Identification of Potential Hazardous Waste Units Using Aerial Radiological Measurements

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Abstract

Remote sensing of radiological phenomena provides valuable support for a variety of environmental applications. Aerial gamma ray spectrometer (AGRS) survey data and the tools of geographic information systems (GIS) can be used to identify radiological hazards in support of risk assessments for contaminated areas. This paper describes an application of AGRS survey data and highlights technology development, previous uses, contemporary applications, and operational characteristics of AGRS technology.

The described application of aerial radiological measurements was employed to delineate geographical boundaries for potential waste units within stream corridors. The project objectives included importing AGRS data into a spatial model and the creation of user-defined contoured boundaries. Potential radiological hazard boundaries were derived using processed exposure rate counts from an aircraft platform as the third dimension in the data model. A procedure was developed using GIS software to produce TIN (triangulated irregular network) structures from ASCII text files of processed AGRS sample data. Contours of exposure rate counts and dose values were interpolated from the TIN structures to provide preliminary boundaries based on individual isotopes. It is intended that these boundaries be used as a reference for field survey and preliminary site characterization.

Introduction

Individual waste management units (WMUs) within the U.S. Department of Energy (DOE) complex have been identified through Resource Conservation and Recovery Act (RCRA) compliance investigations. Individual units are identified by the geographic extent and composition of waste components. As with other DOE facilities, the Savannah River Site (SRS) in Aiken, South Carolina, contains WMUs that present chemical and radiological hazards. Although many of the waste units at the SRS are contained in definite geographic areas (i.e., pits, piles, and basins), some include contamination of surrounding soils, groundwater, and vegetation (DOE EM, 1991). Before remediation of a WMU may begin, characteristics of that unit must be identified. Spatial extent is a key parameter in the characterization process.

At this time, the Environmental Restoration Division (ERD) of the SRS does not have geographical boundaries set for all hazardous waste units. Most defined waste units are referred to in databases as point features and are identified by suspected contaminants. In particular, stream corridors have been labeled in various SRS databases as being hazardous waste units but have only included feature names as a geographic reference. Many hydrographic features at the SRS have not been characterized as to their contamination parameters. The characterization includes field surveys which would define potential boundaries for these units. As environmental characterization and remediation activities proceed at DOE facilities, contamination of such fluvial systems is becoming more important in overall risk assessments. The applications of GIS techniques are expanding to coordinate and analyze the variety of sample data needed to define current and potential hazards. Previous research has concentrated on independent groundwater, surface water, and air dispersion modeling related to chemical and radiological components. In moving toward more comprehensive analysis of multiple exposure pathways, a methodology has been developed to convert remotely sensed gamma data into various GIS products as additional inputs to risk assessments. This type of remotely sensed data has been used previously to provide baseline information regarding the distribution radioactivity at government nuclear facilities (Albers and Purdy, 1994).

Contracted by DOE and the Westinghouse Savannah River Company (WSRC), EG&G Energy Measurements, Inc. (EG&G) collected the data used in this research. The densely sampled collection of AGRS survey data required extensive processing to extract spectral and spatial information. The resulting data points have, historically, been interpolated using proprietary software and distributed by EG&G in hardcopy format as acetate overlays on aerial photography (Hendricks, 1985). The 1991 sitewide survey report included digital data in the form of arc-segment contours for use in GIS (EG&G, 1993a). However, the digital contours were static reproductions of EG&G interpolation results and did not allow end-users to modify defined intervals. Because spatial analysis of the AGRS data in this report format is limited, a point data file (normally reserved for EG&G internal use) was made available to investigate additional GIS processing in this research (Hendricks, 1995, personal communication).

The primary objective of this project was to delineate potential radiological hazard boundaries for stream corridors that can be used as a reference for field survey and preliminary site characterization. To achieve this objective, a procedure was developed to convert AGRS data into a spatial model for interpolation. Processed data from an AGRS survey mission were converted to ASCII files containing planimetric coordinates and detector response values for specific isotopes. From sample point features, TINs were created for surface representation and contour generation. Contours of recorded detector counts and associated dose values were in-

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terpolated from the surfaces to provide preliminary boundaries based on individual isotopes.

