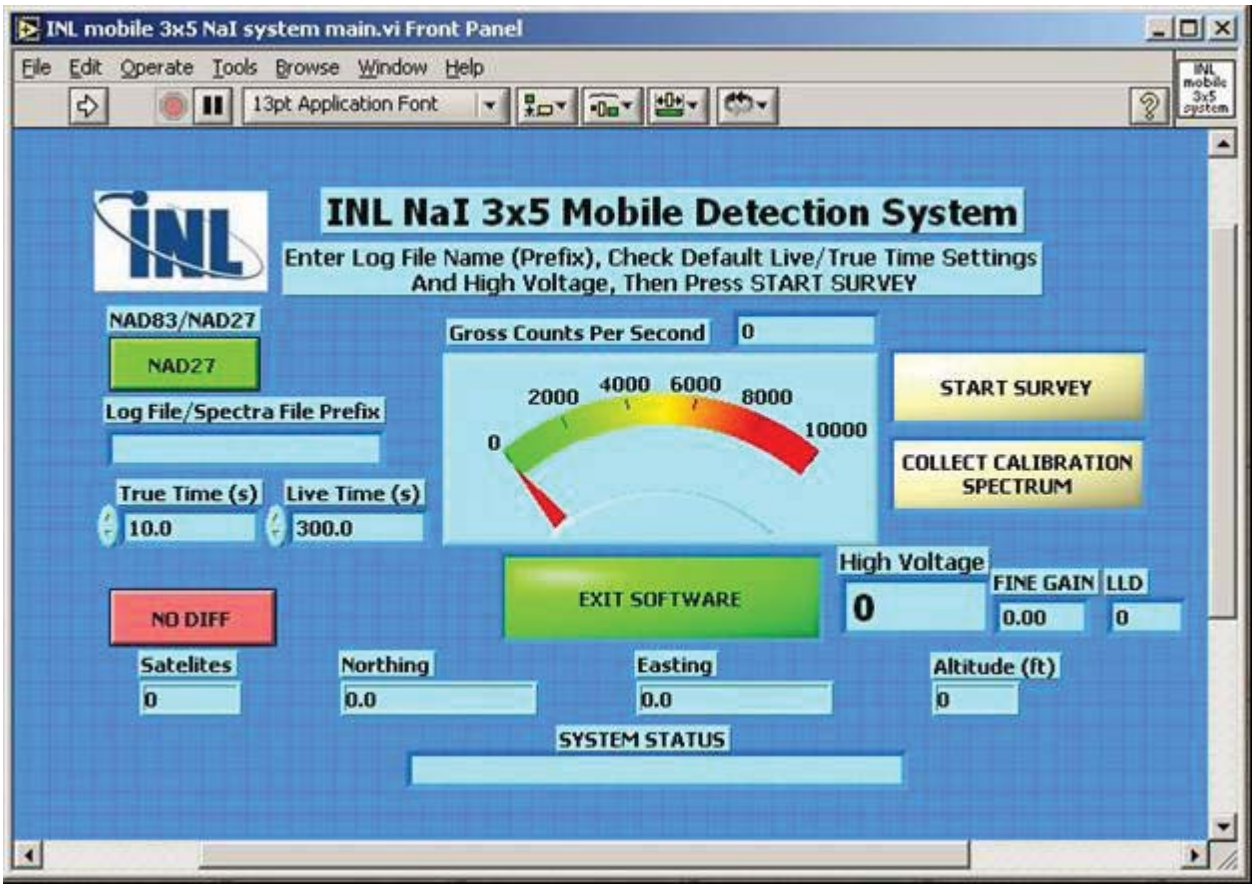

Figure 4. Main screen for control of INL BaSIS system.

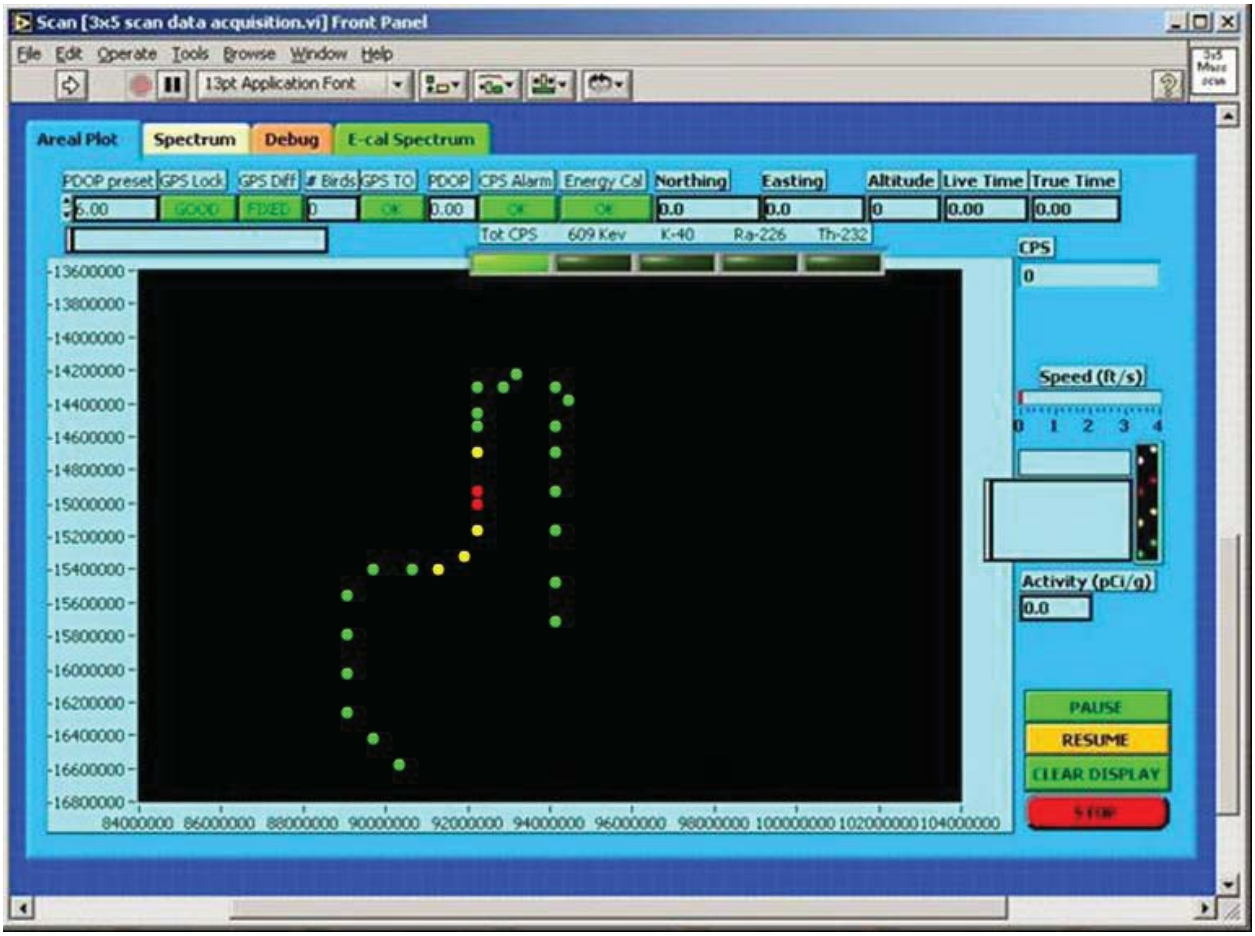

Figure 5. X-Y plot used for display of breadcrumb trail during BaSIS operations.

4. SHEPLEY'S HILL SITE – RADIATION SURVEY METHODS

The Shepley's Hill site and surrounding area identified by the EPA technical assistance request encompasses roughly 100 acres. Due to the large expanse of the area of interest, and the fact that the area is heavily wooded (thus requiring backpack deployment of the radiation survey system), it was determined that specific areas of interest should be identified and prioritized by EPA Region 1 personnel to ensure that the primary areas of interest were surveyed during the week-long field deployment. As such, there were four target areas initially identified for the survey. These areas are identified in this report as follows: 1) Fracture Area, 2) Shepley's Hill, 3) Red Cove, and 4) Landfill Vents. The fracture area is an area identified by EPA Region 1 with known locations of fracture zones, and was given the highest priority and the highest survey density. The remainder of Shepley's Hill was given the next highest priority, followed by locations near Red Cove, and the vent pipes on the landfill cover adjacent to Shepley's Hill.

