MULTISENSOR SURVEYS OF NUCLEAR FACILITIES

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ABSTRACT: Numerous tools are used by the United States Department of Energy Remote Sensing Laboratory to collect and analyze data from multisensor surveys. A survey of the Paldiski Naval Reactor Training Site in Estonia provides an example of the use of such tools. Multisensor survey operations included aerial and ground-based radiation surveys, daytime and predawn multispectral scanner surveys, and low and high altitude aerial photography.
Complete environmental characterization will be accomplished by integrating the results of aerial and ground-based radiological surveys, a multispectral scanner survey, and the aerial photography. The analysis of the radiation survey uses isoradiation contour maps which indicate the distribution of man-made radiation over the Paldiski Naval Reactor Training Site and surrounding area. Preliminary multispectral analysis indicates vegetation anomalies and movement of a diesel fuel spill. Aerial photography is used for both photographic interpretation and base maps for radiological data. Integration of these data are used for a variety of applications involved in comprehensive environmental site characterization.

1. INTRODUCTION

The United States Department of Energy (USDOE) maintains a Remote Sensing Laboratory (RSL) to support nuclear related programs. The mission of the RSL organization includes both emergency response for nuclear incidents and routine environmental assessments of nuclear related facilities. This paper provides an overview of the unique collection of equipment used by RSL for multisensor surveys of nuclear facilities. Preliminary results are reviewed for a recent multisensor survey of the Pakri Peninsula, located near Tallinn, Estonia. The area surveyed includes the former Paldiski Naval Reactor Training Site.

2. RSL BACKGROUND

The USDOE RSL, located in Las Vegas, Nevada, was initially established in 1960 to support the monitoring of nuclear weapons testing at the Nevada Test Site. Over the years, the RSL has developed considerable practical experience in applying airborne remote sensing technology for environmental characterization and oversight at other nuclear related facilities across the United States and abroad.

Today, the primary mission of the RSL organization is to provide emergency response support to nuclear related incidents. Potential accident response scenarios include airborne plume tracking, intensity and spectral mapping of radionuclide depositions, and finding lost sources or their components. To maintain technical and operational proficiency the RSL also conducts more routine environmental surveys. These surveys provide RSL staff with field experience and opportunities to evaluate the use of different sensor systems under a variety of environmental conditions.

RSL currently maintains a small fleet of specially equipped aircraft that are used as platforms for remote sensor systems. The aircraft include helicopters, light aircraft, and a business jet suitable for high altitude acquisitions. The remote sensing systems used by RSL detect in the gamma, visible, and infrared spectral regions. The systems include various types of gamma radiation detectors, mapping quality aerial cameras, video cameras, thermal imagers, multispectral scanners and, hyperspectral scanners. In addition to airborne sampling and mapping systems, various *in situ* equipment are used for ground measurements.

3. MISSION OVERVIEW

3.1 Objectives

The RSL multisensor survey of the Pakri Peninsula was undertaken as part of the US-Estonian cooperation announced by President Clinton during his visit to the Baltic in July, 1994. A USDOE-Estonian Ministry of Economy Agreement for Technical Cooperation was signed by Vice President Gore during his visit to Tallinn, Estonia, in March, 1995. This agreement outlined the nature of the multisensor survey and related technical cooperation.

The mission objective was to provide a comprehensive site characterization using RSL's integrated suite of remote sensing tools. To achieve this, the following goals were set: 1) conduct an aerial radiation survey, 2) collect ground-based gamma spectroscopy for any man-made radiation anomalies detected by the aerial survey, 3) collect sitewide aerial photography, and 4) conduct a daytime multispectral scanner and predawn thermal survey of the site.

3.2 Site Description

The Pakri Peninsula, shown in Figure 1, is located approximately 42 km west of the city of Tallin and includes the smaller towns of Paldiski and Leetse. The peninsula extends into the Gulf of Finland, has moderate to heavy vegetation, and the elevation averages 11 - 23 m above mean sea level. The Paldiski Naval Reactor Training Facility was comprised of two reactors used for training Soviet submarine crews. Reactor operations ceased in 1994, with transfer of the facility from Russia to Estonia occurring on October 1, 1995.