By defining a method in which AGRS data can be incorporated into user-defined GIS representations, this project promotes the application of remote radiological measurements in risk analysis and management. Although AGRS technology has been available for DOE investigations for several decades, inclusion in GIS databases in several formats is significant. This work advances the ability of risk models to consider spatial characteristics of radiological elements in the integration of interdisciplinary data. Furthermore, the results of this project are intended to aid future site characterizations of radiological hazards, provide input for risk assessments, and render a method of applying AGRS data to other inaccessible areas for legislative compliance.

Study Area

The Savannah River Site is located 112 km southwest of Columbia, South Carolina near Aiken and is bordered by the Savannah River (Figure 1). The site encompasses approximately 795 km^2 of land in the upper coastal plain of South Carolina. Bottomland hardwood swamps dominate the wetlands within the SRS, which has been designated a National Environmental Research Park. Various pines, sweet gum, maple, birch, and oak-hickory hardwoods cover the site from the sandy hills to the continually flooded swamps. The SRS is refuge for a wide variety of wildlife that include deer, bobcats, river otters, alligators, eagles, and numerous other species of mammals and reptiles. Five major tributaries feed the Savannah River from within the site boundary and are not used as commercial sources of water.

The SRS is a government-owned facility that is part of the U.S. Department of Energy nuclear defense complex and is operated by the Westinghouse Savannah River Company (WSRC). The site was built in 1951 by the Atomic Energy Commission (predecessor to DOE) to produce materials used in the fabrication of nuclear weapons (WSRC, 1994). Because changes in global politics have limited the need for such materials, the focus of activity at the SRS has been shifted to environmental restoration and waste management. The goal of environmental restoration is to limit or eliminate risks to human health and the environment through hazard remediation. The identification, characterization, remediation, and monitoring of chemical and radiological hazards within the SRS is heavily dependent on current and developing data acquisition and analysis technologies. Application of remotely sensed data and automated geographic information analysis are becoming powerful tools to be applied to such directives. Processing aerial gamma survey data in a GIS provides a robust example of such technology utilization.

Sensor Applications

Energy Measurement Units

Radiation energy is measured in electronvolts (eV) as it is emitted from isotopes and is often expressed as keV (× 1,000) or MeV (× 1,000,000). Conversions from raw energy in electronvolts to estimate effects on humans have been developed. Dose is calculated by multiplying quality factors for different types of radiation and the amount of radiation absorbed (RAD, radiation absorbed dose) and is expressed in REM (roentgen equivalent man). Exposure, and subsequently dose, from a point source is dependent upon the length of exposure, distance (related to flux) from the source, and available shielding from the radiation. These, and other factors, have been considered in the calculation of REM from raw AGRS data by DOE Remote Sensing Laboratory (RSL) personnel.

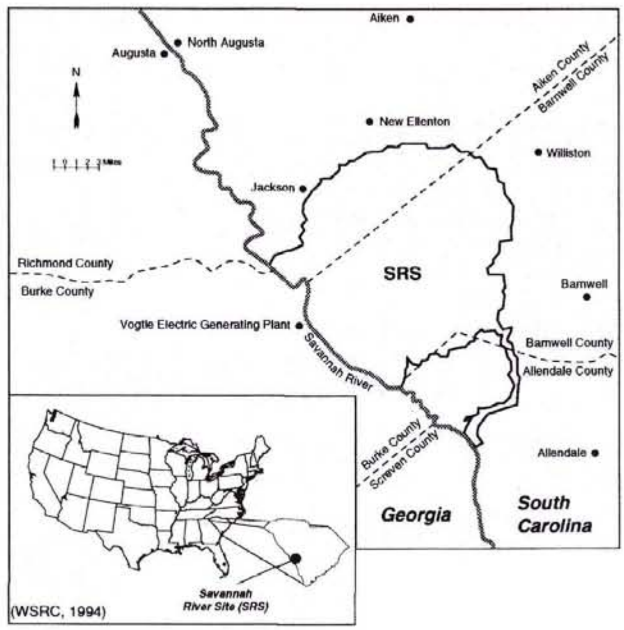

Figure 1. Savannah River Site.

