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**ENVIRONMENTAL
RESTORATION
PROGRAM**

**Airborne Geophysical Survey of
the Oak Ridge Reservation,
Tennessee**

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**MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY**

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Airborne Geophysical Survey of the Oak Ridge Reservation, Tennessee

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ACRONYMS and ABBREVIATIONS

AGL	Above Ground Level
DOE	United States Department of Energy
EG&G	EG&G Energy Measurements, Inc.
EM	Electromagnetic
ER	Environmental Restoration
GPS	Global Positioning System
GWOU	Ground Water Operable Unit
OREIS	Oak Ridge Environmental Information System
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
SWSA	Solid Waste Storage Area
VLF-EM	Very Low Frequency Electromagnetic

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Airborne Geophysical Survey of the Oak Ridge Reservation, Tennessee

Status Report, July 1994

W.E. Doll, J.E. Nyquist, and L.P. Beard
Environmental Sciences Division, ORNL

High-resolution and reconnaissance data, acquired using sensors mounted on a helicopter, were used to characterize waste sites and detect geologic properties that influence contaminant transport on the Oak Ridge Reservation (ORR), Tennessee, between December 1992 and April 1994. To date, these data have been used to support several ORR Environmental Restoration (ER) programs. This report summarizes the techniques used, the ways in which the data have been applied to date, and current plans for enhancing the data and making them more useful to the ER programs.

1.0 Objectives

The primary tasks of the airborne geophysical survey team are to:

- Provide data, special processing and interpretation to ER program managers and project scientists who need information related to buried objects, geologic features, or other subsurface targets
- Process and evaluate airborne data to determine whether there are any unknown waste sites on the ORR and determine whether mapped waste area boundaries are correct

- Conduct quality assurance activities and sensitivity analyses using test data and comparisons with surface measurements
- Develop and perform advanced processing and filtering of the data to enhance detection of particular types of targets

2.0 Instrumentation and procedures

Geophysical methods encompass many techniques which are designed to locate and characterize subsurface features. They are frequently used in the petroleum and mining industries and have been widely used for environmental purposes. Mineral prospecting companies have used helicopter-mounted sensors for the detection of metallic and radioactive ore bodies for many years. These technologies, which we have adapted to environmental applications, employ magnetometers, gamma ray detectors, and both passive and active electromagnetic systems to sense changes in the magnetic, radioactive, or electrical properties of the subsurface. The instruments are placed in a "bird" suspended from the helicopter on a 100-foot tow cable or in the baskets at the base of the helicopter, and are connected to a computer that records data from each sensor at 0.1 second intervals. In this way, data are acquired from all of the instrument in a single pass, at intervals of six to ten feet along the flight path. A post-processed global positioning system (GPS) allowed position to be determined to within two to three feet (horizontally), once per second.

Data Acquisition System

Data were acquired during two time periods. Between November 1992 and January 1993, reconnaissance data were collected over the entire ORR along north-south flight lines at a flight line spacing of 150 feet and a bird altitude of 100 feet above ground level (AGL). Test data were acquired at well-characterized sites during this survey in order to calibrate the system and determine sensitivity. Between February and April 1994, high resolution data were collected over waste areas and other sites which were selected from the earlier reconnaissance data. Some of these data were collected at instrument altitudes of less than fifty feet.

The multifrequency electromagnetic (EM) system consists of transmitting coils and receiving coils placed at opposite ends of the bird. Electrical currents pass through the transmitting coil at five or more selected frequencies, and cause currents to be induced in the ground beneath and in the receiving coil. By measuring variations in the current in the receiving coil, the system is capable of detecting changes in the electrical resistivity of soils and rocks to depths of about 300 feet. Two different coil orientations are used to distinguish different shapes of conductors. Resistivity is controlled by natural features such as changes in rock type, faults, fractures, and water content of the rocks (porosity), and by man-made features such as pipelines, power lines, buildings, and vehicles.

Two cesium magnetometers were placed, one above the other, in the tail of the bird in the low altitude system. In the system which was used for reconnaissance, they were located fifty feet above the bird on the tow cable. Each of these measures the total magnetic field, and the difference in the total field at the two magnetometers is a measure of the vertical magnetic gradient. Although these are sensitive to changes in geology, they are most sensitive to metallic man-made objects including buildings, waste sites, power lines, and pipelines.

A 256-channel sodium iodide gamma ray detector was mounted in the basket at the base of the helicopter. Radiometric data can be processed to generate maps of natural radionuclides (e.g., potassium) for mapping geology, or to generate maps of man-made radionuclides which result from plant operations on the ORR. The radiometric data supplement data that were collected in earlier surveys, including the April 1992, EG&G survey. The EG&G survey differed from our geophysical survey in that it did not cover the entire ORR and was flown in an east-west flight

direction. The cost of including the radiometric sensor in the geophysical survey was minimal and provided an additional layer of quality assurance to the EG&G survey.