3.3 Operations

An area of approximately 90 km^2 in size was surveyed during a two-week acquisition period (June 15-26, 1995). All necesary equipment, including a MBB BO-105 helicopter used for the aerial acquisitions, was shipped to Estonia for the survey.

Radiological results were processed onsite and superimposed on maps and satellite imagery of the site. The objectives of the radiation analysis were to: 1) ascertain data integrity, 2) establish the spatial distribution of the gamma radioactivity, 3) identify the radionuclides contributing to the gamma exposure, and 4) estimate the quantity of radionuclides present relative to the exposure rate and annual dose.

Multispectral scanner (MSS) data processing began immediately following the first MSS flight. Processing involved decommutation which is the conversion of an analog, serial, bit data stream to a digital format that is readable by computers. MSS data was recorded on a high density data taped and then decommutated into a computer compatible file format. The MSS data was then quality checked in the field and assessments were made to determine if MSS objectives were met. Analysis was performed upon return to RSL. This paper summarizes the preliminary results of the survey.

4. DATA DESCRIPTION

To meet the project goals, multiple sensor systems were flown on the BO-105. Table 1 lists the parameters associated with each type of data collected including ground based radiation measurements.

4.1 Aerial and Ground-Based Radiological Surveys

The radiological survey capabilites are a unique and valuable resource for sites where radioactive materials may be present. The data collection system that makes up the airborne element is comprised of highly specialized equipment developed by RSL. This equipment simultaneously collects location and gamma spectral radiation data. These data are routinely calibrated to represent surface intensity levels as well as exposure rates for specific radionuclides.

The airborne portion of the nuclear radiation measurement system detects and records gamma radiation levels with positions determined by a differentially-corrected Global Positioning System (GPS).

There are two nuclear radiation sensor pods that are mounted below the BO-105 helicopter. In these pods, there are eight downward-looking 2 x 4 x 16-in and two 2 x 4 x 4-in upward-looking thallium-activated sodium iodide, NaI(T*l*), scintillation crystals for gamma radiation detection.

Ground-based radiation measurements were collected using a high purity germanium (HPGe) detector system for gamma ray spectroscopy. A pressurized ion chamber was used to measure exposure rates.

Together, the ground-based and aerial radiation collection systems provided three pieces of information: 1) established the spatial distribution of the gamma radioactivity, 2) identified the radionuclides contributing to the gamma exposure, and 3) estimated the quantity of radionucleides present relative to the exposure rate. To achieve the desired results, isoradiation count rate contours of natural and man-made sources were generated and superimposed on aerial photography taken during the timeframe of the radiation survey.

4.2 Airborne MSS Survey

The multispectral element of the multisensor survey used a Daedalus AADS1268 MSS electro-optical scanner to collect data. It is one of three Daedalus scanners maintained and operated by the RSL for DOE applications. MSS systems are flown on a regular basis and the collected data are used for a variety of environmental and target signature applications.

The airborne Daedalus multispectral scanner resolution is altitude dependent. It has an instantaneous field of view of 2.5 milliradians and a total field of view of 85.92 degrees in eleven spectral bands. In the Paldiski survey, flight altitudes of 1000 m have a ground sample distance (GSD) of 2.5 m, 152 m altitude has a GSD of 38 cm, and 91 m altitude has a GSD of 22 cm. Spectral bands are available in the visible, near infrared, middle or short-wave infrared (SWIR) and the thermal infrared regions of the electromagnetic spectrum.

Aerial photography was obtained concurrently with multispectral imagery. While the photography has comparatively limited spectral utility, it does provide very fine spatial detail and overlapping coverage for stereo viewing. In general, successful support of environmental remediation programs results from using both sensors together; that is, many applications require both good spatial and spectral information.

For some applications, the unique features of the airborne MSS systems operated by RSL offer major advantage over traditional aerial photography and commercial remote sensing satellites. The scanners collect spectral response at wavelengths that are impossible to collect with aerial photography. By flying at lower altitudes, the scanners can