4.1 System Configuration

Configuration of the instrumentation for the Shepley's Hill survey provided information regarding NORM signatures as measured by the BaSIS system. As shown in Figure 5, the system was calibrated and configured to display, in real time, measured activities for potassium-40 (K-40), radium-226 (Ra-226), and thorium-232 (Th-232). The BaSIS system was calibrated against a field-portable high-purity germanium gamma-ray spectroscopy system with traceability to the National Institute for Standards and Technology (NIST). Also included in the data output were the total gross count rate of the system, and the count rate for the 609-keV gamma-ray emitted by bismuth-214 (Bi-214). (As shown in Figure 2, Bi-214 is in the Ra-226 decay chain.) The count time for each measurement made in the scan mode was set to 10 seconds, real time, and the count time for each measurement made in the point and shoot mode was 60 seconds live time. The data from each survey performed were stored in a "*.log" file on the BaSIS computer to allow for subsequent mapping and archival of data.

4.2 Radiation Surveys

Based on the prioritization of the areas to be surveyed and discussions with the Shepley's Hill site hydrologist, a combination of scan and point-and-shoot surveys were performed. Prior to deploying the BaSIS at the site, a large portion of the number one priority area, identified as the Fracture Area, was gridded and flagged to guide the survey. A 50-ft. grid was established extending 400 ft. north and 350 ft. west from the point of origin (lower right corner) as shown in Figure 6. This grid was surveyed with the BaSIS in both point-and-shoot and scan modes. Portions of this grid were on the landfill cover (including the point of origin) and, most of these points were not included in the point-and-shoot survey. The point-and-shoot data were collected at the 50-ft. grid nodes, while the scan data were collected along the east-west and north south grid lines. This original grid was expanded to the north during the site survey, and the spatial resolution in this expanded portion of the grid was increased to 25-ft. grid spacing. (See Figure 7a through 7d.)

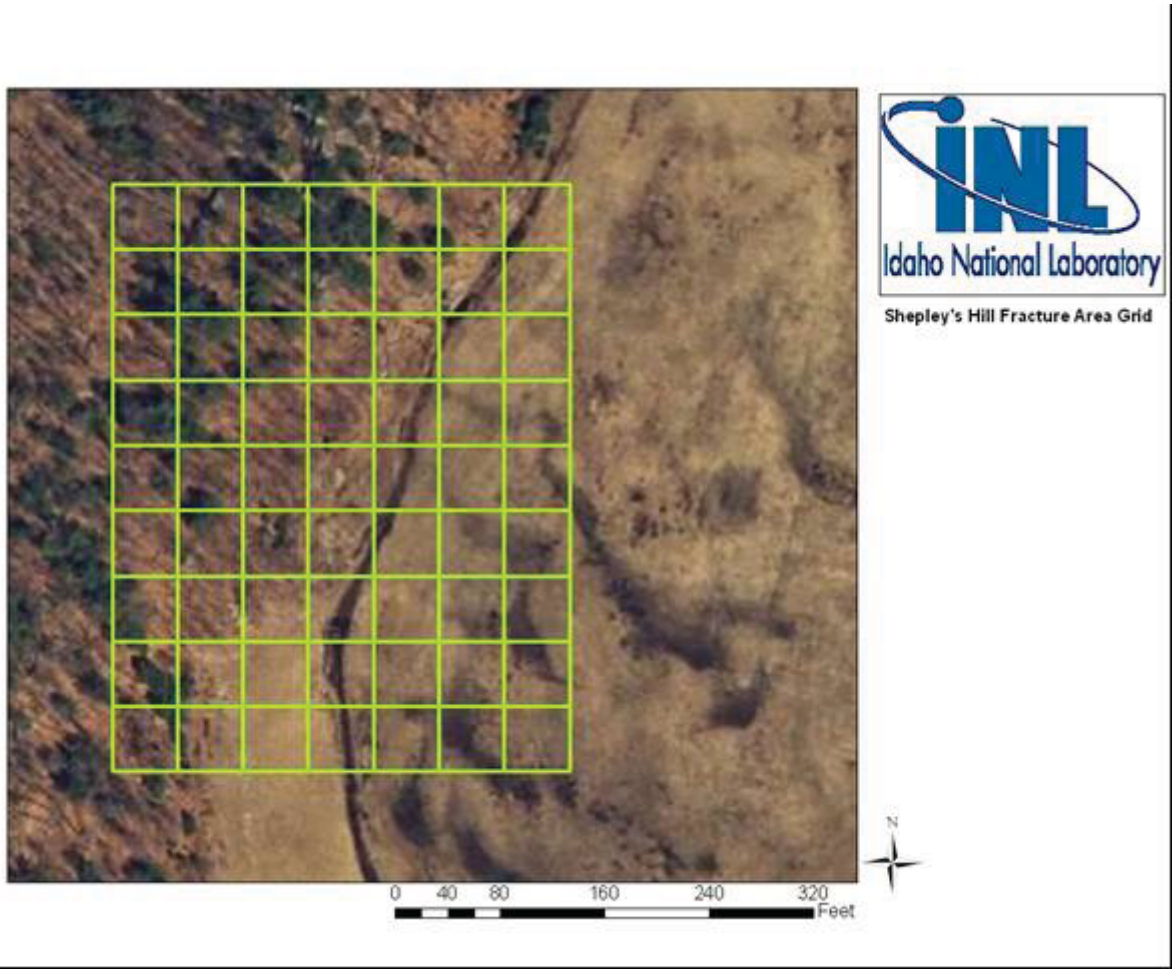

Figure 6. Shepley's Hill fracture area grid.

The remainder of the Shepley's Hill area was given secondary priority, and was surveyed with the BaSIS system in the scan mode. (See Figure 8a through 8d.) This portion of the survey work was completed by walking east-west transects across the hill with 100 ft. between transects. As time allowed later in the survey, north-south transects were surveyed along the eastern portion of Shepley's Hill.

The next two areas that were surveyed with the BaSIS system included Red Cove and numerous vents across the surface of the landfill adjacent to Shepley's Hill. These areas are shown in Figure 9a through 9d. A scan survey was performed near red cove. This survey was performed due to the high concentrations of arsenic that have been measured in water samples from Red Cove. It is hypothesized that the bedrock fracture network that underlies the landfill carries contaminated groundwater to the Red Cove area. Point-and-shoot measurements were made at six landfill vents in the northern portion of the landfill cover. These landfill vents provide a direct conduit for transport of radon gas from the subsurface to the atmosphere.

5. RESULTS AND DISCUSSION

Upon completion of the radiation surveys at the Shepley's Hill site, the data were archived for post processing and further analysis. The analysis comprised of plotting the radioactivity data on high-resolution satellite imagery, and comparing the detailed post plots with existing geologic data including the locations of rock outcrops. Figures 7a through 7d show the total gross count rate, K-40 gross count rate, Ra-226 gross count rate, and Th-232 gross count rate, respectively, from the point-and-shoot data collected in the Fracture Area. Although K-40 and Th-232 data are included in this report, the primary indicator for radon (Rn-222) are the decay products from Ra-226. The K-40 and Th-232 data are included for completeness of the NORM radiation signatures. Also included on each of these maps are the locations of rock outcrops. The rock outcrop data are displayed allowing for comparison of the locations of radiological anomalies (i.e., high count rate data from Ra-226, K-40 and Th-232) with the locations of known rock outcrops. As can be seen from this set of maps, the higher count rates correspond relatively well with the locations of the known rock outcrops. It should be noted that not all of the rock outcrops in the Shepley's Hill have been mapped (geographically). As such, it is not conclusive that all of the radiological anomalies correspond with surface rock outcrops.

