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**PHASE II - FINAL REPORT
PRDA NO. DE-RA05-910R22000**

**INEL COLD TEST PIT
DEMONSTRATION OF IMPROVEMENTS IN INFORMATION
DERIVED FROM NON-INTRUSIVE GEOPHYSICAL METHODS
OVER BURIED WASTE SITES**

CONTRACT NO. DE-AC07-93ID13215

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EXECUTIVE SUMMARY

Under Contract No. DE-AC07-93ID13215, between U.S. DOE Idaho National Engineering Laboratory (INEL) and the Blackhawk Geosciences Division of Coleman Research Corporation (BGD-CRC), geophysical investigations were conducted to improve the detection of buried wastes. Site characterization is a costly and time consuming process with the most costly components being drilling, sampling, and chemical analysis of samples. There is a focused effort at U.S. DOE and other agencies to investigate methodologies that reduce costs and shorten the time between characterization and clean-up. These methodologies take the form of employing non-invasive (geophysical) and minimal invasive (e.g., cone penetrometer driving) techniques of characterization, and implementing a near real-time, rational decision-making process (Expedited Site Characterization).

Over the Cold Test Pit (CTP) at INEL, data were acquired with multiple sensors on a dense grid. Over the CTP the interpretations inferred from geophysical data are compared with the known placement of various waste forms in the pit. The geophysical sensors employed were magnetics, frequency and time domain electromagnetics, and ground penetrating radar. Also, because of the high data density acquired, filtering and other data processing and imaging techniques were tested. The conclusions derived from the geophysical surveys were that pit boundaries, berms between cells within the pit, and individual objects placed in the pit were best mapped by the new Geonics EM61 time domain EM metal detector. Part of the reason for the effectiveness of the time domain metal detector is that objects buried in the pit are dominantly metallic.

Also, the utility of geophysical data is significantly enhanced by 2-dimensional and 3-dimensional imaging formats. These images will particularly assist remediation engineers in visualizing buried wastes.

After completion and analysis of the survey and interpretation over the CTP, the second phase of investigation consisted of testing geophysical methods over the Idaho Chemical Processing Plant (ICPP). The sections of the ICPP surveyed are underlain by a complex network of buried utility lines of different dimensions and composition, and with placement at various depths up to 13 ft. Further complications included many metallic objects at the surface, such as buildings, reinforced concrete pads, and debris. Although the multiple geophysical sensor approach mapped many buried utilities, they mapped far from all utilities shown on the facility drawings.

The work performed under this contract demonstrates the importance of utilizing a multiple sensor approach for mapping buried wastes and underground utilities. A multiple sensor approach, acquisition of data at high spatial density, and advanced processing and imaging, resulted in good definition of the waste pit, and objects within it. On the other hand, the work over the ICPP also illustrates the limitations of present sensor technologies. The sensors lack the capability to effectively work adjacent to metallic surface structures. Moreover, a complex network of utilities, buried at different depths, can presently not be effectively imaged by remote sensors.

1.0 INTRODUCTION

The U.S. DOE, other agencies of the U.S. Government, and our nation's industrial facilities are burdened by a legacy of inadequate disposal practices of radioactive, hazardous, and mixed wastes. Cleaning up of this contamination is a complex process that begins with assessing sources and extent of contamination (site characterization). It then proceeds with feasibility investigations of the effectiveness of various alternate cleanup methodologies, design of remediation procedures, and restoration of a site.

Site characterization itself is a costly and time consuming process. The most costly components of site characterization are drilling, sampling, and chemical analysis of samples. There is a focused effort at U.S. DOE and other agencies to investigate methodologies that reduce costs and shorten the time between characterization and cleanup. These methodologies take the form of employing non-invasive (geophysical) and minimal invasive (e.g., cone penetrometer driving) techniques of characterization, and implementing a near real-time, rational decision-making process (Expedited Site Characterization).

This report contains the results of the research conducted under a PRDA from the Idaho National Engineering Laboratory (INEL). The objectives of the research are to make improvements in non-invasive methods for buried waste detection. The research was conducted in two phases:

- 1) In *Phase I*, data at high spatial density were acquired over the Cold Test Pit (CTP) at INEL. Data were collected with commonly employed sensors (magnetics, frequency domain electromagnetics, broad-pulse ground penetrating radar), as well as with prototypes of new, innovative sensors, such as a time domain electromagnetic metal detector and an Earth Penetration Radar Imaging System (EPRIS) that uses a frequency stepped radar technology and synthetic aperture imaging algorithms.
- 2) In *Phase II*, surveys were performed over selected areas of the Idaho Chemical Processing Plant (ICPP). The sensors selected for surveying over the ICPP were the Geonics EM61 time domain electromagnetic metal detector, the Geonics EM31 and EM38 frequency domain electromagnetic system, two types of Magnetometers and two GPR systems. The results of the interpretation of these surveys were compared by overlaying facility drawings.

Part of the objective of Phase I and Phase II work was also to test innovative filtering, processing, and display procedures to enhance the value of geophysical surveys in planning subsequent intrusive tests, feasibility investigations, and remediation design. Because the logistics, data processing, and results of

surveys with various sensors over the CTP were given in the Final Report on Phase I work, these details are not repeated in this report. Instead, we focus in this report on a comparison between the various sensors and imaging formats for displaying the data. For the surveys over the ICPP the results of the interpretation are compared with available facility maps.

In Section 2.0 an overview of the physical principles underlying the operation of the sensors is given, as well as a brief review of the data collected. Section 3.0 contains a comparison of the interpretation about buried wastes inferred from the various sensors over the CTP with as-built design data. In Section 4.0 the results of interpretation over the ICPP are provided. Conclusions about the utility of all sensors are drawn in Section 5.0.

2.0 OVERVIEW OF PHYSICAL PRINCIPLES OF SENSORS AND DATA ACQUISITION

2.1 GENERAL

Buried wastes occur in many different forms and can be composed of widely varying chemical compounds. The form in which the waste is buried has a direct impact on the success of geophysical technologies employed in detection. In the Cold Test Pit (CTP) simulated wastes were placed in containers, and both metallic and non-metallic containers were buried. All sensors utilized in detection of buried wastes measure remotely a physical property, and if the value of the physical property of wastes differ from that of surrounding soils, anomalies (or perturbations) in sensor measurements may result. Use of multiple sensor measurements offer the potential of moving from detection to characterization, - to distinguish, for example, between wastes buried in metallic and non-metallic containers.

In the next section the physical principles of each sensor type employed is briefly reviewed, and the purposes of each sensor in buried waste characterization is discussed.

2.2 MAGNETICS

The Earth's magnetic field can be represented as a magnetic dipole at the center of the earth with the negative or south magnetic pole directed toward the geographic north pole. The magnetic field is presented in units of gammas (nano teslas). The strength of the Earth's magnetic field is about 60,000 gammas near the poles where its direction is vertical to the Earth's surface, and about 25,000 gammas near the equator where it is parallel to the Earth's surface.

Burial of ferromagnetic objects causes local perturbations in the Earth's magnetic field. The Earth's magnetic field induces a magnetic moment per unit volume in ferromagnetic material, and this induced magnetization is parallel with and proportional to the Earth's local magnetic field. Therefore, the intensity and shape of perturbations caused by a buried drum or a basalt boulder varies across the Earth (Fig. 2-1). At the magnetic poles this anomaly could be a simple positive peak, and at the magnetic equator a negative anomaly may occur. At INEL the inclination of the Earth's magnetic field is about 68°.

Fig. 2-1. Total Magnetic Field Anomaly for Various Inclinations.