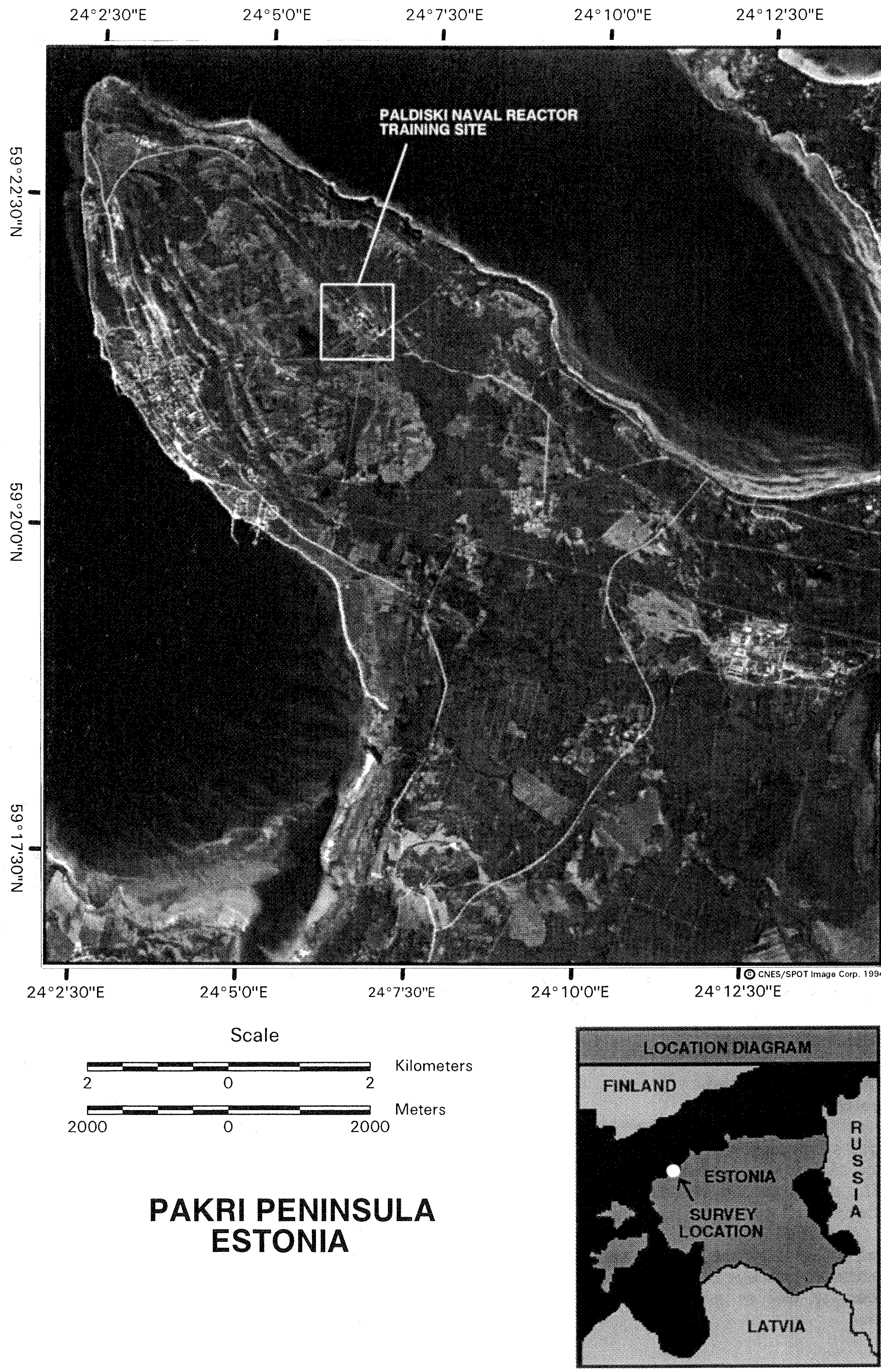

Figure 1: Survey Location

Table 1. Pakri Peninsula Survey Parameters				
	Aerial Radiation	Ground Radiation	Aerial MSS	Aerial Photography
Coverage	90 sq. km	12 points	90 sq. km	90 sq. km
Altitude	46 meters	1 meter	1000 meters 152 meters 90 meters	3000 meters 900 meters
Line Spacing	76 meters		1000 meters 152 meters 90 meters	overlap
Lines	162		38	5
Line Miles	1009		425	30

also collect data at much finer spatial resolution than that available from current commercial satellites.