Previous Applications

The evolution of nuclear weapons and the need to monitor resultant radiation levels drove the development of remote radioactivity sensors. As early as 1952, helicopters were used to crudely map gamma intensity after testing detonations (Bouton *et al.*, 1952). Moving from quantitative sensing of radioactivity using Geiger-Müller counters in the 1950s, gamma ray spectrometer technology has provided qualitative application since the 1960s (IAEA, 1991). Aerial radiological surveys were routinely conducted during nuclear weapons testing to evaluate the severity and distribution of resultant fallout (Edgerton *et al.*, 1967).

As the ability to extract individual isotopic responses from the photopeaks in the collected energy spectrum evolved, AGRS surveying became a common radiological mapping tool for federal facilities (Doyle *et al.*, 1972). Contemporary AGRS data are collected as part of Nuclear Regulatory Commission (NRC) requirements for all nuclear complexes, including commercial utility plants (Berry and Fritzsche, 1983). Although radiation detection and monitoring technology has not changed significantly in the past 15 years, the ability to register aerial sampling to geographic locations and improved data processing has resulted in minor advances (Runyon, 1994).

The ability to discriminate radiological response in the electromagnetic spectrum has also promoted applications in environmental monitoring and defense initiatives. Contemporary platforms are maintained for domestic and international deployment directed by the U.S. government. Due to the often prohibitive cost of AGRS surveys and the distinctive nature of detecting specific radioisotopes, environmental applications have been limited (Burgess *et al.*, 1989).

In conjunction with other remote sensing data, AGRS surveys have aided in the identification and mapping of geologic formations. As suggested by Fernandez-Alonso and Tahon (1991), lithological units and their geological and structural interpretation may be mapped with AGRS for remote and hostile regions. For example, AGRS data was combined with Landsat, SPOT, and aeromagnetic data to map geologic features in Rwanda, Africa where rough topography and dense vegetation hindered field surveys. The successful definition of sedimentary and crystalline lithology, along with geologic structure of the Kibaran belt, helped confirm previous evolutionary hypotheses and provided a much needed update of regional geologic maps.

For agricultural forecasting and hydrologic modeling, the Office of Hydrology within the National Weather Service operates a program which estimates the water equivalent of snow using aerial gamma spectrometer data (Carroll, 1981; Carroll *et al.*, 1993). A change-detection technique is used by determining the natural radioactivity measurements of an area when no snow is present. After the snowpack has been accumulated, data are acquired over survey areas to determine attenuation resulting from water volume in the snow (Bissell and Peck, 1973; Fritzsche, 1982). This procedure allows streamflow volume to be predicted for use in hydroelectric production, irrigation, and flood estimates (Carroll *et al.*, 1993).

In addition to snow water volume estimates, AGRS technology has been evaluated as a passive remote platform for calculating soil moisture in bare soils during hydrologic and agricultural cycles (Carroll, 1981). Using the same baseline AGRS and soil sample data from previous surveys, increasing soil moisture was calculated using attenuation of gamma flux. Gamma flux may be attenuated by increased soil density as a result of precipitation events. Estimates of soil moisture are used in river and flood forecasting as well as crop assessments.

Using gamma detection devices at multiple scales has been an advantage in urban projects. As described by Runyon *et al.* (1994), portable detecting units were required during a survey of individual parcels in a western Chicago suburb. Thorium-laden mill tailings from an extinct local processing facility were used by the City of Chicago in surrounding neighborhoods as fill dirt. Previous survey techniques included field mapping using semipermanent landmarks and grid paper. The preliminary modern survey boundaries were identified and confirmed with EG&G aerial surveys in 1977 and 1989. Using the aerial data as a guide, technicians equipped with hand-held scintillation detectors and Global Positioning System (GPS) units traversed individual properties in uniform survey lines to map areas of high activity.