Magnetic field measurements were made with a proton precession magnetometer (Fig. 2-2) and a cesium vapor magnetometer (Figure 2-3). The proton precession magnetometer utilizes the precession of spinning nuclei of the hydrogen atom in a hydrocarbon fluid to measure the total magnetic intensity. The spinning protons in a sample of water, kerosene, alcohol, etc., behave as small, spinning magnetic dipoles. These magnets are temporarily aligned by application of a uniform magnetic field generated by a current in a coil of wire. When the current is removed, the spin of the protons causes them to precess about the direction of the ambient or earth's magnetic field. The precessing protons generate a small signal in the same coil used to align them. The frequency of the signal is proportional to the total magnetic field intensity and independent of the orientation of the magnetometer sensor. A proportionality constant relates frequency to field intensity and is a well known atomic constant called the gyromagnetic ratio of the proton. With the proton precession magnetometer employed, the total magnetic field intensity is determined with an accuracy of 1 gamma.

The Cesium vapor magnetometer (Figure 2-3) is an alkali-metal vapor magnetometer that was developed in the 1960's as an instrument capable of measuring the earth's total field with greater precision than earlier instruments (e.g. fluxgate, Schmidt balance). This is an optically pumped magnetometer which consists basically of a cell of cesium vapor that is excited by a beam of light from a source of the same vapor. The principle on which it operates makes use of a radio-frequency spectroscopy method called optical pumping (Dobrin 1988).

Fig. 2-2. Photo of Proton Precession Magnetometer.

The Earth's magnetic field generally drifts slowly over time (typically a few gammas per hour), but it can also have large diurnal variations. In fact, during geomagnetic storms these variations can be so large as to preclude meaningful magnetic field measurements. To continuously record this drift in the magnetic field, a base station magnetometer can be set out in a stationary position near the site. The readings from a roving magnetometer can be corrected for the drift observed at the base station.

Fig. 2-3. Photo of Cesium Vapor Magnetometer.

2.3 FREQUENCY AND TIME DOMAIN ELECTROMAGNETICS (EM)

The principles of frequency domain EM (FDEM) and time domain EM (TDEM) sensors are similar (Kaufman and Keller, 1983). Both systems employ a magnetic dipole transmitter, consisting of a closed loop of wire through which a time-varying electrical current is driven. This time-varying current causes a time-varying primary magnetic field (Fig. 2-4a). This primary magnetic field will induce eddy currents to flow in the ground, and in highly conductive (metallic) objects buried within it. These induced eddy currents in turn are time variant, and cause a secondary magnetic field (Fig. 2-4b). From measurements of the electromotive force (emf), associated with this secondary field, in a magnetic dipole receiver coil, information about ground conductivity, and dimensions and depth of burial of metallic objects embedded in the subsurface can be derived.

Fig. 2-4. Illustration of a) Eddy Currents Caused By Primary Field, and b) Secondary Field Due to Eddy Currents.

Figure 2-5 shows the system waveforms employed in frequency and time domain systems. This simple difference in system waveforms has a major influence on sensitivity of EM sensors. Some of the reasons for this are conceptually explained below.

Fig. 2-5. System Waveforms Used in a) Time Domain, and b) Frequency Domain Systems.

The electromagnetic instrumentation used for the INEL geophysical demonstration includes the Geonics EM31, EM34 and EM38 FDEM systems, and the Geonics EM61 and EM47 TDEM systems. Figures 2-6 through 2-10 are illustrations of these instruments.

The emf's measured in the receiver in both frequency and time domain systems can, as a first approximation, be written as the sum of contributions from several sources as given below (e.g., Kaufman and Keller, 1989):

Frequency Domain

$$\text{emf}_t = \text{emf}_p + \text{emf}_s + \text{emf}_{\text{amb}} \quad [1]$$

Time Domain

$$\text{emf}_t = \text{emf}_s + \text{emf}_{\text{amb}} \quad [2]$$

In both equations [1] and [2] the various emf's are defined as follows:

- emf_t is total emf measured at the receiver,
- emf_p is the emf due to the primary magnetic field caused by currents driven through the transmitter,
- emf_s results from the secondary magnetic field due to electrical eddy current flow induced in the subsurface, and
- emf_{amb} are the emf's due to ambient electromagnetic noise fields.

Clearly, the only component of emf that contains information about the subsurface and objects buried within it is emf_s . Neither emf_p (due to direct coupling of EM fields through the air) nor emf_{amb} contains useful information. Moreover, in most situations in geophysical exploration and buried metallic waste detection, $\text{emf}_p \gg \text{emf}_s$. Often emf_p is 10^3 times larger than emf_s . In frequency domain systems therefore, one must attempt to measure a small component, emf_s , containing all useful information about the subsurface, in the presence of a large component that contains no information about the subsurface. This limits accuracy of frequency domain EM sensors.

Fig. 2-6. Photo of EM31 FDEM Instrument

Fig. 2-8. Photo of EM38 FDEM Instrument

Fig. 2-7. Photo of EM34 FDEM Instrument.

Fig. 2-9. Photo of EM47 TDEM Instrument

Fig. 2-10. Photo of EM61 TDEM Instrument

In TDEM systems measurements are made during transmitter off-time, i.e., in the absence of a primary field. During off-time the only contributions to emf_t are caused by EM fields due to eddy current flow in the subsurface and ambient EM noise. The secondary magnetic field can, therefore, be more accurately determined.

The primary EM field of the transmitter will induce eddy current flow both in the metallic target as well as in surrounding soils. The emf at the receiver due to eddy currents (emf_s) induced in the subsurface will have two components (Kaufman, 1978; McNeill et al, 1984):

$$\text{emf}_s = \text{emf}_{tg} + \text{emf}_{bg} \quad [3]$$

where:

- emf_{tg} is the emf due to eddy currents induced in targets (buried metal), and
- emf_{bg} is emf due to eddy currents induced in surrounding soils.

In target detection, the objective is to maximize $\text{emf}_{tg}/\text{emf}_s$. Moreover, large advantages in interpretation arise if this ratio can be made nearly independent of soil types, so that anomalies due to metallic targets look nearly the same as sand and clay soils. Both theory and experiments have shown that in TDEM systems $\text{emf}_{tg}/\text{emf}_s$ can be maximized.

For a conceptual explanation, first consider the schematic behavior of eddy current flow in the Earth without buried metallic targets. The behavior of eddy currents is a function of time after current turn-off in the transmitter as illustrated in Figures 2-11a and 2-11b. Immediately after current turn-off, all eddy currents are concentrated near the surface under the transmitter loop (time t_0). With increasing time the currents are induced at greater depth. Figure 2-11b shows that at later time most eddy currents flow at greater depth, and currents have largely dissipated from the near surface.

Fig. 2-11. Schematic Illustration of Induced Eddy Current Distribution in the Subsurface in the Absence of Metallic Objects.

The rate of migration (diffusion) of eddy currents is a function of ground conductivity. The distance the eddy current maxima migrate as a function of time is given by (Kaufman and Keller, 1983):

$$d = 2\pi \left(\frac{2t}{\mu\sigma} \right)^{1/2} \quad [4]$$

where:

- d is distance of current maximum from the center of the transmitter loop,
- t is time after current turn-off in transmitter loop,
- μ is magnetic susceptibility (1.257×10^{-6} henry/m), and
- σ is ground conductivity (siemens/m).

In Table 2-2 the time required for the current maxima to migrate 6 m (20 ft) is computed as a function of ground conductivity. A depth of 6 m (20 ft) was chosen because most metallic objects will be encountered between the surface and 6 m (20 ft). Thus, currents can be expected to dissipate in the upper 20 ft of ground in a fraction of a millisecond even at high conductivities.