Once collected, these data are useful for providing detailed environmental oversight for small and moderate sized areas. Data acquisition can be customized to meet the requirements of the application and spatial and temporal characteristics of the site. The spectral capabilities of the Daedalus multispectral scanner have proven effective for detecting land surface features and anomalies important to environmental restoration and monitoring (Richards, 1986). Areas of interest include old waste disposal sites, historic vegetation damage from toxic materials, large area surface disturbances, geohydrologic features such as seeps and faults, and environmental effects of current operations.

4.3 Aerial Photography

The RSL photography laboratory has a complete inventory of photographic equipment that supports the collection of both airborne and ground-based photography. The systems used during the Paldiski survey were both airborne and ground-based. Vertical and oblique aerial photographs were acquired using Hasselblad and Linhof Aerotechnika cameras, respectively, and a Canon still video system. The ground-based systems used were Nikon 35mm and Hasselblad cameras, and Canon still video.

Aerial photography was acquired for two purposes. The first is for photographic interpretation. Aerial color photography from a helicopter platform provides high spatial detail that is extremely useful for site characterization. The combination of high spatial resolution and color make aerial photographs an integral part of the multisensor survey (McCreary, 1979). The color aerial photography permits scientists to interpret hydrology, land forms, vegetation pattern, and other environmental conditions which are important factors in comprehensive site characterization (Smith, 1968).

The second purpose for the aerial photography was to provide base maps for radiological data. Vertical and oblique aerial photographs were taken of the radiological survey area. Current color aerial photographs were overlaid with radiological contours. The integration of color photographs with radiological data has proven to be an extremely valuable environmental assessment and remediation tool.

Ground-based photographic systems were also used extensively throughout the survey to document site conditions.

5. RESULTS

5.1 Radiation Survey

Aerial radiological surveys were conducted over an area encompassing 90 km^2, including the Pakri Peninsula and surrounding area. Ground-based measurements were taken in background areas and areas where anomalous activity was detected by aerial systems.

Isoradiation contour maps generated from the aerial data were used to show the distribution of the gamma exposure rate, annual dose, and count rates due to total terrestrial activity. The typical exposure rate range for the area was 7 to 9 μR/h with a maximum value of 125 μR/h estimated for the anomaly detected at the solid waste storage facility found on the Paldiski Naval Reactor Training Site (Feimster, 1995).

Figure 2 illustrates the distribution of the man-made radiation over the Pakri Peninsula. The gamma energy spectrum

Figure 2: Man-made Count Rate Map of the Pakri Peninsula

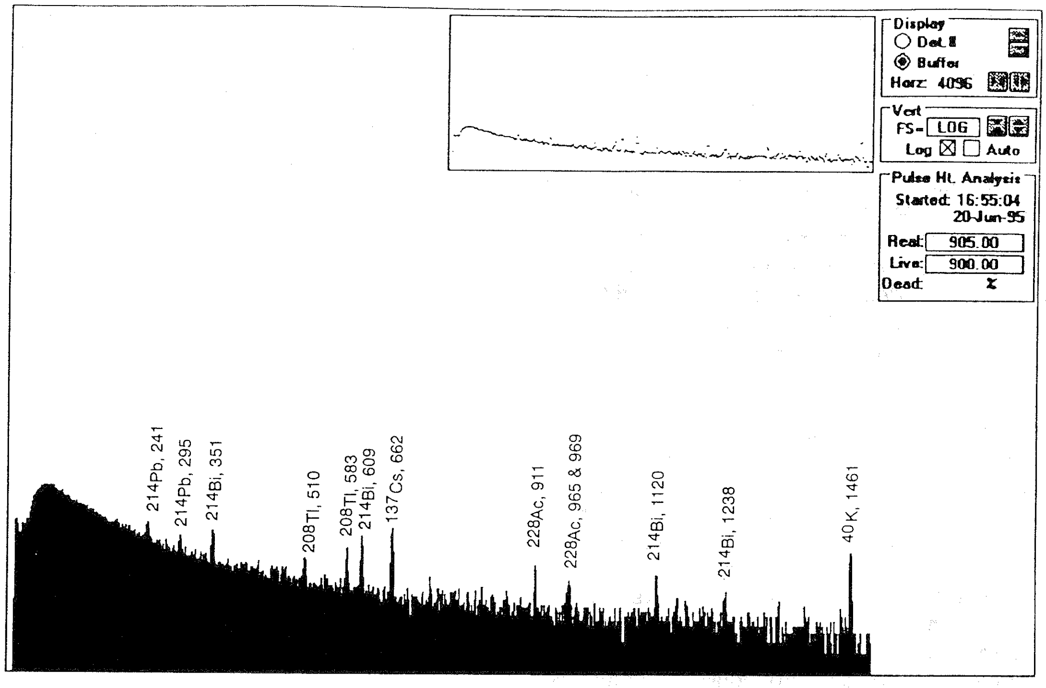

Figure 3: HPGe Gamma Energy Spectrum Typical of the Seven Measurement Locations near the training site