Use at the SRS

As part of the Comprehensive Integrated Remote Sensing program at the SRS, AGRS data have been collected in sitewide surveys and for change detection of individual geographic features. Ten such surveys have been conducted since 1974. Gamma contour maps for total and natural exposure rates and ^{137}Cs (cesium) and ^{60}Co (cobalt) count rates have been reported for each survey. The area containing L Lake and Steel Creek has attracted the most onsite attention regarding environmental impact from radiological releases. AGRS data have been collected over this region during six missions (in addition to the 1991 sitewide survey) designed to evaluate changes in concentration and distribution of specific radionuclides (EG&G, 1992). Radionuclides clinging to sediments have also been the focus of AGRS missions over Steed Pond. Following a dam failure in 1984, successive aerial surveys were conducted to evaluate gamma values for sediments exposed after the drop in water level (EG&G, 1993b). The most recent sitewide aerial survey was conducted during October and November of 1991. Data processing for this survey was more extensive than previous missions and included matrix stripping and other techniques to extract additional information. This 1991 survey information included overall gross activity, overall man-made activity, overall natural activity, and excess ^{214}Bi (bismuth) activity (EG&G, 1993a). The 1991 survey report also included concentrations for the man-made isotopes ^{137}Cs, ^{60}Co, and ^{234m}Pa (protactinium) as well as concentrations of natural isotopes K (potassium), U (uranium), and Th (thorium).

Although ground-based gamma spectrometry bares a wealth of spectral data, the high cost of equipment and collection often prohibit practical application (Burgess *et al.*, 1989). The sensor and recording equipment, themselves, can prove to be too large for an individual task. Beyond these limitations, contemporary gamma survey methods are often limited by field conditions and practicability. Surface vehicle-based detector pods provide high resolution results when used with differential GPS (Gibbons, 1992; Wendling and Wade, 1994). However, the time needed for surveys of large areas is often cost prohibitive. Furthermore, the detector may only measure areas accessible by the platform. Such projects at the SRS would be impossible to implement due to dense vegetation and soft surfaces of stream corridors and swamps. Vegetation and swamps at the SRS also provide obstacles for field surveys by technicians using hand-held equipment. However, guided by preliminary boundaries identified by AGRS surveys, ground truthing is streamlined to minimize cost and maximize resolution.

Data

SRS Survey Mission

To define a methodology for the conversion of processed AGRS data and delineation of hazardous waste unit boundaries, a survey of the entire 795 km^2 SRS conducted during October and November of 1991 was used (EG&G, 1993a). The sitewide survey was conducted during optimum conditions with limited rainfall previous to and during the mission. During the 41-day mission, a total of only 4.26 cm of rainfall were recorded. Thus, attenuation due to soil moisture and standing water was negligible. Rainfall and streamflow effects on measured gamma activity have been reviewed during change detection studies in which an inverse relationship between soil moisture and dose rate has been identified (EG&G, 1992; EG&G, 1993b). A comparison of *in situ* measurements showed good correlation between AGRS and ground sampling within parameters of the varied resolution of each method.

The 1991 SRS survey was performed using thallium-activated sodium iodide (NaI(Tl)) detector arrays (EG&G, 1993a). The detector pods and data acquisition systems were mounted on a pair of Messerschmitt-Bolkow-Blohm BO-105 helicopters. Each platform included a pair of pods that each contained four (4- by 4- by 16-inch) downward-looking NaI(Tl) arrays. A single 4- by 4- by 16-inch NaI(Tl) detector was also used to aid in classifying high concentration areas.

Gamma ray spectra and positional data were recorded at one-second intervals at an altitude of 46 metres at 36 metres/sec with a flight line spacing of 76 metres. Thus, sample points along the flight line were approximately 36 metres apart. Positional information was recorded using an ultra-high-frequency ranging system and a radar altimeter. The positional accuracy for this equipment was estimated at $\pm$ 3 metres horizontally and $\pm$ 0.6 metres vertically.