Table 2-2
Time Required for Eddy Current Maxima to Diffuse at a Distance of 6 m (20 ft)

Ground Conductivity (Siemens/m)	Typical Soil Type	Time in Millisec
10^{-3}	clean sands and gravels	6×10^{-7}
10^{-2}	silts, sandy clays	6×10^{-6}
10^{-1}	clays	6×10^{-5}
10^0	saline soils and rocks	6×10^{-4}
4	sea water	2.5×10^{-3}

Next, consider the eddy current behavior in the Earth in the presence of metallic targets. The behavior of eddy current flow in the presence of a metallic target is schematically illustrated in Figure 2-12. At early time (t_1) after current turn-off, eddy currents are induced in soil layers surrounding the targets, as well as in the targets. At this instant of time, the ratio $\text{emf}_{tg}/\text{emf}_s$ will be small (Fig. 2-13). Because the metallic target is highly conductive compared to the surrounding soils, the eddy currents in targets will decay more slowly with time than the currents in surrounding soils. At later time currents in surrounding soils will have dissipated in the upper 20 ft, but eddy currents in the targets remain. Measuring the field at time t_2 will result in an increased ratio of $\text{emf}_{tg}/\text{emf}_s$. At still later time currents in both soils and metallic objects will largely have decayed and the signal to noise ratio will be decreased.

There is, thus, an optimum time range for metallic object detection. In this time range metallic object detection should also be nearly independent of soil types, because eddy current flow in surrounding soils have dissipated.

Fig. 2-12. Eddy Current Flow Induced in the Subsurface in the Presence of Metallic Objects.

Fig. 2-13. Schematic Behavior of Ratio of Signal Due to a Metallic Object and Surrounding Soils.

The computations in Table 2-2 showed that eddy currents dissipate in the upper 20 ft of soils in times less than 10^{-4} millisecc. Dissipation of eddy currents in highly conductive targets, such as metallic objects, mainly depends on dimensions of targets. For a 55-gallon drum, eddy current flow in the drum persists to about 1 millisecc, and for metallic objects of smaller dimensions, significant eddy current flow will still be present after 0.1 milliseccs (McNeill et al, 1984).

Hence, if measurements are made in a time range from about 0.01 millisecc to 1 millisecc after turn-off, the time range of optimum metallic target detection would be covered. Over that time range, eddy current flow in surrounding soils will have dissipated from the upper 20 ft, while signals due to metallic objects should still be measurable. The Geonics EM61 makes measurements in one time gate from 0.4 millisecc to 0.85 millisecc. The concepts illustrated above are thoroughly documented by theoretical treatises in the published literature (Kaufman and Keller, 1983; Kaufman and Keller, 1989). There also is ample experimental evidence to support the theoretical computations.

2.4 GROUND PENETRATING RADAR (GPR)

In a ground penetrating radar (GPR) system, the two-way travel times of high frequency electromagnetic pulses launched by an antenna at the surface to reflecting boundaries in the subsurface and back to a receiving antenna at the surface are measured. Reflecting boundaries for high frequency electromagnetic pulses are interfaces where changes in dielectric constant occur. In this program, GPR surveys were run with two systems:

- the commercially available GSSI SIR-10 system which uses EM pulses with a broad frequency band (Fig. 2-14), and
- a frequency stepped radar technology with synthetic aperture imaging algorithms (Fig. 2-15).

Fig. 2-14. Photo of GSSI SIR-10 GPR Instrument.

Fig. 2-15. Photo of Coleman Research Corporation EPRIS GPR System.

In addition, a number of other GPR surveys have been run over the CTP by other investigators, such as EG&G, INEL, the South Dakota School of Mines, and the USGS. These investigators all used GSSI model radars. The soil cap placed over the INEL CTP has proven to have a high attenuation. From laboratory measurements on samples, Olhoeft (1994) inferred that the attenuation was due not so much to high electrical conductivity, but high magnetic susceptibility.

At the ICPP, the GSSI SIR-10 was used to determine the effectiveness a commercially available GPR to locate the piping under the selected site. The depth of investigation for piping was expected to be from near surface to about 13 feet below the ground surface. Preliminary testing of the GSSI SIR-10 system provided encouraging results so that the entire site was covered by 300 MHz and 500 MHz transducers. The resolution of subsurface reflectors was judged to be best with the 500 MHz transducer, no significant penetration depth was observed in the 300 MHz data.

The EPRIS system was also used over the site to compare results of a newly developed system with the commercial system. Because of the data density required for this prototype system and its advanced processing and imaging software, only small areas were scanned with the system.

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3.0 RESULTS OVER COLD TEST PIT (CTP)

3.1 DESCRIPTION OF CTP

The CTP is located in an old soil borrow area adjacent to the Radioactive Waste Management Complex (RWMC) outside of the chain link fence. The CTP is about 200 yards south of the fence. Access to the site is via a gravel road outside of the RWMC (Fig. 3-1).

The near surface geology of the INEL-CTP consists of flow basalts and up to 10 ft of fine-grained Snake River Plain sediments. The average depth to basalt from the bottom of the pit is about 2 ft, with a maximum of approximately 6 ft. Some basalt cobbles and boulders are present within the sediments. The characterization cell and retrieval cell floors are set about 3 ft to 5 ft higher than the original CTP due to higher elevations in the basalt.

The construction of the CTP was completed during two periods. Complete descriptions are provided in EG&G Engineering Design Files (EDF's) from 1988 and 1992 of the Buried Waste Integrated Demonstration (BWID).

The original CTP was constructed in 1988 to provide a cold non-radioactive/non-hazardous test bed for demonstrating retrieval and other remedial action scenarios. The test pit was constructed, filled with simulated waste, and backfilled in the same manner in which transuranic waste pits were constructed at INEL between 1953 and 1970. The simulated waste forms included metal scrap, asphalt, concrete blocks, cinder blocks, scrap wood, cloth, paper, glass, and HEPA filters. Simulated waste was loaded by hand and heavy equipment into primarily cardboard 55-gallon drums and cardboard 4' x 4' x 8' boxes. In addition, about 40 metal drums were placed in the pit. Cardboard was used as the simulated waste container material to promote rapid deterioration of the containers. This was done to simulate up to 35 years of burial in shallow land-filled pits in the SDA of the original metal drums and plywood boxes. To further promote deterioration, water was extensively sprayed on the waste forms while being back filled with moist dirt. After emplacing the waste forms moist back fill was used to cover the trenches. After emplacing the waste forms and back filling the pit, a contoured cap of soil was placed over the pit.

Fig. 3-1. INEL Site Location Map

The excavated area of the pit was approximately 150 ft long by 50 ft with an approximate depth from the undisturbed level (sage brush level) of about 10 ft. During the survey the pit was compartmentalized into five zones as shown in Figure 3-2. The southern most zone, 30 ft in width, was reserved for large objects. Large tanks, concrete vaults, concrete blocks, and metal drums were organized in this section. Details of this section were eliminated from the EDF's to preserve the blind status of subsurface investigation planned for that section. Going north, the next 30 ft was reserved for the stacked large box zone; this was followed by another 30 ft section designated for stacked 55-gallon drums; the next 30 ft contained randomly dumped drums and boxes; the final 25 ft section was reserved for randomly dumped drums.

Waste Containers

The waste containers consisted of cardboard drums, boxes and metal drums. The dimensions of the cardboard boxes were 4' x 4' x 8' and were constructed of double-wall cardboard material with no weather treatment.

The 55-gallon cardboard drums were constructed of untreated cardboard with a nominal 300 pound payload. The drums were nominally 35" high and 22" in diameter and had a removable cardboard lid with metal rims and lock down mechanism.

Simulated Waste Materials

Based on content code inventories from Rocky Flats Plant (RFP) of the waste that was shipped to RWMC during the period 1971 to 1973, simulated forms were formulated. RFP waste forms in drums consist of plutonium/americium contaminated sludge, grease, cemented sludge, combustibles (paper cloth), metal, concrete, asphalt, dirt, glass, filters and insulation material.

Schematic of Cold Test Pit

Detail of Objects in Characterization Cell

Item ID	Waste Form Type	Net Wt (kg)	Contents
A	55 gal. Drum w/liner	380	Concrete
B	30 gal. Plastic Drum	105	Saltwater
C	55 gal. Drum w/liner	15	Foam
D	Wood Box	54	Wood and Paper
E	2 Wood Boxes Stacked	E1=44 E2=411	E1=Wood and Paper E2=Ferrous Metals
F	Wood Box	252	Mixed Metals
G	Wood Box	405	Non-Ferrous Metals
H	Wood Box	991	Dense-Pack Metal
File 1	Metal Cabinet	25	Empty
File 2	Metal Cabinet	25	Empty

Fig. 3-2. Schematic Diagram of INEL Cold Test Pit

Table 3-1 summarizes the target waste fraction for boxes and drums. Table 3-2 summarizes the contents of the original Cold Test Pit.

