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Project Summary

Nondestructive Testing (NDT) Techniques to Detect Contained Subsurface Hazardous Waste

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A systematic and comprehensive study was conducted to detect buried containers with nondestructive testing (NDT) remote-sensing techniques. Seventeen techniques were considered but only four were ultimately selected. Those four were electromagnetic induction (EMI), metal detection (MD), magnetometer (MAG), and ground penetrating radar (GPR). The containers — both steel and plastic — varying in size from 5 gal to 55 gal were buried in known distributions in a wide variety of soils; also, some were submerged in water. Five diverse field sites were used.

As a result of the work at the five field sites, a relatively complete picture has emerged concerning the strengths and weaknesses of the four NDT subsurface container location techniques. GPR is the only reliable method to detect plastic containers, but it has limitations. GPR, EMI, and MD all suffer severe loss of detection ability when the background electrical conductivity exceeds 40 millimhos/meter. In dry sandy soil EMI, GPR, and MAG are all capable of picking up a single 55-gal steel drum to a depth of at least 10 feet. The MAG method works well for steel under all subsurface conditions, and GPR can usually pickup the side walls of the excavations where waste is dumped. Application of signal enhancement techniques (background suppression) can be expected to enhance NDT utility.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, Ohio, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Since there is a vast amount of hazardous waste buried below the surface of the soil, it is important to clean up these wastes before they do additional damage to the environment. The first step in any cleanup procedure is to detect the waste and then determine its spatial extent. As in any subsurface exploration, many techniques can be brought to bear. Test borings and limited excavations are very valuable but are not without their problems. The information obtained is not continuous and the destructive nature of the test makes it possible that waste could inadvertently be released during the probing phase. Therefore, there is an interest in probing from the surface with nonintrusive methods.

The goal of this project is to identify and assess the best possible NDT techniques for detecting and delineating hazardous waste. Since another EPA laboratory was performing the same type task for monitoring hazardous waste leachate plumes, this work concentrated on the detection of steel and plastic containers buried beneath the surface of soil and water bodies.

Literature Phase

The first phase of this project consisted of identifying as many NDT techniques as possible which could have possible application to a broad spectrum of hazardous waste problems. Seventeen such techniques were identified. They were:

- Microwave-pulsed — also called ground penetrating radar (GPR)
- Microwave-continuous (CWM)
- Eddy current - also called metal detection (MD)
- Magnetometer (MAG)
- Seismic reflection
- Seismic refraction (SR)
- Electrical resistivity (ER)
- Penetrating radiation (x-rays, gamma-rays, neutrons, etc.)
- Acoustic emission
- Liquid penetrant
- Infrared radiometry
- Pulse-echo ultrasonics
- Sonar
- Very low frequency electromagnetic — also called electromagnetic induction (EMI)
- Induced polarization
- Self-potential
- Optical techniques.

A detailed report was prepared on each of these techniques. (These are available from the authors.) Information was sought from the literature, company brochures and personal communications. The literature search eliminated a number of the techniques from further experimental evaluation. Some of the reasons for eliminations were:

- prediction of very little chance of success
- high cost of equipment
- no indication from literature search of success for container detection
- inaccessibility of equipment.

As a result of this first phase of the project, the number of techniques considered was further reduced from seventeen to seven. The remaining techniques were ground penetrating radar, microwave-continuous, metal detection, magnetometer, seismic refraction, electrical resistivity, and electromagnetic induction.

Field Tests

Each of the NDT methods will operate "ideally" under a prescribed set of soil types and man-made interferences. The typical sites where most waste material containers are buried are far from those "ideals." Rather than burial in dry granular soils, drums are usually dumped in swamps, mudflats, water and the like. Furthermore, the most successful methods we have worked with are based on measuring electrical or magnetic effects. High electrical conductivity areas, e.g., near equipment storage areas, junk yards, or ocean water, can severely influence the techniques. Soil homogeneity and water conductivity are major issues. Quantities of ferromagnetic material (e.g., steel objects) can severely affect the MAG method. With these thoughts in mind, test sites were obtained, containers of various sizes were carefully placed at different depths and geometric arrangements, backfilled, and then located using the various NDT methods.

The first field site was a nearly ideal dry sandy soil in an open field, free of man-made interference. This site provided an excellent starting point and essentially narrowed the selection (after careful literature review) from seven of the possible NDT methods to the four mentioned previously. The surviving methods were MAG, EMI, GPR, and MD. Steel containers buried to 10-ft depths were accurately located and could possibly have been located deeper if stable burial pits could have been excavated. Various steel container arrays and the boundaries of a "metal trash dump" were accurately located. Some plastic containers were also located, but with poorer results.

The second site was more formidable. Here a saturated silty clay soil overlying shallow shale rock was used. Detection depths with the four methods indicated techniques were much shallower, approximately 4 ft, and the results were influenced by the large amount of background metal in the areas (e.g., trailers, equipment, fences, etc.).

The fact that containers are sometimes dumped directly into water and that the salinity of the water can range from fresh to brine, the third study was directed at drums under water. Containers were submerged in water and placed on the bottom sediments at four different sites. The salinity of the water ranged progressively from fresh to ocean. (The work was actually performed at various positions along the Delaware River.) To depths of 3 ft of water above the containers, the detection and delineation results were "excellent" to "no good" in direct proportion to the increase in water salinity, i.e., electrical conductivity of the water.