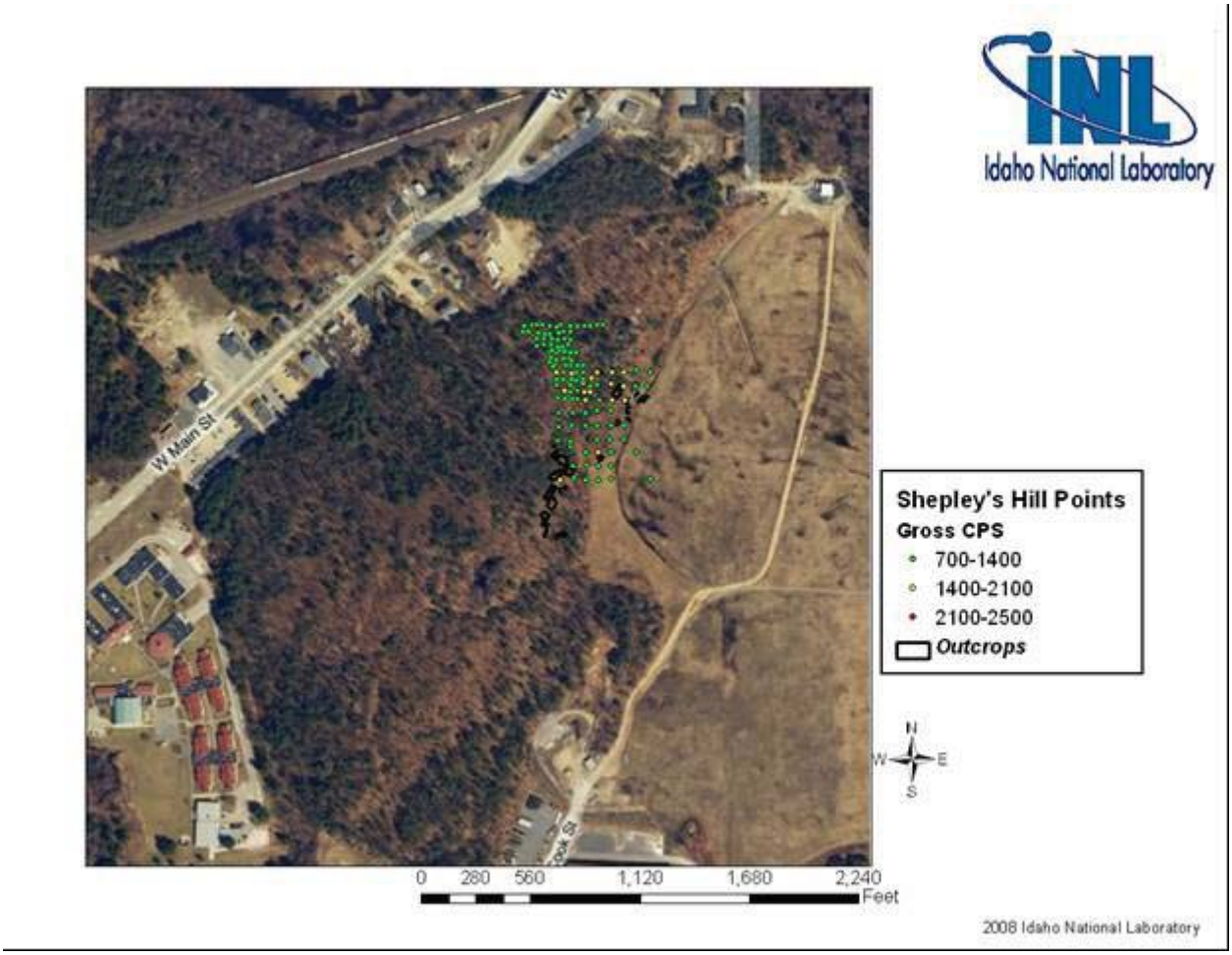

Figure 7a. Gross count rate data collected in point-and-shoot mode at the known fracture area at Shepley's Hill.

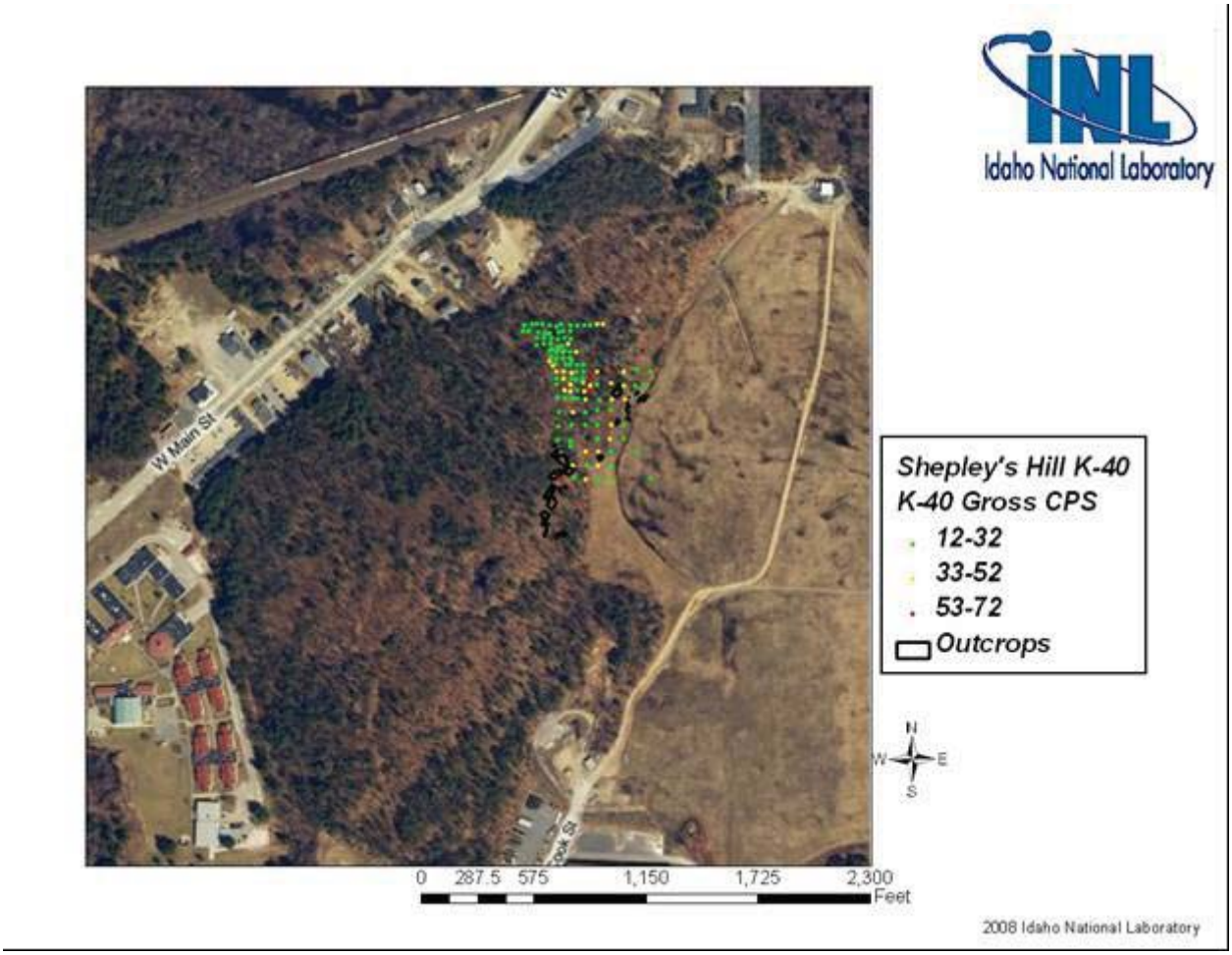

Figure 7b. Potassium-40 count rate data collected in point-and-shoot mode at the known fracture area at Shepley's Hill.