Table 3-1

Target Waste Fraction for Boxes and Drums

Content	Fraction of the Total Number of Containers in a Given Zone
Drums	
Sludge	0.30
Combustibles (paper, cloth)	0.50
Metals	0.08
Concrete Asphalt	0.10
Filter wood glass	<u>0.02</u> 1.00
Boxes	
80% Metal	
20% Concrete/glass/asphalt/wood	

Table 3-2

Contents of Original Cold Test Pit

Cell	Total Drums/Weight	Total Boxes/Weight	Comments
Stacked Boxes (2)	-0-	60/174,200	boxes ranged from 1,500 lbm (metal) to 6,200 lbm (concrete); machine loaded metal boxes averaged 1,600 lbm; hand loaded metal boxes averaged 2,500 lbm; concrete/asphalt boxes averaged 5,000 lbm
Stacked Drums (3)	sludge - 208 drums/118,900 lbm combustibles - 352/48,149 lbm metals - 56/10,000 lbm concrete/glass - 72/34,400 lbm filter/wood - <u>12 / 2,300 lbm</u> 700/213,749	-0-	8 sludge drums made of metal; sludge drums averaged 571 lbm; 8 combustible drums are metal; combustible drums averaged 140 lbm; 8 metal drums made of metal, metal drums averaged 178 lbm; concrete/glass averaged 478 lbm; filters/wood average 191.16 lbm

Table 3-2 (Continued)

Random Dump Drums and Boxes (4)	sludge - 40/23,700 combustibles - 64/9,530 metal - 12/2,150 concrete/glass - 16/8,400 <u>132/43,780</u>	12/28,510	one of the boxes contained used HEPA filters; 8 sludge drums made of metal; boxes average 2,375 lbm; sludge drum average 592 lbm; combustible drums average 149 lbm; metal drums average 179 lbm; concrete average 525 lbm
Random Dump Drums (5)	sludge - 104/57,600 combustibles - 164/25,570 metals - 28/5,450 concrete/glass - 32/15,800 filters/wood - 8/800 <u>336/105,220</u>	-0-	8 sludge drums made of metal; sludge drums averaged 554 lbm; combustible drums average 156 lbm; metal drums average 195 lbm; concrete/glass drums average 494 lbm; filters/wood drums average 100 lbm

Addition to Cold Test Pit

The addition to the CTP was built to provide an additional test area for BWID characterization and retrieval activities for FY1993. Figure 3-2 also shows the basic addition layout and dimensions based upon the EDF and conversations with BWID personnel concerning the position of the addition with respect to the original CTP.

The new addition is located on the north end of the existing CTP. The total size of the new addition is 40 ft in width, by 29 ft in length, by 12 ft in depth. The addition consists of two cells; a characterization cell and a retrieval cell. A third cell has been removed. The characterization cell is 40 ft x 13 ft x 12 ft. The retrieval cell is separated from the characterization cell by a 40 ft x 6 ft x 12 ft soil berm. The dimensions of the retrieval cell are 40 ft x 10 ft x 12 ft.

Details of Characterization Cell Construction and Waste Forms

Figure 3-2 is a top view schematic of the characterization cell as-built. The cell is 40 ft x 13 ft x 12 ft and contains ten separate waste forms placed at strategic locations. A detailed statement showing the characteristics of each waste form is shown in Table 3-3.

Table 3-3

Detail of Waste Forms Placed in the Characterization Cell (Cell 6)

Item Id.	Waste Form Type	Dimensions	Net Wt. (kg)	Contents
A	55 gal. Drum w/liner	24" dia. x 36"	380	Concrete
B	30 gal. plastic drum	18" dia. x 28"	105	Saltwater
C	55 gal. Drum w/liner	24" dia. x 36"	1.5	Foam
D	Wood Box	2' x 4' x 4'	54	Wood and Paper
E	2-Wood Boxes Stacked	2' x 4' x 4' ea.	E1 = 44 E2 = 411	E1= Wood and Paper E2= Ferrous Metals
F	Wood Box	2' x 4' x 4'	252	Mixed Metals
G	Wood Box	2' x 4' x 4'	405	Non-Ferrous Metals
H	Wood Box	2' x 4' x 4'	991	Dense-Pack Metal
File 1	5-Drawer Metal File Cabinet	14" x 28" x 57"	25	Empty
File 2	5-Drawer Metal File Cabinet	14" x 28" x 57"	25	Empty

Figure 3-3 shows a photograph of the characterization cell as-built. The drums are placed in position on their sides. All of the waste forms were placed at equal distances and centered on the instrumentation access pipes.

An 8 ft by 10 ft area of the characterization cell was backfilled with sand and gravel to provide a different soil media in the test area. The remainder of the characterization cell is backfilled with typical INEL/RWMC soil taken from the lake bed area near the RWMC. The same soil was used to fill the pits and trenches of TRU contaminated wastes throughout RWMC. In addition, a 5 ft by 5 ft notch was cut in the west wall to provide a irregular pit boundary to test the ability of non-intrusive sensors to define pit boundaries.

Retrieval Cell Construction and Waste Form Placement

Figure 3-3 also shows a photograph of the retrieval cell with the characterization cell to the right. The retrieval cell is separated from the characterization cell by a 6 ft soil berm. The purpose of the retrieval cell is to provide a test area for the SEA vehicle. The SEA vehicle is a remotely operated excavator. This vehicle will be tested during FY93 to determine its ability to excavate waste forms in different positions and configurations. To this end, the retrieval cell is divided into four waste zones.

Fig. 3-3. Photo of the Characterization Cell with Retrieval Cell (also shown)

Each waste zone contains a different waste form type and configuration designed to mimic actual waste form configurations found in the pits and trenches at the SDA in RWMC.

Waste Zone 1 of the retrieval cell contains a mixture of random dumped 55-gallon (11) and 30-gallon (11) cardboard drums and 4 metal 55-gallon drums. These drums contain wood, paper, cloth, plastic, metal, sludge and soil.

Waste Zone 2 of the retrieval cell contains two desks stacked one on top of the other. Waste Zone 3 contains 24 metal 55-gallon drums and 23 metal 30-gallon drums dumped randomly, containing a similar variety of materials as Zone 1. Waste Zone 4 contains 17 cardboard 55-gallon drums, 17 cardboard 30-gallon drums, 2 metal 55-gallon drums, and two metal 30-gallon drums also containing similar materials as Zones 1 and 3.

During the summer and fall of 1993, many experiments were performed over the CTP after geophysical data collection in May. This included:

- removal of the retrieval cell,
- leveling of the surface over the characterization cell, thereby decreasing the depth of burial. As a result, some objects were now about 1 foot below the surface.

The EPRIS GPR survey was conducted after these latter activities had taken place.

3.2 SURVEY LAYOUT

The layout of the grid is given in Figure 3-4 showing the location of grid control points and the CTP as interpreted from the geophysical survey and additional input from the EDF's. Instrument access pipes into the characterization cell were the only physical feature to tie the geophysical grid to. Two orange capped markers were also tied to the grid. These markers were later found to be EG&G project coordinates. The survey lines were marked using either wooden stakes or wooden golf tees at 5 ft intervals. A declination of 14 degrees east was used on the compasses. USGS 1972 topographic maps indicate a declination of 17.5 degrees while the new USGS Geomag program calculates the true declination 1993 to be 15.3 degrees. All data are based upon grid coordinates.