Because the field-of-view of the detector was 92 metres (twice the survey altitude), the recorded data were significantly oversampled. To create the dense set of sample data used in this research, numerical filtering was applied to the positional and derived radiological elements by the survey contractor during processing. Although the distribution of the resulting data points is semi-uniform, the helicopter platform actually produces an irregularly spaced set of samples.

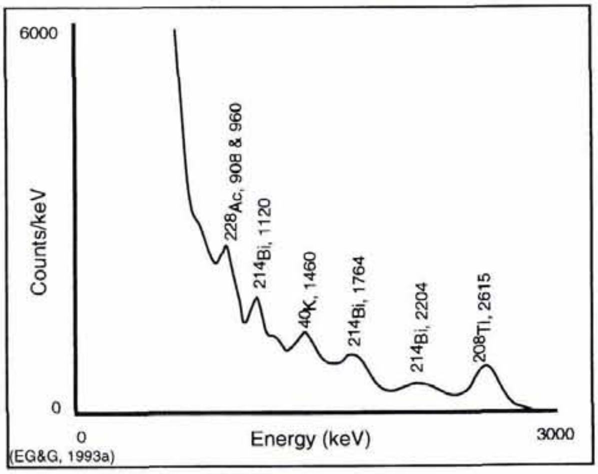

Figure 2. An example of gamma energy spectra delineation.

This is due, in part, to the inability of any slow moving aircraft to maintain perfectly straight flight lines and the necessity to avoid tall structures (i.e., stacks, antennae, etc.). Thus, an appropriate spatial data model must be selected to maintain the integrity of the original data while producing interpolations representative of the actual conditions.

Spectral Extraction of SRS Survey Data

Remotely sensed gamma spectra are a complex summation of every contributing isotope, whether natural or man-made. While the qualitative presence of a specific isotope, in relatively large quantities, will be seen in the energy spectrum as a distinctive peak (or multiple peaks), extraction of quantitative information must be done by application of statistical and matrix methods to "strip" out each contributing isotope. Figure 2 represents a natural spectrum (no man-made contributors) and illustrates the complexity of an unstripped spectrum.

The AGRS platform is based on the conversion of gamma energy to recorded electronic pulses. Photons from the interaction of gamma energy and the NaI(Tl) crystals generate electronic pulses in photomultiplier tubes and are classified for analysis. In any given measurement, AGRS measures an observed spectrum which is the complex sum of all individual unique contributors. In principle, given a combined spectrum and knowing the pure spectrum of each possible isotope, stripping equations (in many unknowns) may be developed and solved by matrix methods to determine the contribution of each isotope at every spatially sampled point. Energy windows are established in the vicinity of features representative of the isotopes present. These windows are generally established around significant photopeaks as listed in Table 1. There must be as many statistically unique windows as there are isotopes to obtain a unique solution. Pure spectra are obtained from the data set by collecting many spectra, which have varying proportions of the isotopes of interest, and extracting pure spectra by mathematical operations between the sample spectra and computed resultant spectra. This extraction of spectral information and extensive gamma analyses were conducted by the contractor prior to data delivery. The actual statistical methods, specific spectral windows, and dose conversion factors used in this research are describe in detail in the 1991 survey report (EG&G, 1993a).

TABLE 1. SELECTED RADIOISOTOPE SPECTRAL PEAK IDENTIFIERS

Radionuclide window	Minimum energy (keV)	Maximum energy (keV)	Major peak (keV)	Window name
^{214}Bi	1588	1946	1764	uranium[a]
^{137}Cs	590	734	662	cesium
^{60}Co	1046	1466	1250[b]	cobalt
^{40}K	1298	1610	1460	potassium
^{208}Tl	2342	2882	2615	thorium[c]

[a] ^{214}Bi is a transmutated daughter in the uranium disintegration series.
[b] Two primary peaks for ^{60}Co are combined for an average energy value (EG&G, 1993a).
[c] ^{208}Tl is a transmutated daughter in the thorium disintegration series.