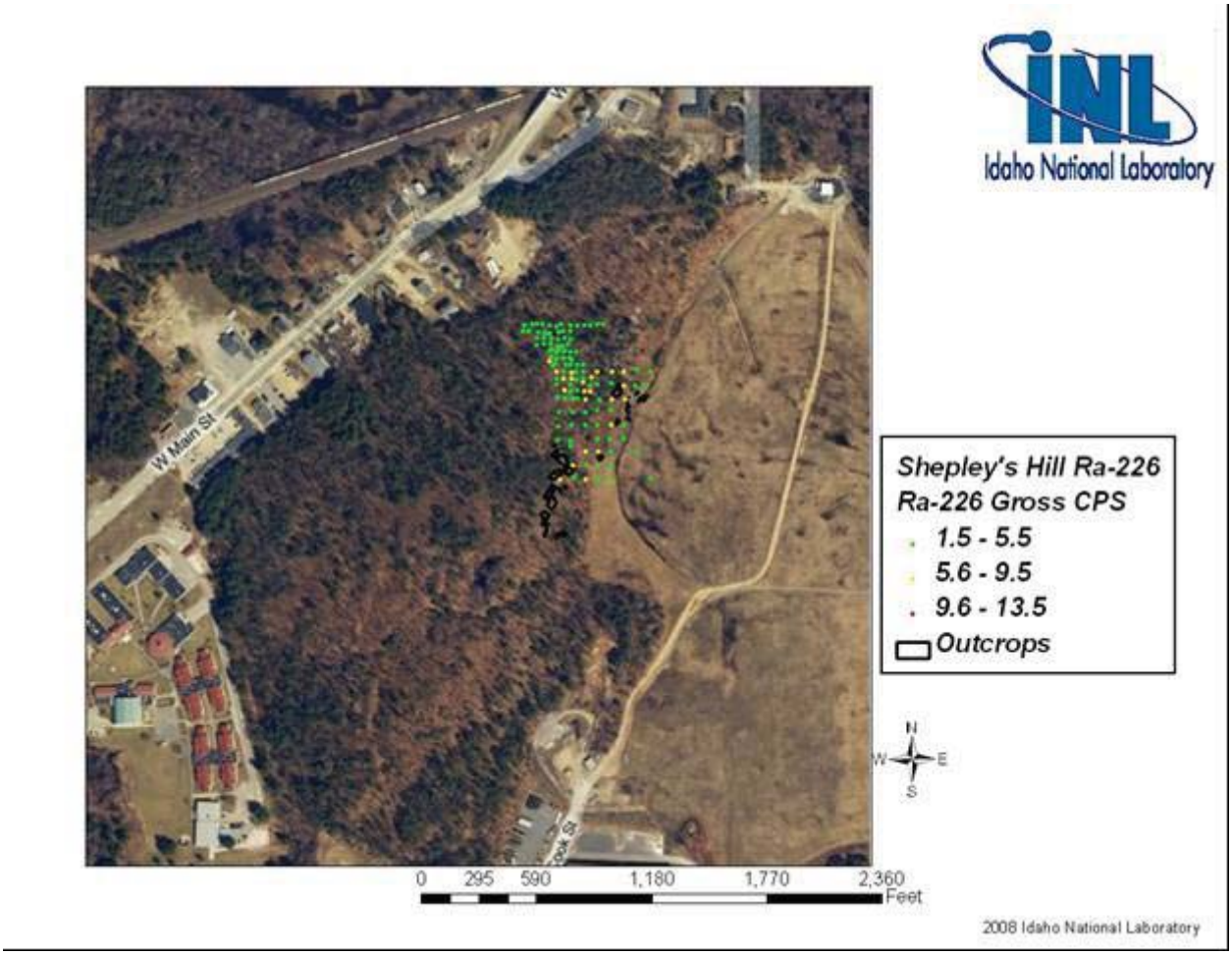

Figure 7c**.** Radium-226 count rate data collected in point-and-shoot mode at the known fracture area at Shepley's Hill.

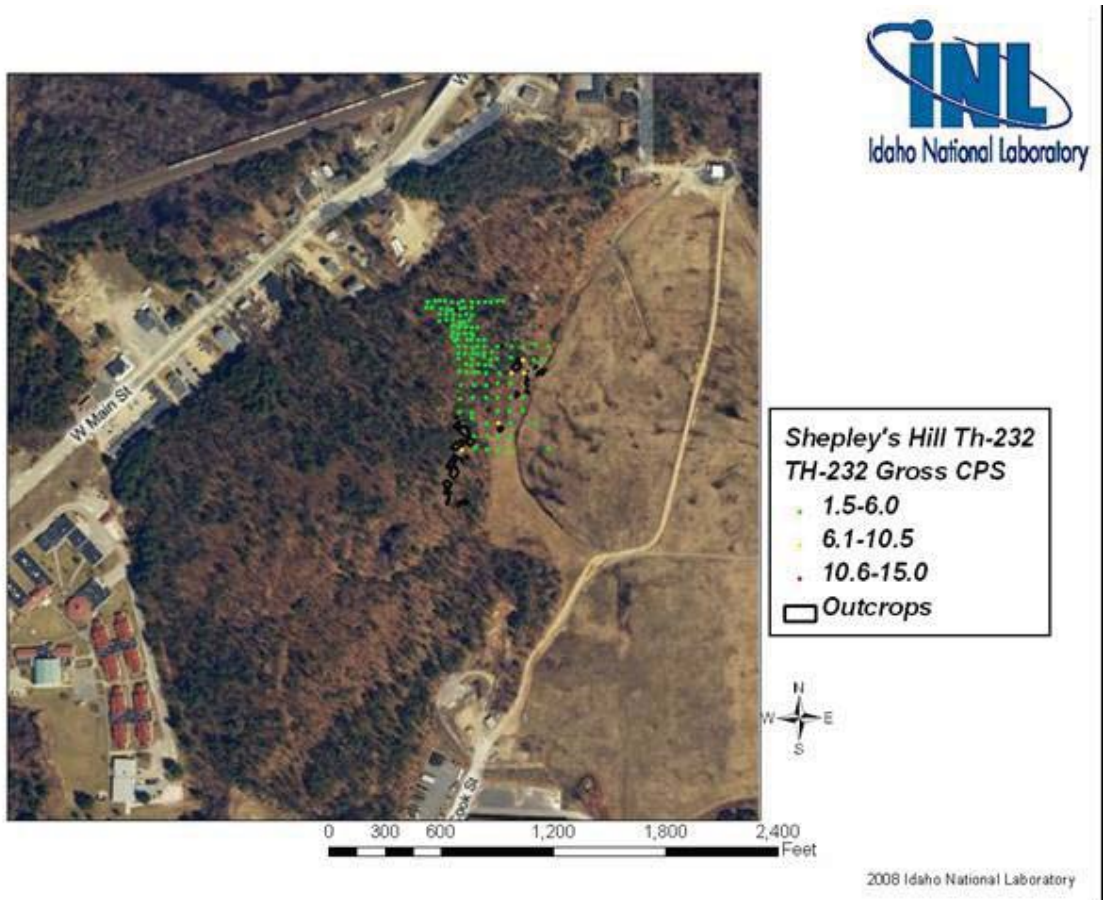

Figure 7d.Thorium-232 count rate data collected in point-and-shoot mode at the known fracture area at Shepley's Hill.

The scan data covered a considerably larger area, and encompassed the known fracture area at Shepley's Hill. Similar to the point-and-shoot data collected on the grid in the fracture area, the radiological data from the scan data set were also broken into the gross count rate and individual NORM components as shown in Figure 8a through 8d. These data sets also show the rock outcrop data. Due to the higher density of data collection points, it is more clearly depicted in the scan data sets that the areas with elevated NORM (i.e. higher count rates) correlate to the surface rock outcrops. It is plausible from these images that not all of the rock outcrops on Shepley's Hill were mapped prior to the BaSIS surveys, and that the elevated count rate data from these data sets correlate to unmapped surface rock outcrops. This is also supported by the data from two grab samples that were collected and analyzed using high resolution gamma-ray spectroscopy at the INL. Two grab samples were collected, one of soil material, and one of pulverized rock material present at the Shepley's Hill site. These samples were counted for 60,000 seconds, and the concentrations of NORM components were calculated. These data are shown in Table 1.

Table 1**.** NORM data from Shepley's Hill soil and rock materials.

Radionuclide	Soil Concentration (pCi/g)	Rock Concentration (pCi/g)
K-40	25.8	34.3
Ra-226	0.76	1.6
Th-232	2.8	2.0

As shown in the table, the K-40 and Ra-226 are present at relatively higher activity levels in the rock materials than in the soil material. These concentrations are consistent with those reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The average K-40, Ra-226 and Th-232 concentrations, as reported by UNSCEAR, found in igneous rocks are 22 pCi/g, 1.3 pCi/g, and 1.3 pCi/g, respectively. (UNSCEAR 1958).