Magnetometer
Base Station

EG&G
Project
Coordinates
N668099.22
E266813.21

EG&G Project Coordinates
N668099.22 E266828.21

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

LEGEND:

- Survey Monument

Perimeter of Cold Test Pit Cells

GRID NORTH

Scale 1:480

Fig. 3-4. Layout of INEL CTP Survey Grid

3.2.1 Cold Test Pit Objectives and Individual Sensor Results

The objectives of the geophysical surveys over the Cold Test Pit(CTP) were to evaluate different geophysical methods in terms of:

- accuracy in determining pit boundaries,
- accuracy in determining boundaries between cells within the pit, and
- ability to detect individual objects within the pit. In evaluating detection of buried objects, the focus is placed on the Characterization Cell where the position of several objects was well known.

In this report, only the EM61, EM31, and magnetic data are analyzed. The results with other methods were less successful and are discussed in detail in the report on Phase I work. A display showing 2-D and 3-D surfaces of the EM61, EM31, and magnetic field data is shown in Figure 3-5. Figure 3-6 shows the results of the same sensors over the characterization cell using a 2-D display. These figures will be referred to in discussing the ability of each of these methods in achieving the objectives listed above.

3.2.1.1 Determining Pit Boundaries

Magnetic Data

The magnetic data obtained over the CTP was characterized by a high degree of geologic noise. Geologic noise can be defined as signal variation unrelated to the exploration objective. At the CTP the magnetic field varies due to changes in the magnetite content of the underlying basalts and thickness of overburden over the basalt. This variation is unrelated to mapping buried wastes. On the 3-D surface display in Figure 3-5, this noise is seen as a low spatial frequency variation in the magnetic field outside the CTP, and a high amplitude anomaly to the south of the grid. Various types of processing including low cut filtering and Euler deconvolution were unable to remove this geologic noise. This background variation makes it more difficult to map the pit boundaries from magnetic data alone.

INEL COLD TEST PIT

Fig. 3-5. 2-D and 3-D Illustrations of INEL CTP EM61, EM31 and Total Magnetic Field Data

EM31 Survey

The EM31 data showed different results for the in-phase data versus the conductivity data. The conductivity data is more sensitive to geologic noise likely due to changes in depth to bedrock and excavations outside the CTP primarily on the east side. However, the in-phase data, which is more sensitive to the presence of metal, is more effective in mapping the boundaries of the pit. Figure 3-5 shows the results from the in-phase data collection using an Tx-Rx boom in an E-W orientation. The major boundaries are perpendicular to the E-W orientation of the boom. Comparing pit boundaries inferred from the EM31 data with as-built pit design, accuracy of mapping pit boundaries is evaluated to be ± 2.5 ft.

EM61

The 3-D surface display of the EM61 data in Figure 3-5 shows the background variation in the EM61 outside the CTP to be nearly independent of geologic variation. Also, the change in signal magnitude over the CTP is higher for the EM61 than the EM31. In areas with metallic objects in the CTP, the boundaries are evaluated to be defined within ± 0.5 ft. In areas with no buried metallic objects, the EM61 does not define pit boundaries well.

3.2.1.2 Mapping Cell Boundaries and Berms Within the Pit

Magnetic Survey

The presence of geologic noise in the magnetic data makes delineation of cell boundaries difficult. Resolution is further reduced by the fact that magnetic anomalies often extend over 20 ft (e.g., the anomaly due to one drum buried 3 ft below surface). Since berms are approximately 6 ft wide, this results in poor definition of berms.

EM31

The EM31 data is successful in mapping the berms with the in-phase data. The data acquired with the Tx-Rx boom in the N-S orientation was slightly better in defining E-W oriented berms than measurements with the Tx-Rx boom in a N-S orientation.

EM61

The EM61 provides a better definition of berm locations than the EM31. This is likely due to the smaller amount of subsurface volume sampled with the EM61 measurements than EM31 measurements.

3.2.1.3 Delineation of Individual Objects

Magnetic Data

The usefulness of the magnetic data in delineation of individual objects is limited by (i) geologic noise, and (ii) spatial extent of shallow buried anomalies. Objects having high amplitude anomalies often obscure nearby smaller objects. The major feature of the magnetic data collected over the characterization cell shown in Figure 3-6 is the large response caused by ferro-metallic objects in the retrieval cell. Techniques such as Euler Deconvolution were not effective in isolating anomalies due to smaller objects. To recognize individual ferro-metallic objects, the objects must be spaced far enough apart to mitigate overlap of anomalies. This is generally not the case in the CTP.

EM31

The EM31 in-phase data displayed in Figure 3-6, shows that some of the objects are defined by the EM31. In particular, the anomalies due to one of the file cabinets, Box E1 & E2 and Box H, are clearly defined on the map. In addition, there are small anomalies which correspond to the A (metal drum), B (plastic drum filled with salt water) and C (metal drum) objects. These smaller anomalies are mainly present in the in-phase data collected using the E-W boom orientation. This is because the drums are oriented E-W, and better couple with the parallel boom orientation. The amplitude of the anomalies due to the drums buried 6 ft deep is about 2 parts per thousand, which is close to the noise level of the instrument. These features would likely not have been interpreted as buried objects, if the presence of these drums had not been known.

Objects A, B, and C produce negative amplitude anomalies, whereas the remaining anomalies have positive amplitudes. The fact that some objects create negative anomalies, and other positive anomalies makes it difficult to interpret signatures in terms of depth and size information.

Fig. 3-6. 2-D Illustrations of INEL CTP Characterization Cell. EM61, EM31 and Total Magnetic Field Data

EM61

The majority of the metallic objects are defined in the EM61 data. The position of the metal file cabinets inferred from the EM61 data is offset somewhat from the actual location. This may be due to the fact that the file cabinets and Box H create large EM61 anomalies, and individual anomalies are indistinguishable and are displaced from the as-built location. Because the EM61 background noise is low, the anomalies due to the metal drums are more reliably interpreted from the EM61 data than the other data sets.

Some depth information can be obtained from the EM-61 data by using the ratio between the two EM61 channels in a polynomial relationship, as described in Section 5.2.6 of the Phase I Final Report. The depth values computed for the larger isolated anomalies, such as the file cabinets and Box E2, correspond closely with the design data. The depth algorithm computes a distance to an object rather than its depth. A method was developed to limit the depth point computation only to vertical incidence of the EM61 over the buried object. To keep only to the vertical incidence points, a grid was first constructed with a depth value associated with each node. Individual nodes were then set to a null value (invalid value) if they failed to meet certain criteria. A variety of criteria were used, including:

- 1) A minimum emf value measured in channel 1.
- 2) An uncertainty in the depth value that is greater than a cutoff value. The uncertainty is computed using measured background noise values and then using the noise statistics of the raw data to compute $\pm 1 \sigma$ uncertainties of the depth. If the ratio between the $\pm 1 \sigma$ uncertainty and the computed depth exceeded a specified ratio the value was thrown out.
- 3) The depth value computed at a node was less than the four adjoining nodes values minus a specified cutoff value. This has the effect of keeping only values which are at or very close to a local maximum. This method was judged to produce the best results for visualization.

To visualize the EM61 depth data, the CELLVIEW program was written using the Inventor™ library from Silicon Graphics. It allows the user to input known or interpreted objects position in 3-D coordinates. It also displays the windowed depth points derived from the processing described above as separate points. The objects and the data are displayed within a cube which can be rotated and zoomed so that the operator can view the scene from any angle. This 3-D geophysical data allows examination of the data in a 3-D virtual display. An example plot of this program is shown in Figure 3-7.

COLD TEST PII

Characterization Cell Contents and Depths Derived From EM-61 Data

EM61 CHANNEL 2 (NOTE: SCALES DIFFER)

EM31 IN-PHASE E - W

Fig. 3-8. Profile Plots of (a) EM61 data and (b) EM31 Data Over Characterization Cell

Comparison Between the Methods

The profile plots of the EM31 and EM61 data in Figure 3-8 show much of the same information, - however, it is easier to distinguish individual anomalies in a profile plot than in a 2-D contour map.