shown in Figure 3 is typical of the activity in the seven measurements made near by, but outside the training site; only naturally occurring gamma emitters and the gamma ray of ^{137}Cs due to world-wide fallout are present (Feimster, 1995). The most intense anomaly was detected over the solid waste storage facility located at the former Paldiski Naval Reactor Training Site. Due to the shielding of that source, the spectral identity of the contributors could not be established. The results of the radiological survey are indicated as contours in Figure 2. This information will be useful in guiding further ground-based investigations.

5.2 MSS Survey

Detailed MSS analysis has only recently been initiated. However, there are several preliminary findings that can be discussed. A variety of image processing techniques are being used to enhance specific spectral features for individual target applications. These techniques range from simple contrast stretch to more complex algorithms, such as principal components analyses and target specific spectral indices. The intent is to characterize a variety of key indicators of environmental conditions including vegetation stress, surface disturbances, and soil moisture.

One preliminary result indicates stressed vegetation patterns both within and outside the Paldiski Naval Reactor Training Site. These patterns seem to be consistent with site use. Another preliminary result shows the movement of a diesel fuel spill in the north-east corner of the site. The fuel spill is relatively noticeable in the visible section of the electromagnetic spectrum. However, further from the site there are similar spectral signatures that are found in the SWIR bands. This is not apparent in the visible spectrum because the vegetation canopy is spectrally confused with it. Analysis of the thermal data to depict moisture content has also been initiated. This data, in conjunction with elevation data, will be useful in identifying probable drainage pathways.

6. DATA PROCESSING AND INTEGRATION

The integrated analysis and presentation of RSL multisensor data requires special attention to the multiple data types and formats involved. For example, the Paldiski survey included both aerial and ground photography (film format), radiological sensor data (point spectral responses), and multispectral scanner data (digital spectral imagery).

Maps and imagery provide the standard base for presenting RSL radiological survey results. Coincidentally acquired photography or satellite imagery is usually preferred to identify current land cover conditions. The use of aerial photography and multispectral scanner imagery also provides an opportunity for multidisciplinary assessments of ground conditions.

7. DISCUSSION

Environmental assessments can be useful for identifying potential radionuclide transport problems and environmental pathways affecting risk assessments. The multisensor data can also be useful for general site characterizations needed for planning purposes. Examples of the environmental conditions that can be studied include landcover (vegetation type, amount, and condition), terrain elevation and related drainage patterns, and soil conditions (including near-surface soil moisture).

The USDOE has made use of similar remote sensing surveys for the detection and potential identification of historically contaminated sites at nuclear materials production and processing sites (Blohm, 1994). Remote sensing has proven especially useful for the detection of undocumented buried waste sites (Brewster, et.al., 1994), hazardous material spills, and vegetation and habitat damage related to previous or ongoing operations.

To take advantage of multisensor surveys, many analyses involve the use of a group of experts from several disciplines who collaborate to provide a more comprehensive understanding of a site's environmental conditions. Remote sensing expertise, specific application disciplines (e.g., hydrology, botany, or geology), and site knowledge all contribute to make a multidisciplinary analysis more meaningful. The combination of expert collaborations and the use of multisensor survey data has proven useful for several environmental restoration and monitoring programs.

Another key element of the RSL multisensor survey program is the use of spatial data handling and analysis tools. Sensor data is collected and tagged with positional data provided by the Global Positioning System (GPS), which is used for both navigation and flight path recovery to index the remote sensing data. Image processing tools are also important to image registration and rectification, critical steps for multisensor data integration. Once integrated, spatial statistics, Geographic Information Systems (Christel et.al., 1994), and 3D visualization tools are used to analyze and view the composite data.

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