Methods

Data Model

Unlike other remotely sensed data that maintain inherent topology when defined by rasters, processed AGRS data are represented as individual point samples. By using an exposure rate or dose value for each sample point as the Z dimension in a continuous surface, conversions to cell models and contour interpolations could be made from a TIN data model. The implementation of a TIN structure allowed the original X and Y coordinates to be retained within a non-uniform boundary that did not require initial interpolations. This is of paramount importance in that multiple-data interpolations must be avoided in order to preserve the most plausible representation of real-world conditions.

The extensive data recovery and spectral classification of AGRS data by EG&G personnel resulted in radioisotope-specific ASCII files containing X, Y, and Z values. Activity counts and associated dose values were used as the Z component of each file. A summary of ^{137}Cs data demonstrates the variance in the range of response values. The maximum detected value for samples within the SRS boundary was 225,605 cps (7,896 MREM/yr) for ^{137}Cs. Because the survey encompassed such a large geographic area and sample values tend to increase exponentially to a source, the data range was skewed toward the low mean of 3 MREM/yr (^{137}Cs).

An Arc Macro Language (AML) routine was employed to convert the ASCII data files into separate ARC/INFO Generate format and attribute files. Although X, Y, and Z values could be written to a single text file for input directly to TIN structures, a point coverage with an associated attribute table containing detector counts (Z) and corresponding dose (MREM/yr) for each radioisotope was derived. This approach was selected to allow the construction of TINs from each of these attribute items. Once the TIN was created, it could be used as a digital terrain model (DTM) or as the origin of contour interpolation. As with many other aspects of GIS implementation, the selection of data model and interpolation method exert a significant impact on the final product.

Interpolation

The goal of most surface representations is to define the function which best describes existing data while predicting unknown values at various locations (Lam, 1983; Goodchild, 1992). Once the AGRS data were represented in a spatial data model, a method of calculating these non-sample point values was investigated. As described by Lam (1983), numerous algorithms have been developed for point interpolation, which may be divided into exact and approximate methods. The implementation of a particular interpolation method is largely dependent on the type of data used, the degree of accuracy required, and whether the original sample points are to be pre-

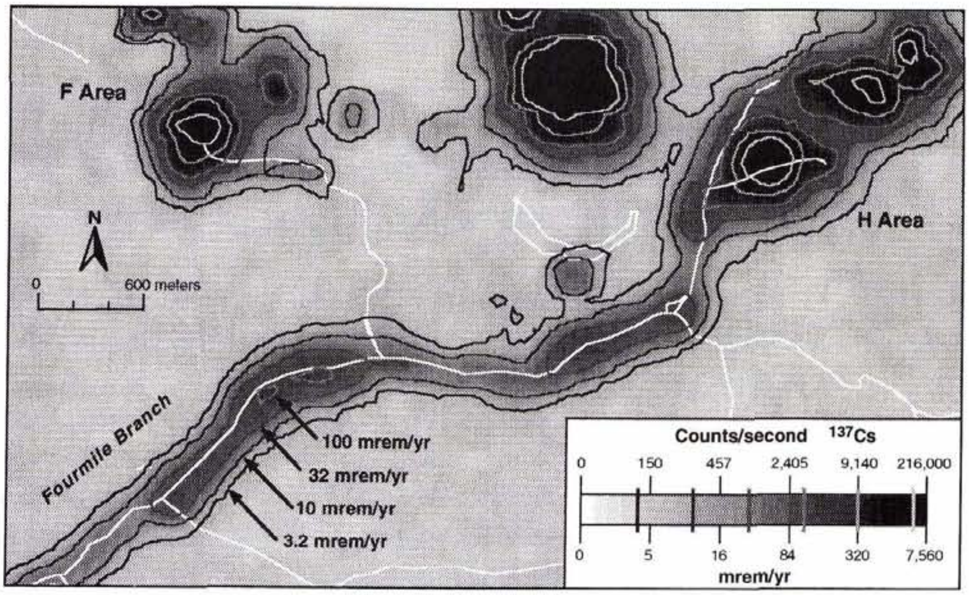

Figure 3. Distribution of ^{137}Cs in Fourmile Branch.

served. Exact interpolation derives non-sample point values from mathematical functions that define the continuous plane. Such methods include linear, spline, polynomial, and kriging functions to preserve the original data while representing the entire surface. Approximate methods such as trend surface models and distance-weighted least-squares assume functions that closely model the sample locations within the surface but do not include the exact value of those points.