In comparing the two profile plots, the EM31 information shows less resolution, but in some cases, such as Box H, which is close to the file cabinets, the box is better defined in the EM31 data than the EM61 data. The file cabinet creates a much larger anomaly in the EM61 data and this masks the anomaly due to Box H. The EM31 data also detected drum B (plastic drum filled with saltwater) as a minor anomaly; the EM61 does not. Other than these two objects, the EM61 provides better information on object location than the EM31.

Earth Penetration Radar Imaging System (EPRIS)

Over the CTP measurements were made with both the GSSI SIR10 GPR system and the Coleman Research Corporation EPRIS system. Measurements with the commercial system were made prior to removal of some of the soil cap placed over the objects in the Characterization Cell. The EPRIS GPR system was used after removal of most of the soil cap.

The scans made with the EPRIS system are shown in Figure 3-9. The imaged results of scan AE, DH and GC are shown in Figures 3-10 through 3-12, respectively. In scan AE (Fig. 3-10) the stacked boxes with their top at 1 ft below surface are imaged, but the 55-gallon drum about 3 ft to 4 ft below surface is not seen. In scan DH (Fig. 3-11) one of the boxes (H) and one of the file cabinets, and some clutter are visible in the 3-D view, but the other box (D), and the other file cabinet is not. In scan GC (Fig. 3-12) both the box and the drum are visible in 3-D view amidst relatively large clutter returns. There is some return energy at the objects' location, but it is not significant enough to declare the targets correctly without a priori knowledge.

Fig. 3-9. Location of EPRIS Radar Data Scans over INEL CTP Characterization Cell.

Fig. 3-10. EPRIS Radar Image Results; Scan AE; INEL CTP Characterization Cell.

Fig. 3-11. EPRIS Radar Image Results; Scan DH; INEL CTP Characterization Cell.

Fig. 3-12. EPRIS Radar Image Results; Scan GC; INEL CTP; Characterization Cell.

In summary, the EPRIS radar imaged objects in the Characterization Cell to a depth of about 2 ft to 3 ft. In the presence of the original thicker soil cap, the EPRIS may have encountered difficulties in mapping objects.

3.3 CONCLUSIONS

To map the trench boundaries, the berms between cells within the trench, and individual buried objects in the trench, data were acquired with a magnetic sensor, frequency and time domain electromagnetic sensors, and ground probing radar. With all sensors (except the GPR) measurements were made over a 2.5 ft grid.

The sensors yielding the most definitive information were a magnetic field sensor, the Geonics EM31 terrain conductivity meter and the Geonics EM61 time domain metal detector. In the presence of a thick (as much as 6 ft) soil cap, GPR was ineffective. After removal of part of the soil cap, objects within the characterization cell could be imaged with CRC EPRIS to a depth of about 3 ft.

To recognize and map trench boundaries, berms between cells within the trench, and individual objects in the trench, different displays are helpful. Boundaries and berms are best recognized from 2-D color contour maps, while individual objects are better visualized by 3-D perspective plots and profile plots.

Overall, the best definition of trench boundaries, berms between cells, and objects within the trench were achieved with the Geonics EM61 time domain metal detector. The success of the EM61 is, however, largely due to the fact that in the CTP a preponderance of metallic objects were buried. For mapping trenches containing no metallic objects, the Geonics EM31 terrain conductivity meter is the tool of choice.

These tests over the CTP emphasize the importance of employing multiple sensors. Use of multiple sensors mitigate against total failure of accomplishing the objectives (e.g., if only GPR had been employed), and provides greater confidence in the interpretation inferred from sensor data, and allows some measure of waste characterization.

Another objective of this R&D was to move from merely locating waste trenches to characterization of the buried wastes. That objective was but partially accomplished. Specific accomplishments were:

- wastes containing metallics (file cabinets, drums, wooden boxes with metal) can be differentiated from wastes with no metallics (e.g., high saline solution in plastic containers),
- approximate dimensions of objects can be inferred from amplitude of anomaly, and
- approximate depth computations can be made.

Finally, the results of testing this technology over a known test pit have already been applied to other DOD and DOE facilities in successful routine surveys. The Geonics EM61 was employed to map burial of isolated drums in the ash pits at Rocky Flats, and in locating ordnance at a number of DOD installations.

4.0 RESULTS OVER IDAHO CHEMICAL PROCESSING PLANT (ICPP)

4.1 SURVEY SITE/SURVEY LAYOUT

For Phase II work, a section of the Idaho Chemical Processing Plant (ICPP) was recommended by DOE-INEL personnel. The section of the ICPP initially selected was the High Level Liquid Waste (HLLW) tank farm (Fig. 4-1). The HLLW tank farm is an area approximately 250 ft by 550 ft containing eleven 300,000-gallon tanks buried inside concrete vaults about 10 ft below ground surface.

At the time of the survey, a number of construction projects were ongoing, and the only portion of the site available for the survey was the northwestern portion of the HLLW tank farm. Therefore, in consultation with DOE-INEL personnel, a section outside the HLLW tank farm was selected. A considerable amount of subsurface piping and electrical lines are present beneath the site, and mapping these subsurface utilities became the objective of Phase II work. The location is west of Beach Street, south of Building CPP-630, east of Building CPP-601, and north of the overhead exhaust duct. The overall site area is approximately 100 ft by 200 ft. Several obstructions exist on the site including small buildings, generally reinforced concrete structures with stairways leading to subsurface areas, fenced off areas, protective barriers, and other buildings. Walkways are present leading out of Building CPP-630 toward other facility areas.

The following geophysical instrumentation was used on the surveys:

- Proton Precession Magnetometer (EDA PPM500),
- Cesium Magnetometer (Geometrics),
- Terrain Conductivity (Geonics EM38 and EM31),
- Metal Detector (Geonics EM61), and
- Ground Penetrating Radar (GSSI SIR-10).

The site was divided into two sub-grid areas as shown on Figure 4-1, the North Grid and the South Grid. Figure 4-2a and 4-2b are photos of the South Grid and North Grid, respectively. The site was split up this way to avoid the small buildings and other obstructions within the site. The South Grid area ranged from about 28 west to 70 east, and 0 to 60 north. The North Grid area ranged from about 40 west to 20 east, and 110 north to 180 north. With the aide of EG&G and WINCO personnel, the grid areas were barricaded, as necessary, to keep pedestrian traffic off of the grid sites.

Fig. 4-1. Location Map of INEL ICPP HLLW Tank Farm Illustrating Geophysical Survey Areas

South Grid - Looking Northeast

North Grid - Looking Southeast

Fig. 4-2. Photo Illustrating Surface Conditions of (a) South Grid and (b) North Grid

Survey marks were placed on the site at 4 foot intervals, and measurements were made with each instrument at 2 foot or less intervals. The EM31, EM38, and GPR measurements were taken in both the north-south and east-west orientation. The EM31 data were collected in both the horizontal and vertical dipole mode, while the EM38 data were collected only in the vertical dipole mode. The GPR data was collected using 300 MHz and 500 MHz antennas.

Data Processing

With the exception of the GPR data, all data sets were combined, gridded and contoured using the Geosoft mapping software. The data from all of the methods can be found in Attachment A (one copy provided to DOE-INEL field office). Using the utility maps provided by WINCO (Fig. 4-3), a digitized utility map relating the geophysical grid coordinates was constructed with a scanner (Figs. 4-4 and 4-5). The utility maps were superimposed on the individual contour maps.

Fig. 4-3. WINCO ICPP Geophysical Survey Site Underground Utility Map

4.2 RESULTS

The data from all methods are presented in contour maps in Attachment A, with the exception of the GPR data (one copy of Attachment A provided to DOE-INEL field office). Only selected data sets are presented in the body of this report because more than 34 individual maps from the data sets were produced.