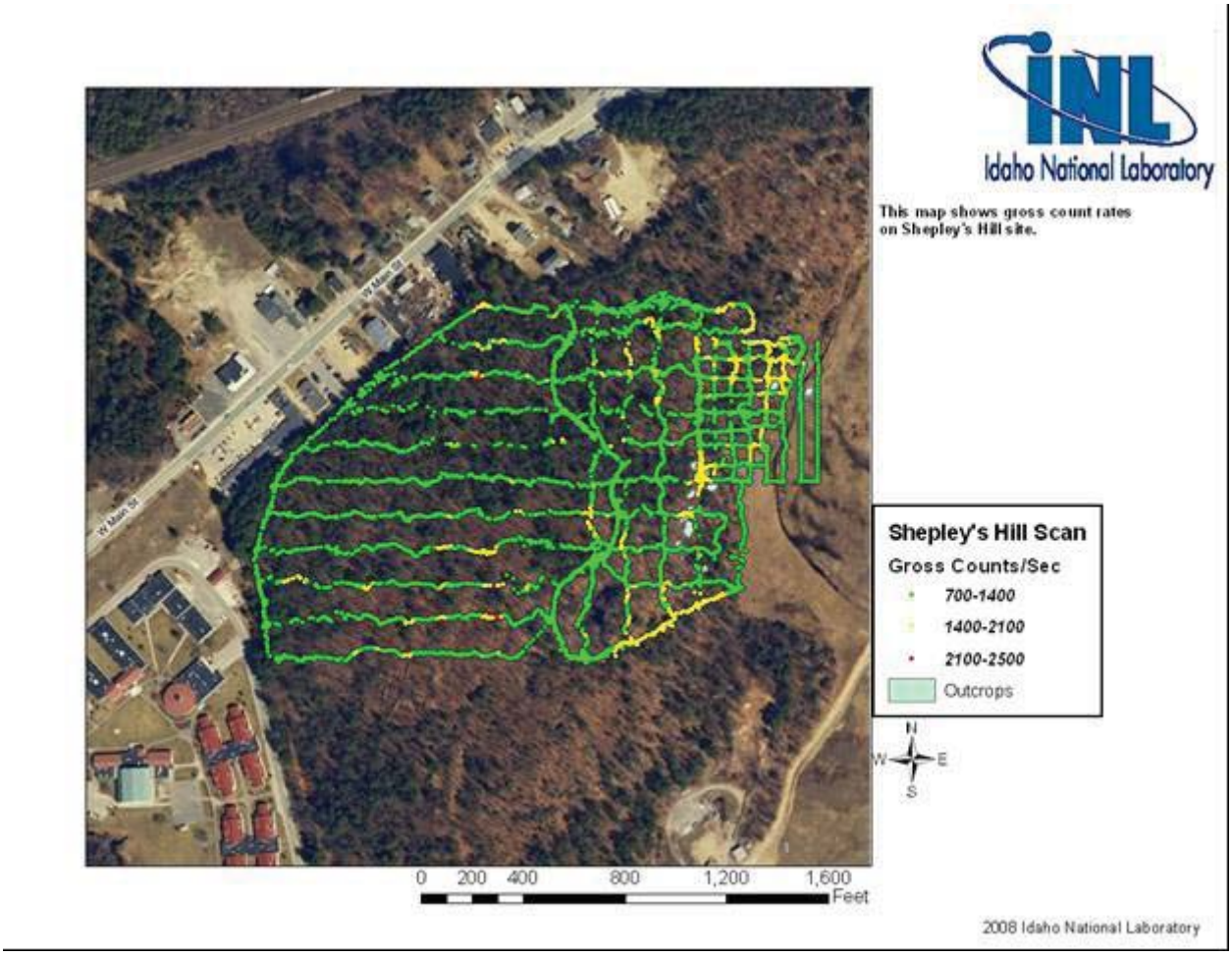

Figure 8a. Gross count rate data collected in scan mode at the known fracture area at Shepley's Hill.

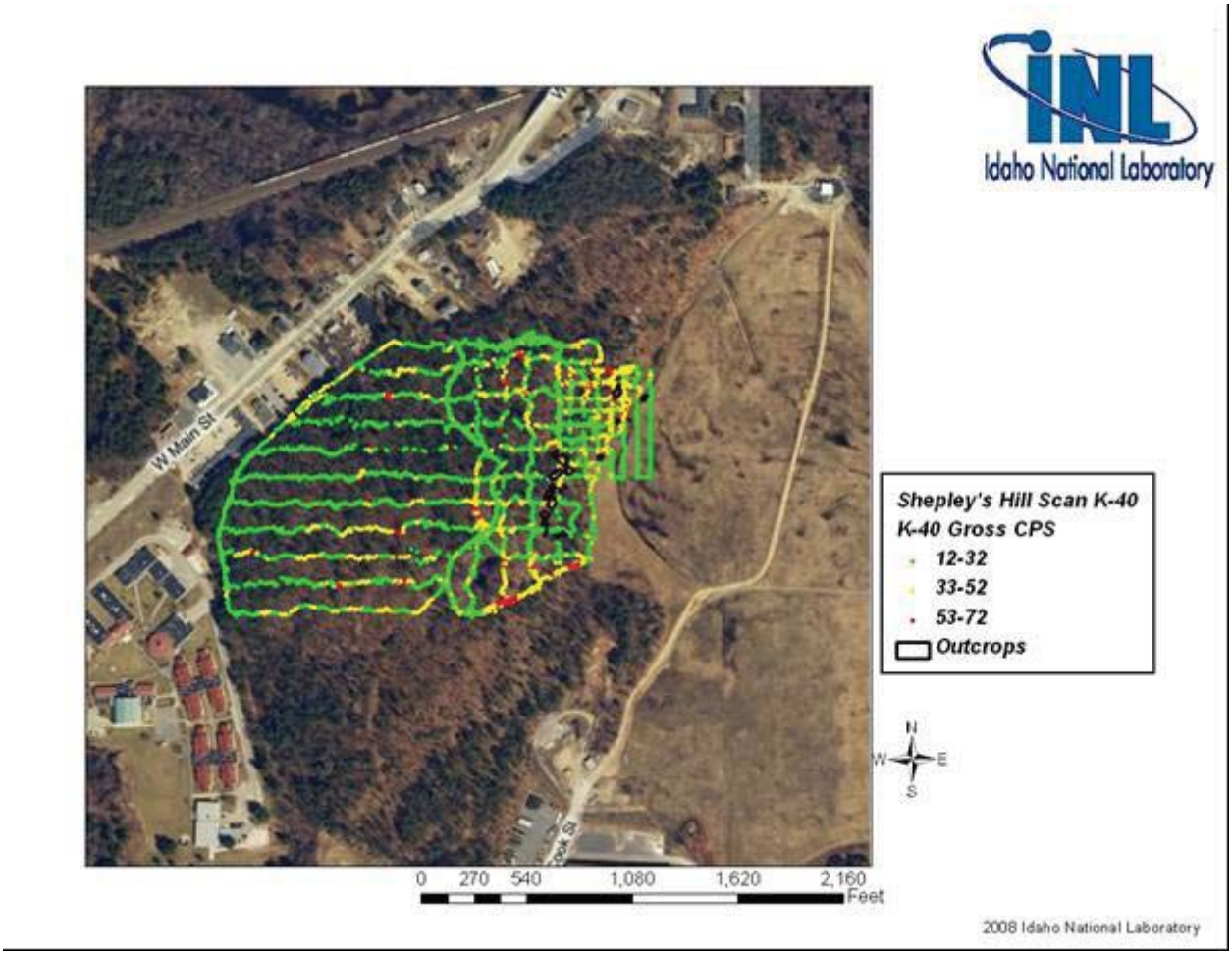

Figure 8b**.** Potassium-40 count rate data collected in scan mode at the known fracture area at Shepley's Hill.