Unlike models of terrain, surfaces depicting radioactivity are not tangible. Therefore, they have no inherent sense of shape, distribution, morphology, and other fundamental parameters. Carter (1988) suggests that gross errors in representing such data may only be detected by an individual's familiarity with a specific data set. This is the case in evaluating AGRS data in a spatial data model context. Although the resulting interpolations are produced through the application of fundamental physics and spatial theory, GIS products using AGRS data are subjective with respect to the end-user. As noted by Monmonier (1982), "Interpolation is a highly subjective process, and an estimation procedure is not right or wrong, but merely plausible or absurd."

To limit the degree of abstraction from original values, linear interpolation methods were employed to construct contours. This decision was supported by the ability of linear interpolations of TIN models to be made directly from heights of triangle nodes without entering the X and Y values of each facet into a polynomial function. Furthermore, polynomial functions are more suited for interpolation of sparse data sets while systematically sampled phenomena, as in AGRS surveys, limit discontinuous slope problems of linear methods to maximize computational speed. The linear method allowed the most direct computation of values between nodes, which limited false assumptions of the spatial variance of gamma emissions. As defined by Weibel and Heller (1991), the efficiency and flexibility of TIN-based interpolation makes it a valid choice for the large data sets used in this project.

Contouring

Contours of dose values were calculated from TINs using a base value and constant interval. This was necessary due to the parameters of ARC/INFO contouring procedures that require uniform interval values. To accommodate arbitrary user-defined intervals, an AML routine was utilized to derive contours for selected values and combine them into a single coverage. The range of TIN node data values was determined and used as the interval to assure that each successive coverage contained only one contour value. Thus, the value for each interval was equal to one unit above the data range (i.e., Interval [Max Z − Min Z] + 1).

The frequency distribution of data values also promoted the use of non-uniform contour intervals. Areas of interest were concentrated at the high end of a data range (0 to 7,896 MREM/yr for ^{137}Cs) that was skewed toward the low mean (3 MREM/yr). Frequency decreased as sample values reached an exponential maximum. Thus, single contour intervals would either over-represent or under-represent AGRS data values.

Gridding

Summary statistics describing the distance between AGRS sample points were used to define the grid-cell resolution of 20 metres. Due to the large range of values of converted data, the cells were reclassified to 25 classes. Gray-scale look-up tables were created to display the classified categories as a gradation between response values. The display of the gridded ^{137}Cs data, along with the contours, provides an informative picture of activity transition between contour intervals (Figure 3). By representing radiological hazards as graded values along with contour intervals, more information is conveyed about areas of contamination than with previous display methods.

Surfaces

Surface displays that included reference meshes were also created to depict extreme AGRS values and to identify areas of contamination. The surfaces calculated from these data were used to demonstrate the interaction between potential radiological hazards and physical and cultural phenomena. Hydrographic features were draped over these surfaces to demonstrate the influence of fluvial systems on the distribution of radioactivity. As seen near F and H industrial areas, Fourmile Branch is one transport mechanism for ^{137}Cs (Figure 4). Techniques involving three-dimensional imaging were

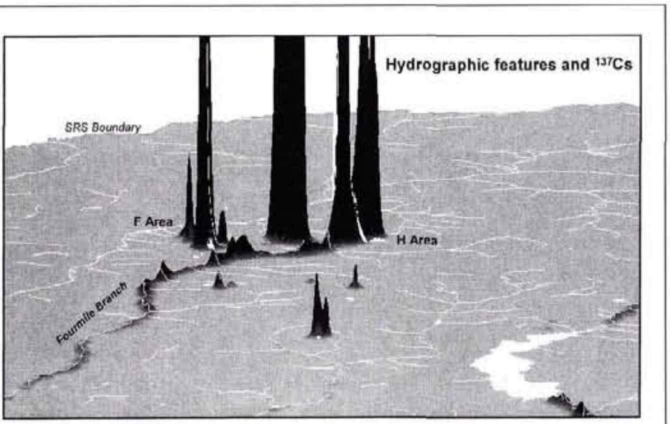

Figure 4. Overlaid by stream networks, the spatial distribution of radioactivity highlights hydrographic features as transport mechanisms.

also researched to demonstrate the importance of visualization in synthesizing decisions regarding complex data sets. Combining diverse information in a GIS promotes integration of individual discipline constructs to analyze and evaluate complex relationships in models.