The objectives of the geophysical surveys at the ICPP are to locate and chart the course of multiple pipelines criss-crossing the area, particularly in the South Grid. Utility lines of different diameter and of different composition are buried at depths up to 13 ft. In addition, many metallic objects are visible at the surface, such as buildings, reinforced concrete pads, debris, manholes, and monitoring wells.

The ground truth for comparing interpretations about buried utilities inferred from geophysical surveys are the facility engineering maps. Many of the utilities that have been plotted on the utility map consist of multiple lines (as many as 4 or 5) less than several feet apart, and buried at depths up to and perhaps exceeding 13 ft below surface.

Another objective was to map contaminant plumes. Contaminant plumes are often inferred from an increase in conductivity as measured by terrain conductivity meters. However, at the ICPP sites responses due to surface debris and buried metallic objects dominate, so that any responses due to contaminant plumes are obscured.

4.2.1 South Grid

Figure 4-6 shows contour maps of EM61, EM31, and EM38 with the known utilities superimposed from the engineering drawings. The South Grid had several surface features including a monitoring well, a building, and a metal access door. The presence of these features is clearly evident in the data. Magnetic data is particularly effected by these surface features. The EM methods are also influenced by these features, although to a lesser degree. All of the EM methods show anomalies with amplitudes an order of magnitude higher than anomalies recorded over the CTP. These high magnitude values are mainly the result of surface metal. To improve the visualization of lower amplitude anomalies due to buried objects in the presence of larger amplitude anomalies caused by surface metal, amplitudes above a certain value were assigned a constant value (clipped). The assigned value selected was somewhat above the maximum anomaly response of buried objects.

ICPP SOUTHERN SITE COMPARISON BETWEEN EM METHODS

Fig. 4-6. Contour Map of EM61, EM31 and EM38 With Known Utilities Superimposed (Southern Grid)

The GPR data also map underground utilities to a depth of about 6 ft. This is in contrast to the GPR results in the CTP area where soils strongly attenuated the signals so that no useful data could be obtained below 2 ft. The soils at the ICPP site consisted of gravels which do not attenuate the radar signals as severely at the soil cap over the CTP. The 500 MHz and 300 MHz transducers were shielded, and were less sensitive to the cultural features around the site.

EM61

The EM61 detected three subsurface lines running N-S. Two of the lines are on the eastern edge of the map and are believed to correspond to an 8" high pressure steam line and a 4" high pressure air line at 58E, and a 3" service waste line and electrical duct bank at 64E. The line in the central part of the map is believed to be an electrical duct. Also nearby are 3 high pressure air lines (possibly non-metallic) and a 4" service waste line. These interpreted lines are displayed on the EM61 contour map in Figure 4-7. The lines are more clearly seen in the EM61 apparent depth surface map shown in Figure 4-8. The bend in the easternmost utility line to the west in the northern part of the grid is evident in the apparent depth surface. This occurs within a 5 ft. of where the bend is predicted to be in the engineering drawings. The CELLVIEW program was used for the data display. Figure 4-9 shows the windowed EM-61 data points and the interpreted depth and location of the two underground lines. To facilitate visualization of the data, the utilities are not drawn at their correct size.

The stainless steel process lines which are shown on the map to be 13 ft. below the surface were not detected using the EM-61. This is likely due to the large signals present from surface and near surface metallic objects masking the presence of signal from deeper pipes. Also not detected was the 24-inch clay conduit because of the lack of metallic material.

EM38 and EM31

On the contour maps of Figure 4-6 of the EM38 and EM31 data, the engineering drawings of utility lines are superimposed. Figure 4-7 shows the position of interpreted utilities. The electrical conduit, seen in the EM61 data, is imaged but appears displaced to the west. Furthermore the two lines at the eastern edge of the map appear to be only a single line on the EM31 and EM38 maps. This result shows that the interpretations made by frequency domain EM (FDEM) methods, in areas with a high number of surface and subsurface objects, may not be reliable.

ICPP SOUTHERN SITE INTERPRETATION OF EM METHODS

Fig. 4-7. Utility Line Interpretation Superimposed on EM61, EM31 and EM38 Contour Maps

The EM61 upper and lower coil EMFs are used to compute apparent depth at each grid point on the surface. These apparent depths are then processed to obtain an image of buried objects

Fig. 4-8 EM61 Apparent Depth Surface Map Illustrating Location of Interpreted Pipes

ICPP Interpreted Line Locations and Depth Points Derived From EM-61 Data

GPR Pulsed System - GSSI SIR10

The GPR data which was acquired using the 500 MHz antenna shows primarily two utility lines running north-south. Figure 4-10 shows a sample GPR profile running east to west over the South Grid. Several anomalies corresponding to underground utilities are present. These lines are shown in Figure 4-11, which show the 3-D location of all interpreted GPR anomalies. They appear to correspond to the electrical conduit and the westernmost stainless steel line detected by the EM61. There is some indications that the GPR did detect the second stainless steel pipe in the southern part of the grid, but the signals are weak and disappear to the north. To some extent the westernmost utility line signal also weakens to the north. Perhaps where the pipe bends, the profiles are no longer perpendicular to the pipe and the GPR anomaly is less clear. Thus, the signature from buried lines can vary considerably over short distances, and when only a small number of profiles are obtained utility lines may not be detected.

The overlay of the location of the lines from the engineering drawing show that the GPR did not detect the 24-inch clay pipe. The deeper buried process lines were not detected by any of the GPR units.

2: Created Nov 3, 1993 10:16 Modified Date Unknown
256 samples/scan 32.002 scans/sec position: -5.6235 ns range: 30 ns
500 MHz Antenna
Southern Site
x = -16 to 70
y = 20

Fig 4-10. Sample of Typical Radar Profile Obtained With GSSI SIR-10 System and 500 MHz Transducer (Southern Grid)

Interpreted GPK Anomalies ICPP Southern Site 500 Mhz Transducer

Fig. 4-11. Composite Interpretation Map of GSSI SIR-10 Data Over South Grid Area

With the CRC EPRIS GPR system three small scans were made in the South Grid as shown in Figure 4-12. These scans (A, B and C) are given in Figures 4-13, 4-14 and 4-15, respectively. In scan A (Fig. 4-13) two objects are visible in 3-D view, - the electrical duct bank at 3 ft, and an 8-inch steel pipe at 4.6 ft.

In scan B (Fig. 4-14) the set of four 1-inch diameter stainless steel pipes were observed as a single object at a depth of 1 m. The other two pipes 3 inches in diameter, believed to be buried at a depth of 12.5 ft, are not seen in the image.

In scan C (Fig. 4-15) two objects are visible in 3-D view, - the electrical duct bank at 5.2 ft, and a 24-inch diameter pipe at 4.3 ft.

Fig. 4-12. Location of Scans Obtained with EPRIS Radar over South Grid Areas.

Fig. 4-13. EPRIS Radar Image Results; Scan A; INEL ICPP (South Grid).

Fig. 4-14. EPRIS Radar Image Results; Scan B; INEL ICPP (South Grid).

Fig. 4-15. EPRIS Radar Image Results; Scan C; INEL ICPP (South Grid).

4.2.2 North Grid

There is little correspondence between buried utilities inferred from the geophysical data and the location of utility lines based on the engineering drawings. For example, electrical conduit lines shown on the facility maps could not be inferred from the geophysical sensor data. This is peculiar since lines of similar construction and buried at the same depth were seen in the geophysical data on the South Grid. On the other hand, the EM61, GPR, and magnetic data all detected a buried object not shown on the facility map.

EM61

The feature of highest amplitude in the EM61 data is likely caused by the large amount of rebar present in Building 661. Again to assist visualization of the data, values above a certain maximum were assigned a constant value. Once this was done, the anomalies outlined on Figure 4-16 become evident. This anomaly is believed to be due to a possible underground storage tank (UST) or remnants of a UST and associated piping. There is a marker sign at the surface near this object warning of an "environmentally sensitive area", so that there is little doubt that this anomaly arises from a subsurface object.