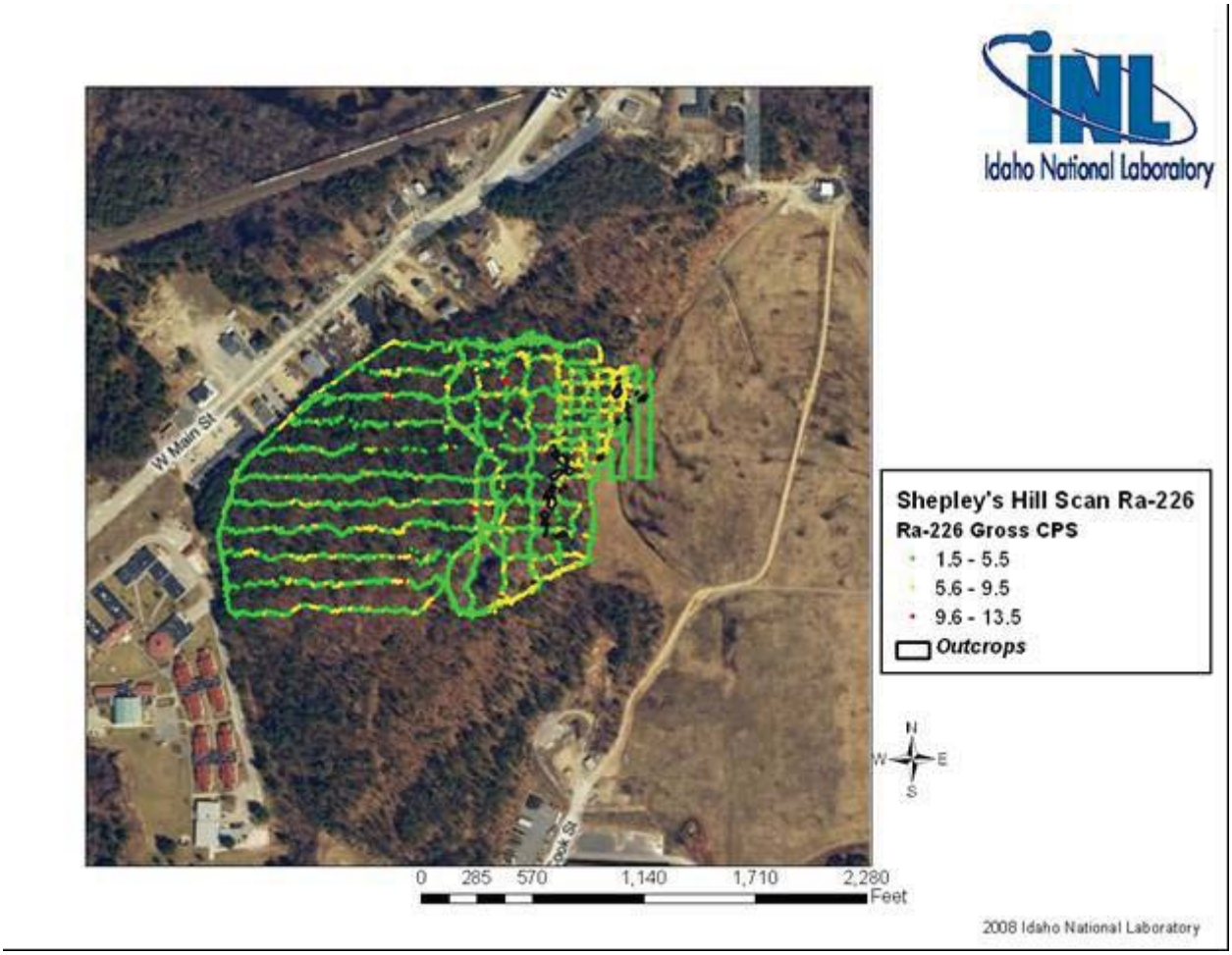

Figure 8c**.** Radium-226 count rate data collected in scan mode at the known fracture area at Shepley's Hill.

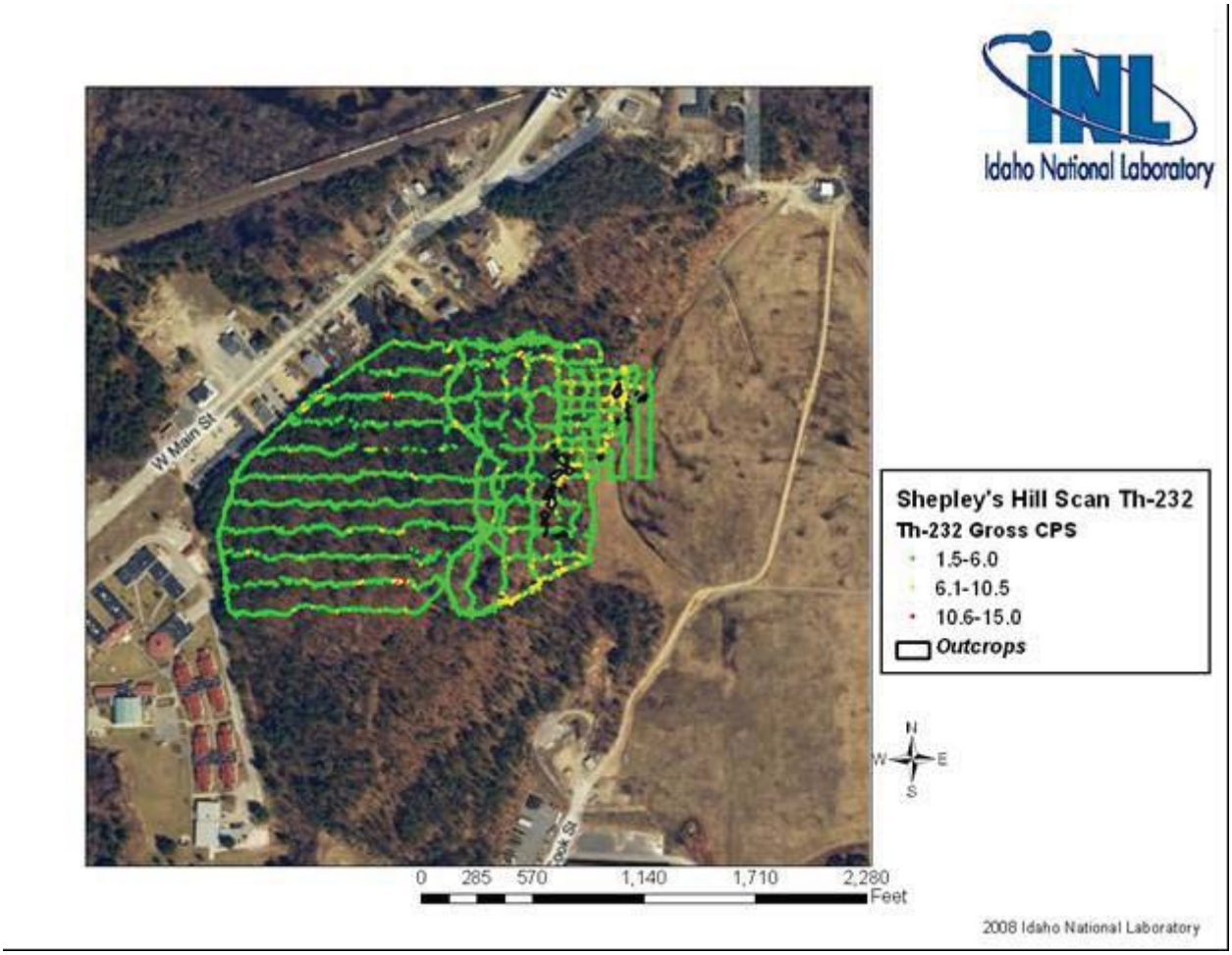

Figure 8d**.** Thorium-232 count rate data collected in scan mode at the known fracture area at Shepley's Hill.

Figure 9a through 9d show the radiation survey results from the Red Cove area and the landfill vents. This data set does not show the marked variation in NORM activities as was observed in the Shepley's Hill data sets, nor did the surveyed area contain any surface rock outcrops. The observed count rates at the landfill vents for Ra-226 and Th-232 did not show any anomalously high values. The only variations apparent in this data set are some moderately elevated K-40 count rates in the Red Cove area (Figure 9b).