Discussion and Conclusions

Potential Hazard Boundaries

As a product of AGRS survey data, contoured boundaries may be derived for potential radiological hazards. Such boundaries can define areas of high contamination related to the sum of man-made radioactivity or for individual radioisotopes. As a tool for identification and monitoring, the developed routines allow project-specific constraints to be applied to hazard mapping. Exploiting this capability, hazard boundaries can be identified by contouring various maximum dose limits for radiation workers and the public. The resulting potential hazard boundaries will prove a valuable resource for directing sampling plans and mapping projects in focussed investigations.

Spatial Implications

GIS and spatial modeling promote the identification of interactions between phenomena. In addition to previous contouring methods, TIN representations of AGRS data may be used to identify human and environmental entities affected by contamination. However, the degree of risk from such hazards are quantifiable only by those models developed for such assessments. In addition to extracting quantitative data from point or contour coverages for risk models, static displays of hazardous waste management units (WMUs) serve as a map to direct characterization and cleanup efforts.

Moving beyond static representation, models of radiological activity, when combined with physical and cultural geographic elements, can be used to identify cause and effect relationships. Characteristics of SRS hydrologic systems determine the direction, speed, and destination of radioactive contaminants introduced at various point-source locations (Whicker *et al.*, 1990; Davison *et al.*, 1993). This is quite evident in the Fourmile Branch area. The relationship between fluvial system and ^{137}Cs distribution is displayed in Figures 3 and 4. The source of radionuclide introduction into Fourmile Branch is obviously from the northern banks of the stream. This statement is supported by results of health physics investigations that identify facility areas, their seepage basins, the burial grounds, and a single spill incident as the source of all traceable ^{137}Cs in Fourmile Branch (Carlton *et al.*, 1994). Elevated gamma values along Fourmile Branch decrease as the stream nears the Savannah River. The destination and transport rate of ^{137}Cs is dependent on interaction with soils, vegetation, stream flow, and subsequent erosion (Briese *et al.*, 1975; Whicker *et al.*, 1990; Davison *et al.*, 1993). Thus, activity is reduced by time (decay) and distance (redistribution) as radionuclides are transported downstream.

Summary

The objective of this paper was to illustrate the capabilities of available GIS tools and aerial gamma spectrometer technology that may be utilized to define radiological hazards. The described application was intended to provide hazard information about inaccessible areas of a large industrial facility. Specifically, the goal was to delineate boundaries in unyielding terrain along fluvial systems. The application of *in situ* survey methods, as used in production areas, is not practical in such remote and hostile terrain. Thus, remote sensing technology may be employed to identify hydrographic features that exceed specific radiological criteria.

The results of this project included a method to convert processed AGRS data to TIN structures from ASCII text files of sample points. User-defined contour intervals of critical value are interpolated from these TIN models. These user-defined critical level contours are then used to delineate boundaries of potential radiological hazards. Cell models can be derived to highlight the transition of radiological activity between contour intervals. In addition, by converting AGRS point data to TIN models, surface displays identify relationships between the distribution of radiological activity and fluvial transport systems.

By defining procedures to incorporate AGRS data into user-defined GIS representations, this research promotes the application of remote radiological measurements in risk analysis and management. The greatest advantage to promoting individualized output products is in supporting results that may be used in applications with varied standards. Although AGRS technology has been available for U.S. Department of Energy investigations for several decades, inclusion in GIS databases in several formats is significant. This work advances the ability of risk models to consider spatial characteristics of radiological elements in the integration of interdisciplinary data.

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