Fig. 4-16. Contour Maps of EM61 and EM38 Data With Interpretation of Buried Objects Superimposed (South Grid)

EM38

The main anomaly in the EM38 (Fig. 4-16) is believed to be related to cathodic protection lines shown on the engineering facility drawings, but the anomaly is displaced from the location on the drawings. This feature is also present in the EM31 data. The FDEM sensors may be more sensitive to these small metallic lines, because a dipole-dipole transmitter-receiver array may couple better to long thin wires than the coincident dipoles of the EM61. The FDEM data sets did not show an anomaly over the suspected UST anomaly present in the EM61.

GPR

In contrast to the GPR data from the South Grid, the North Grid did not contain many anomalies due to underground objects. In the area of the suspected UST, there were some small anomalies present near to the surface. These may arise from excavation conducted to emplace or remove the subsurface features. The remainder of the site, contains only scattered anomalies, with no linear features.

4.3 CONCLUSIONS

The objectives of the geophysical surveys at the ICPP were to locate and chart all buried utilities. These objectives could not be accomplished with present geophysical technologies because of the complexity of the site. Complicating the geophysical interpretation are (i) burial of many utilities crossing the site, (ii) occurrence of utilities at different depths up to 13 ft, (iii) utilities of different diameters and composition, and (iv) presence of a large number of surface metallic objects, such as buildings, reinforced concrete pads and debris. A large number of objects were detected by the various sensors employed over the South Grid. However, if the facility engineering drawings are correct far from all objects were detected.

In contrast to the experience at the CTP, GPR was as effective as frequency and time domain electromagnetic sensors. Again, this illustrates the sensitivity of GPR to site-specific conditions.

5.0 OVERALL CONCLUSIONS

Multiple geophysical methods were tested over two different sites with different objectives. The sites and objectives are given in Table 5-1.

Table 5-1
Site Objectives

Site	Objectives
Cold Test Pit	Evaluate geophysical sensors in terms of: <ul style="list-style-type: none">• accuracy in determining boundaries of waste trench,• accuracy in determining cells and berms within trench, and• ability to detect individual objects.
Idaho Chemical Processing Plant	Evaluate geophysical sensors for their ability to detect underground utilities in a complex environment. Detect migration of possible contaminants from leaking process lines.

The methods used and corresponding instrumentation are given in Table 5-2.

Table 5-2
Geophysical Methods and Instrumentation

Method	Instrumentation
Time Domain EM Induction Metal Detection	Geonics EM-61
Frequency Domain EM Induction Profiling	Geonics EM-31, EM-34 and EM-38
Magnetic Surveys	EDA PPM 500 Proton Precession Magnetometer Geometrics G-822L Cesium Vapor GEM Systems 19
Ground Penetrating Radar	Coleman EPRIS FMCW GSSI SIR-10 with 100,300 and 500 MHz transducers
Time Domain EM	Geonics EM-47

This program also evaluated the effectiveness of different types of processing methods and algorithms as well as the ability of different types of displays to maximize the information obtainable from the data.

5.1 COLD TEST PIT CONCLUSIONS

A summary of the abilities of each the instruments to achieve the objectives listed in Table 5-1 is given in Table 5-3. The two most effective sensors were the Geonics EM-61 and the Geonics EM-31 using the in-phase mode. The ability of the magnetic data to achieve the objectives was limited due to the high levels of background noise resulting from basalts underlying the CTP. The interpretation of individual objects from the magnetic data was hampered by the relatively large spatial extent of the anomalies causing overlapping of anomalies of different objects. GPR was initially ineffective at the CTP due to high attenuation caused by the soil cap placed over the trench. After removal of some of the soil cap the CRC EPRIS radar was effective in mapping buried objects to a depth of about 2 ft to 3 ft.

Table 5-3
Summary of Instrument Capabilities at the INEL CTP

Geophysical method and instrument	Mapping pit boundaries	Mapping boundaries between cells within pit	Delineating individual objects	Characterizing objects - depth determination
Frequency Domain EM Geonics EM31	good, ± 2.5 ft with in-Phase	good	fair	poor
Time Domain EM Geonics EM61	good, ± 2.5 ft	good	good	fair
Magnetics	poor	poor	poor	poor
GPR	not effective	not effective	not effective	not effective

5.2 ICPP

The objectives at the ICPP were to locate and chart all buried utilities. It is a complex site with many utilities buried at different depths crossing the site. Furthermore, many surface metallic objects are present. The various geophysical sensors employed detected several utilities, but far from all. Detection of all utilities and isolating anomalies due to each utility is presently not achievable with surface geophysical sensors.

The sensor with the potential for the highest resolution to detect buried utilities crossing at different depth is GPR. Although both the GSSI SIR10 and CRC EPRIS GPR systems were more effective at the ICPP than at the CTP, they generally did not detect utilities below 5 ft.

At the southern portion of the survey area the EM61 data shows three linear features corresponding to three separate utility lines. The GPR data also is interpreted to reveal at least two of the utility lines, in the same location as the EM61.

According to the engineering drawings, the North Grid also contains several underground utilities. However, the EM61 and GPR data show no evidence of underground lines as indicated in the drawings. However, both methods do show evidence of a underground storage tank and possible associated piping. The EM31 and EM38 data both show the likely location of cathodic protection lines offset from the location shown in the engineering drawings. Table 5-4 is a summary of the results of various methods.

Table 5-4
Summary of Results with Various Methods

Method	Result
EM61	Detected metallic utility lines to a depth of 6 ft, and possible UST
FDEM Methods (EM31, EM38)	Possibly detected metallic lines and cathodic protection lines
Magnetic Surveys	Did not detect any utility lines. Detected possible UST
GPR	Detected some metallic utility lines and possible UST. EPRIS radar detected non-metallic line, GSSI radar did not

5.3 DATA PROCESSING AND DISPLAY

In an attempt to increase the amount of information obtainable from geophysical data several processing methods were employed. The methods, the data on which they were employed, and the results are summarized in Table 5-5.

Table 5-5

Summary and Conclusions About Utility of Data Processing Techniques Tested

Method	Sensor Data	Results
EM-61 Depth Conversion	EM-61	Provided accurate depths on large objects, isolated objects and metallic utility lines
Decorrugation Filtering	EM-31	Reduced line to line noise
	Magnetic	Reduced line to line noise
High/Low Pass Filtering	EM-61	High pass filtering improved the ability to distinguish individual objects
	EM-31	High pass filtering slightly improved the ability to distinguish individual objects
	Magnetic	No improvement
Reduction-to-pole	Magnetic	No improvement
Euler Deconvolution	Magnetic	No improvement
Deconvolution, Hilbert Transforms, Migration	GPR	No improvement
Continuity Processing	GPR	No improvement

Several different methods of visualizing the data were also attempted. The advantages and disadvantages of each of the methods are summarized in Table 5-6.

Table 5-6

Summary and Conclusions of Visualization Techniques Evaluated

Display	Advantages	Disadvantages
2-D Color Contour Map	<ul style="list-style-type: none"> • All x,y positioning information preserved • Simple to generate 	<ul style="list-style-type: none"> • Information on smaller anomalies often lost • Difficult for many people to visualize
3-D surface plots, with surface lighting	<ul style="list-style-type: none"> • Displays easier for many people to visualize • Can effectively display data with a high dynamic range • User can manipulate viewing parameters in real time to obtain optimum image 	<ul style="list-style-type: none"> • Currently requires expensive hardware and software • X,Y positioning information lost
Profile Plots	<ul style="list-style-type: none"> • Can effectively display data with a high dynamic range 	<ul style="list-style-type: none"> • Difficult to use for large quantities of data
CELLVIEW	<ul style="list-style-type: none"> • Allows display of 3-D data and interpreted objects • User can manipulate viewing parameters in real time to obtain optimum image • Limits amount of data that end-user has to look at 	<ul style="list-style-type: none"> • Currently requires expensive hardware and software • X,Y positioning information lost

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