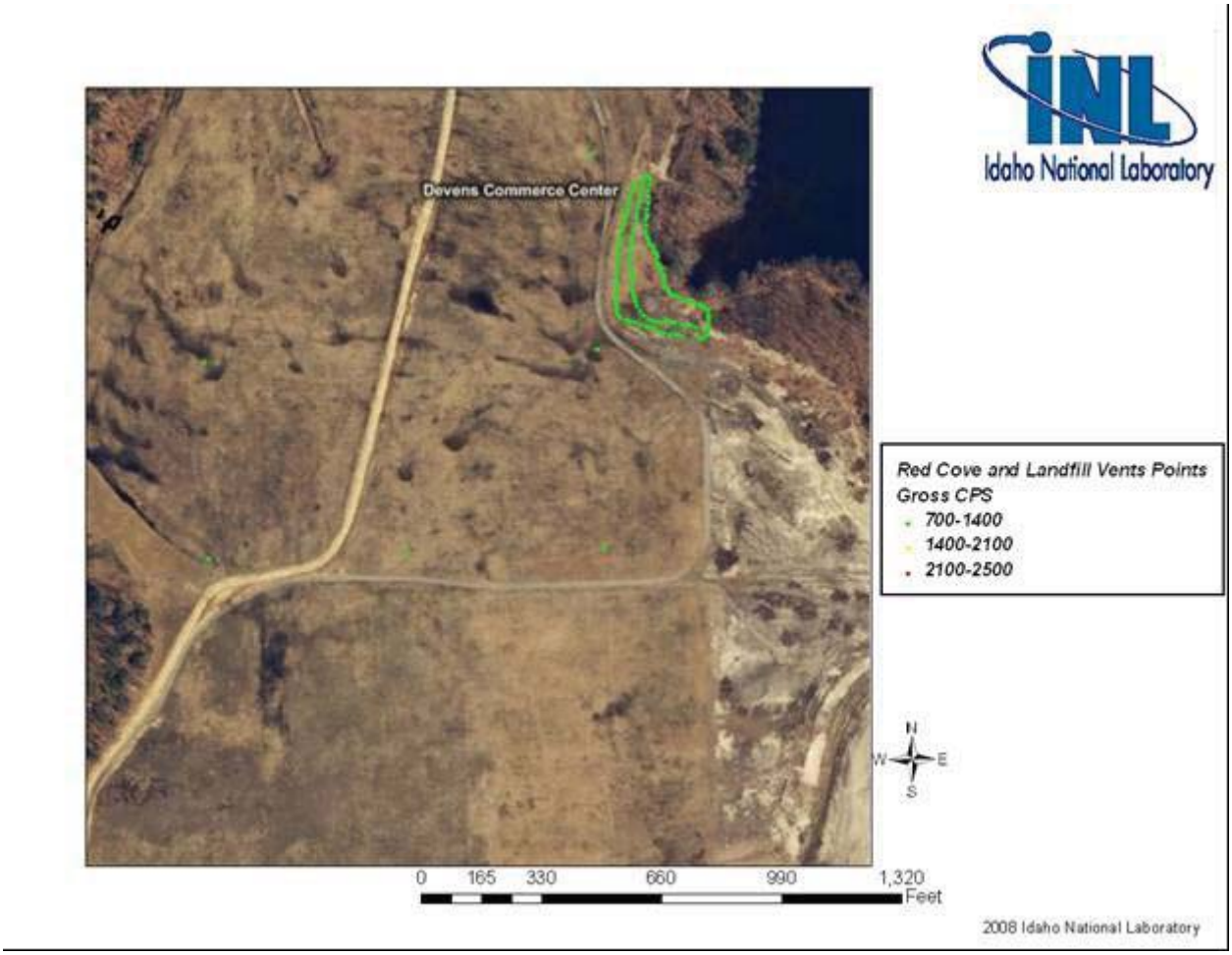

Figure 9a**.** Gross count rate data collected at Red Cove and vents on the Devens' landfill cover.

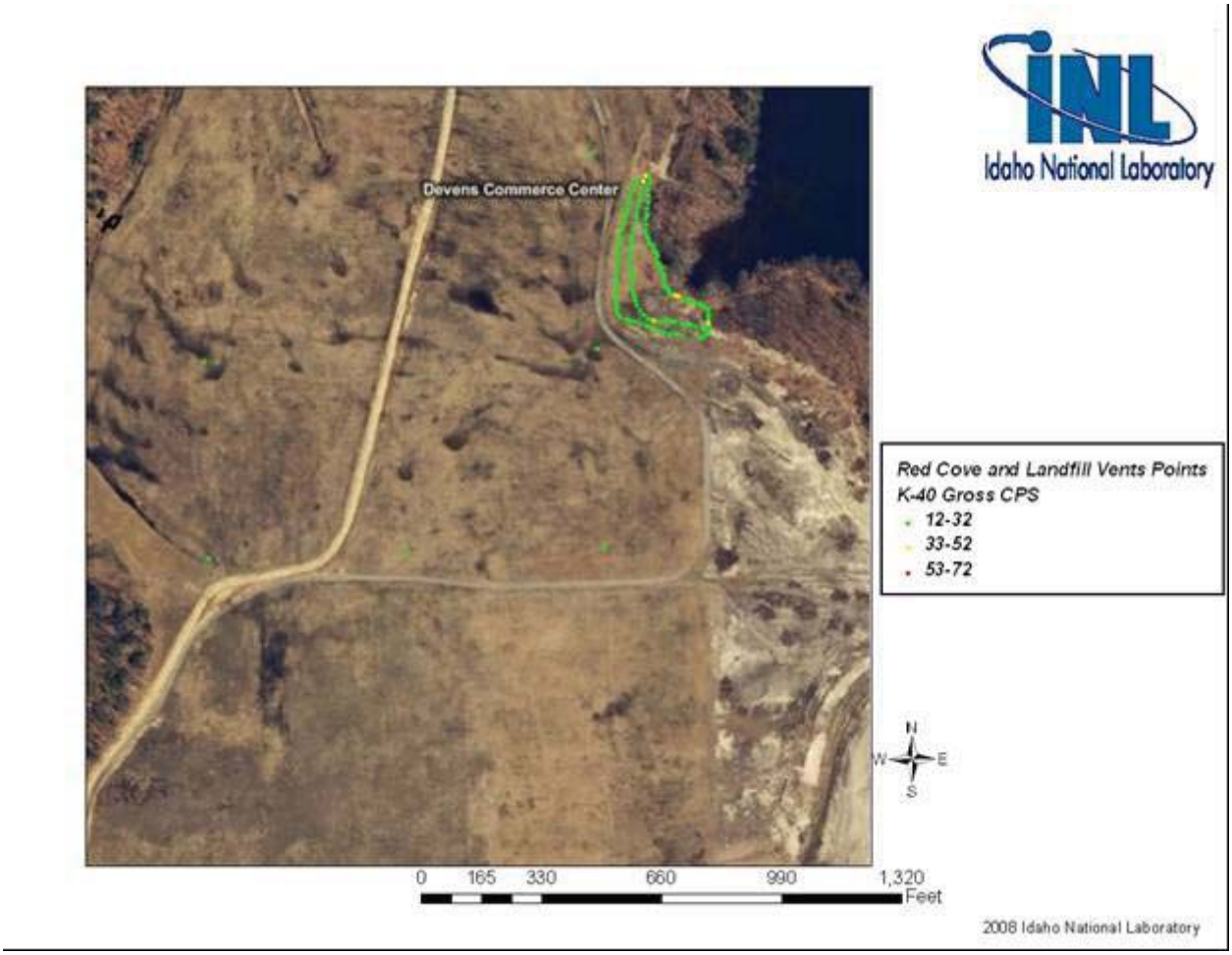

Figure 9b**.** K-40 gross count rate data collected at Red Cove and vents on the Devens' landfill cover.