In addition to the above instruments, a very low frequency electromagnetic (VLF-EM) receiver was placed in the bird. This is a passive system in that it does not have its own transmitter, unlike the multifrequency system discussed earlier. Rather, it senses changes in the electromagnetic field from several U.S. Navy transmitters located in Maine, Maryland, Washington, and other states and countries. It is sensitive to long, continuous conductors such as power lines, faults, and possibly subsurface karst conduits. As with the radiometric system, data from this sensor were collected at little additional cost.

3.0 Data Products

Most of the deliverables from the reconnaissance survey were received by October 1993. The remaining reconnaissance maps and products from the 1994 high resolution survey will be delivered by August 1, 1994. Appropriate maps will be placed in the OREIS data base as soon as possible. Map products which were not delivered by the contractor, or which require input from geophysicists, will be handled on an as-needed basis. Meetings have already been held with site managers and specialists representing particular sites, and we expect these to continue.

Apparent resistivity maps show a strong correlation with mapped geologic contacts over the entire reservation. Shales behave as electrical conductors (red in the map below) while limestones act as resistors (green in the map below), producing the striped appearance of the map.

4 kHz Apparent Resistivity Map of the ORR

The magnetic maps, including the vertical gradient map shown below, are most sensitive to buried metals on the ORR. We are currently evaluating large-scale maps of these data to confirm that mapped boundaries of waste areas are consistent with magnetic anomalies. This is difficult because of the limited accuracy of existing base maps upon which the geophysical data can be overlain, but will improve when new base maps become available.

Vertical Magnetic Gradient Map of the ORR

The VLF-EM data have effectively delineated power lines, as expected, but also seem to be the most sensitive data to faults on the ORR.

VLF-EM Total Field Map of the ORR

Radiometric maps for potassium and several man-made isotopes have been reviewed. The potassium maps reflect near-surface geology (as with the apparent resistivity maps), and the man-made isotope maps, when fully processed, are similar to those produced in the EG&G survey. Because the processing of the man-made isotope maps is

being conducted locally using data that have only recently been delivered, we have not yet conducted a thorough comparison of our data with that from earlier surveys.

4.0 Environmental Restoration Applications

Since receipt of the first maps from the contractor, our efforts have been divided among three tasks: 1) evaluation of data quality and sensitivity, 2) development of tools for rapid display and enhancement of these data, and 3) interaction with

TABLE 1. Listing of Environmental Restoration Applications of Airborne Geophysical Data.

ER Participant	Site	Application / Issue
Ralph Turner	Rogers Quarry	Airborne magnetic data show magnetic anomalies at the west and southern ends of Rogers Quarry that match expected locations of waste materials there.
Dick Ketelle	ORNL GWOU	Airborne EM and magnetic data are being used to gain a regional perspective on geologic features constraining groundwater movement, including karst features, faults, and contacts. Locations of surface surveys including mapping of the brine layer will be selected in part on the basis of these data.
Peter Lemiszki	K-25 Geologic Mapping	Complex folding between White Wing Scrapyard and K-25 is imaged in the airborne EM and potassium radiometric data. Sites for surface geologic investigations are being chosen on the basis of the airborne data, and contacts which were once thought to be tentative have been confirmed.
C. Steve Walker	Y-12 Burial Grounds	Preliminary comparisons of airborne magnetic data with the S-16A base map suggested that a large waste site might exist east of the Boneyard Burnyard area. However, surface follow-up activities showed that existing roads differ from those mapped on the S-16A, and that no large discrepancies exist. When the new base map becomes available, careful comparisons of anomalies with mapped waste area boundaries will be conducted.
Clay Bednarz	White Wing Scrapyard	Surface magnetic surveying was planned to locate waste areas within White Wing Scrapyard. Existing and new airborne geophysical data were evaluated to assist in selection of data acquisition parameters for the site.
Clay Bednarz, Dale Huff, Dick Ketelle	SWSA4	Airborne and surface data have been collected at SWSA4 in order to determine the sensitivity of airborne systems. These data have been provided to those planning the remediation of SWSA 4.
Dave Watson	Union Valley Carbon Tetrachloride Plume	Union Valley was not included in the area covered in the 1993 reconnaissance survey because it is outside the boundaries of the ORR. Data were acquired over Union Valley during the 1994 data collection phase at the request of those who are attempting to characterize the recently-discovered carbon tetrachloride plume there. Delivery of maps from this area is expected within a few weeks.
Tom Zondlo	Waste site north of K-25	A well, north of K-25 and outside the boundaries of the ORR showed high alpha during one sample test. A poorly characterized waste site, located within the ORR, between K-25 and the well, was considered as the possible source. Aerial survey data were used to determine the levels of radioactivity and character and location of materials at the waste site.
Scott Morey	Freel's Bend	Airborne maps of Freel's Bend were delivered to Radian Corp. personnel who were conducting a site investigation to determine whether a remedial investigation would be necessary there.