Bearing directly on the above three studies is the extent to which ground salinity can influence the detecting capability of the NDT methods used. At this point, studies were made at a fourth site with steel containers buried in a soil of varying electrical conductivity. The ocean was used as an electrical conductivity extreme and the conductivity decreased substantially as the survey moved inland. The soil was a medium-to-fine granular sand indigenous to the coastal area. The sand density ranged from loose (near the surface) to intermediate (at a depth of 6 ft).

Background conductivities greater than 40 millimhos/meter seriously impaired the use of those methods based on electrical conductivity measurements, i.e., MD, EMI and GPR. The MAG method worked much better since it is a method based on magnetic measurements and not on electrical conductivity. The boundaries of a "trash dump" containing metal objects were observed with all methods even though the background conductivity varied from 25-60 millimhos/meter.

Site 5 was the same location as Site 4 but, in this case, plastic containers were used instead of steel. The MD, EMI and MAG did not detect any of the plastic containers even when these were filled with salt water. The ability of GPR to pick up the water table, as well as the containers, was demonstrated.

Conclusions

Table 1 presents the results obtained at all five field sites and should be considered the final results of the project and can serve as a guide for the practitioner. Some additional remarks are in order to help assimilate all the results of these studies.

In a dry, granular soil with medium interference, individual typical steel containers can easily be seen to a depth of at least 10 ft with all methods except MD, which detects to 6 ft. Deeper detection is probably possible, but 10 ft was the limit of our burial ability. As the soil water electrical conductivity becomes larger, the detection ability of the MD, EMI, and GPR methods suffers. When the background conductivity rises to 40 millimhos/meters or above, the detection ability is seriously impaired. The MAG method works well under all granular soil conditions for it is not affected by high background electrical conductivity.

In cohesive soils (clays), there are definite problems with MD, EMI, and GPR due to the usual high water content and soil inhomogeneities. A logistical problem arose with respect to the MAG data, since work in cohesive soils was performed in the presence of magnetic interfering materials (trucks, fences, etc.). Research should be conducted in an interference-free cohesive soil using the MAG method. The use of MD, EMI, and GPR in relatively uniform, dry cohesive soils is of interest.

When steel containers were submerged under water, the MD, EMI and GPR

Table 1. *General Acceptability of Using Various NDT Methods to Locate Typical Sized Buried Containers (Maximum Penetration Depth Achieved in Parentheses)*

Subsurface Material (Reference)	*Saturation*	*Type of Void Water*	*Metal Detector (MD)*	*Electromagnetic Induction (EMI)*	*Ground Penetrating Radar (GPR)*	*Magnetometer (MAG)*
			Steel Containers			
Granular (sand)	0% - 20%	fresh	excellent (6')	excellent (10')	excellent (10')	excellent (10')
	20% - 50%	intermediate	excellent (2')	average (4')	excellent (3')	excellent (4')
	50% - 100%	ocean	not good	not good	poor (2')	excellent (10')
Cohesive (clay)	50% - 100%	fresh	moderate* (4')	moderate* (4')	moderate* (4')	poor (4')**
Water	100%	fresh	excellent (3')	excellent (3')	excellent (4')	excellent (3')
	100%	intermediate	poor	not good	not good	excellent (3')
	100%	ocean	not good	not good	not good	excellent (3')
			Plastic Containers			
Granular	10% - 50%	intermediate	not good	not good	excellent - if contents conductive (4') fair — if contents non-conductive	not good
	50% - 100%	ocean	not good	not good	poor	not good

**Excellent in dry clay.*
***Many interfering magnetic objects. Excellent in absence of interference.*

methods are only of value in relatively fresh water. When the water conductivity rises above 60 millimhos/meter, the three methods are quite useless. The MAG method functions well in water of all conductivities.

Plastic containers are more difficult to detect than steel containers. The MD, EMI and MAG methods are useless in detecting buried plastic containers. The GPR method works well for typical size plastic containers, especially if the containers are filled with electrically-conductive material. However, the method still works with non-conductive contents. These results for plastic containers apply only for granular soil with relatively low electrical conductivity. If the granular soil has high conductivity material in its voids or if the soil is a wet, non-uniform cohesive material, then the same limitations apply to GPR as were mentioned earlier.

While this is a systematic and comprehensive study of NDT methods, it is not complete and a few additional situations still remain to be studied.

As a brief bottom line, it can be stated:

- MD, EMI, and MAG all work extremely well in detecting buried steel containers in dry, granular soil to any typical depth.
- The MAG method works well under all subsurface conditions.
- MD, EMI, and GPR will suffer severe loss of detection ability when the soil's electrical conductivity rises above about 40 millimhos/meter. The same conductivity limitations also apply to the detection ability for containers submerged under water.
- GPR is the only reliable method to detect buried plastic containers.
- GPR can "see" excavation boundaries. This is an extremely important point.
- For a preliminary survey of a metal-container dump site, the MD (instrument costs about $500) is a good first method, followed closely by the MAG method (cost about $4000). More detailed surveys can use the more expensive instruments: EMI (cost about $8000) and GPR (cost about $30,000).

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The complete report, entitled "Nondestructive Testing (NDT) Techniques to Detect Contained Subsurface Hazardous Waste," (Order No. PB 88-102 405/AS; Cost: $13.95, subject to change) will be available only from:
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