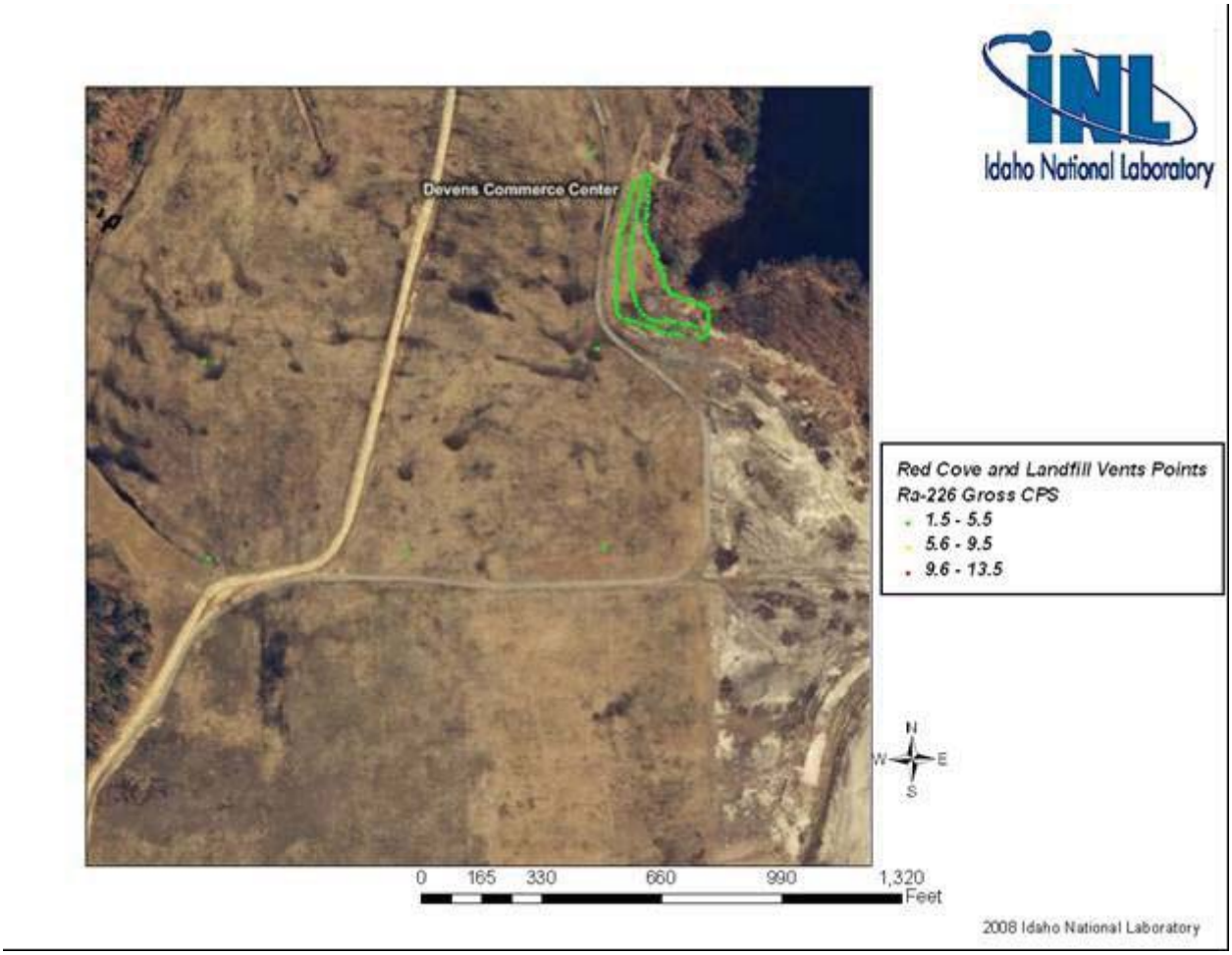

Figure 9c**.** Ra-226 gross count rate data collected at Red Cove and vents on the Devens' landfill cover.

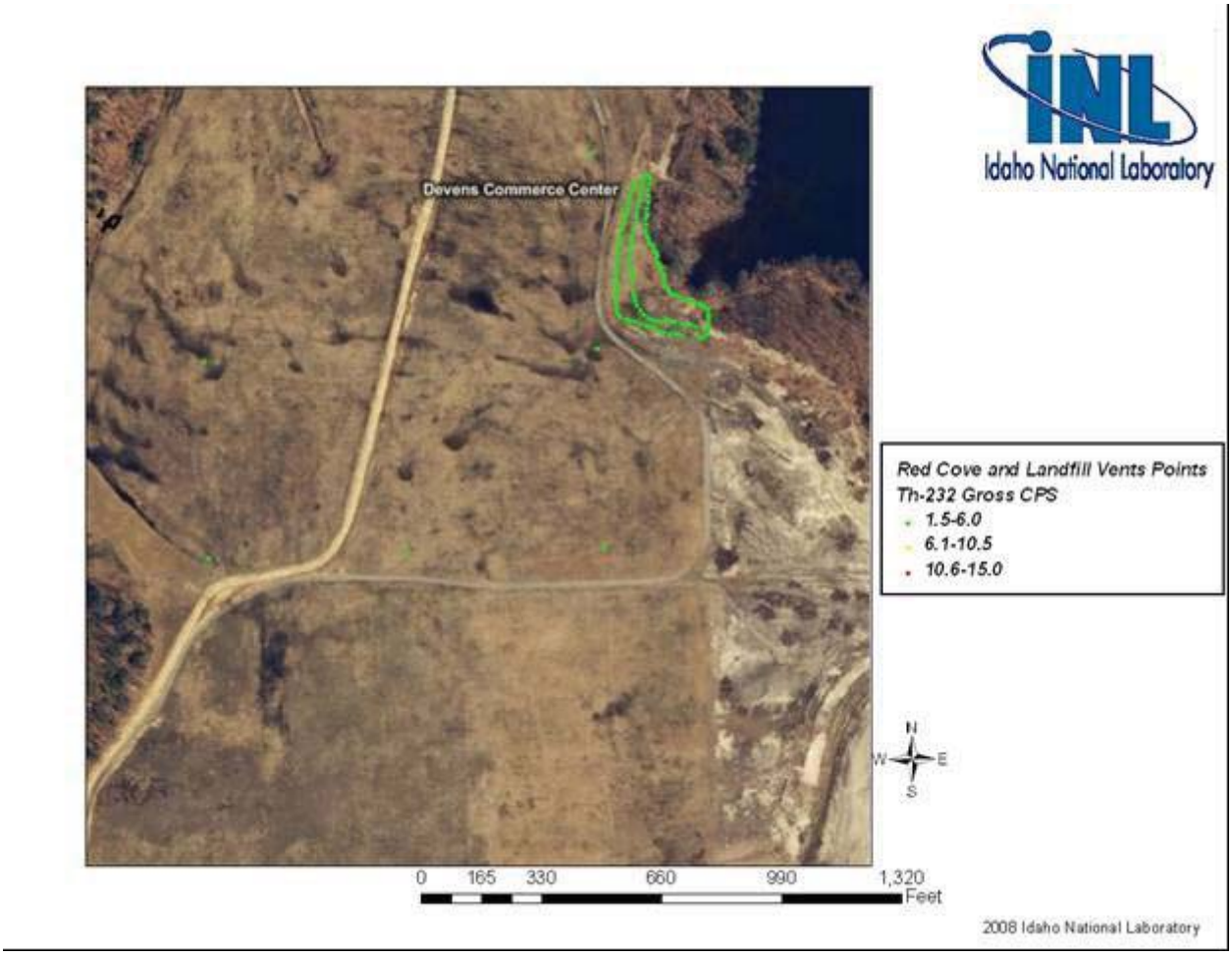

Figure 9d**.** Th-232 gross count rate data collected at Red Cove and vents on the Devens' landfill cover.

6. CONCLUSIONS

A radiation survey of NORM was conducted at the Shepley's Hill site and at the adjacent Red Cove and Devens' landfill cover area. The purpose of the survey was to determine whether or not subsurface fractures could be located due to elevated radioactivity readings, primarily from the decay of radon-222, which is thought to be in elevated concentrations above the fracture sets.

Although the BaSIS radiation surveys conducted in this study seem to have depicted the locations of surface rock outcrops, this does not rule out the potential for elevated concentrations of radon (specifically Rn-222) to be present in the soils above the subsurface fractures. Mazur et al., Swakoń et al., and İnceöz et al. have shown that elevated Rn-222 soil concentrations can be correlated to the locations of subsurface fractures. (Mazur 1999; Swakoń 2005; and İnceöz 2006). These studies used CR-39 particle track detectors. These radiation detectors are used to directly measure the alpha particles emitted during the decay of Rn-222. In these studies, it was shown conclusively that elevated Rn-222 concentrations existed in soils above subsurface fractures. The primary reason for the effectiveness of these Cr-39 detectors in measuring Rn-222 concentrations is that they are typically deployed for a minimum of 10 days. Measurements lasting this length of time will overcome the shortfalls associated with the short measurement times associated with direct surface measurements using gamma-ray spectrometers such as that used in the BaSIS system. Radon concentrations in soil, and the subsequent emanation rate of radon into soil gas, are affected by numerous factors including Ra-226 concentrations in the soil and rock matrix, soil moisture, fracture density in rock formations, barometric pressure, and the 3.8 day radioactive half-life of Rn-222. All of these factors affect the transport of Rn-222 gas through the rock/soil matrix. Due to the complexity of Rn-222 emanation into soil gas, and the subsequent soil gas transport mechanisms, short duration measurements can be ineffective in measuring Rn-222. The CR-39 particle track detectors provide a method that is not hindered by short-term fluctuations in barometric pressure and soil moisture content.

As such, it is proposed that a more detailed study of the Rn-222 concentration in soils at Shepley's Hill be conducted using CR-39 particle track detectors. As with the studies in Poland and Turkey, this may be a more effective means for locating subsurface fractures using a minimally invasive, proven technique.

7. REFERENCES

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