High resolution airborne magnetic gradient data from the March 1994 survey of White Wing Scrapyard superimposed on a rectified aerial photograph. Reds are positive magnetic peaks and blue are negative peaks.

site managers who have immediate need for the data from a particular site. Table 1 lists the people with whom we have held discussions and their application of the data from this survey. We are planning for an increasing number of these meetings once the utility of these data becomes known.

Rather than discuss all of these applications in detail, we will focus on data we have analyzed from White Wing Scrapyard and on airborne detection of karstic features.

4.1 High Resolution Data From White Wing Scrapyard

High resolution data were acquired in March 1994 at White Wing Scrapyard, located in the western part of the ORR, in response to a request from the DOE Field Office for information that could help set parameters for a surface magnetic survey scheduled for the site. Vertical magnetic gradient data from that survey are shown superimposed on a rectified aerial photograph in the image shown on this page. Peaks greater than 1 nanoTesla per meter (nT/m) or

4.2 Airborne Detection of Karst Features

Considerable attention has recently been directed toward identifying underground dissolution features because of their potential for transporting contaminants off site. These features can be detected when the resistivity of the material that fills the void is sufficiently lower than that of the host rock. From airborne electromagnetic data, we have identified five conductive areas within limestone units on the ORR which appear to be related to voids or collapse structures due to karstification (dissolution of limestone). One of these (Copper Ridge Cave) was previ-

less than -1 nT/m are represented in red and blue, respectively. The image demonstrates the integrated approach which combines aerial photography with airborne geophysical data which we have found to be very helpful in locating the sources of anomalies on the ORR. These data are being used to set boundaries for a surface survey and to select detection thresholds for that survey. This results in better planned and less expensive surface data collection and analysis.

850 Hz airborne electromagnetic anomalies which may be related to karst areas on the ORR. Inset shows 4kHz coplanar data.

ously known, and a second was known to be located near the K-25 disappearing stream anomaly. These are identified on the figure above. It is important to note that none of these areas are located where offsite contaminant transport is a concern. We have so far been unable to detect anomalies associated with the known karst features in parts of the ORR which *are* of concern (e.g. near the Y-12 plant).

To better understand what is causing the electromagnetic anomalies over karstified areas, we have been comparing observed anomalies with anomalies generated by computer modeling programs. The models, as shown below,

assume that the structures are made up of some combination of air and conducting sediments or water (10 ohm-meter resistivity) embedded in limestone (1000 ohm-meter resistivity). By testing a range of depths, resistivities, and void dimensions, we can gain an improved understanding of the sensitivity of airborne systems to karst and may develop techniques for enhancing karst anomalies which remain hidden in our data.

5.0 Ongoing and Planned Activities

The following activities are in progress or planned in order to accomplish the tasks outlined in Section 1.0:

- Overlaying cultural and geologic maps on the geophysical maps to screen for unexplained anomalies.
- Field inspection and follow-up surface measurements at selected sites.
- Development of computer programs to aid interpretation of observed anomalies.
- Measurements of the electrical and magnetic properties of soil samples and rock core samples from the ORR to aid in interpretation.

Computer Model of a Karst Feature

- Processing and analysis of test data acquired over pickup trucks, 55-gallon drums, and waste sites to establish sensitivity and limitations of the data.
- Subcontracts with U.S. Geological Survey, University of Utah, and the University of California - Berkeley to develop special processing schemes that can be applied to these data.
- Surface measurements at the Portsmouth Gaseous Diffusion Plant, Ohio, through a subcontract with Ohio University, to determine whether airborne methods will be appropriate there.

6.0 Further Information

For more information about the Airborne Geophysical Survey, you may contact W.E. Doll at 576-9930, or J.E. Nyquist at 574-7420, both at MS6317, Bldg. 3504, ORNL. Program Manager for the Remote Sensing and Special Surveys Program is Amy King, and she may be contacted at 576-1509 or MS 6480, Bldg. 1060 Com. Email addresses for the three persons named above are d8e@ornl.gov, nyq@ornl.gov, and kingad@ornl.gov respectively.

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