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THE IDENTIFICATION AND LOCATION OF BURIED CONTAINERS VIA NON-DESTRUCTIVE TESTING METHODS

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Summary

The problem of identifying and locating containers of hazardous materials located beneath the ground surface or under water can be solved by either some form of excavation or by a suitable non-destructive testing method. In this latter category are techniques which include standard geophysical methods, as well as a number of newer methods adopted from other technologies. This paper reviews these methods giving examples of each as it pertains to the buried container problem.

The conclusions section gives recommendations as to where each method is most applicable, as well as a comparison of each method on the basis of cost, deployment, interpretation, results and maximum depth of penetration.

Introduction

The investigation of sub-surface objects (either buried beneath the ground surface or underwater) can be approached in two very different ways. The first type that generally comes to mind is by use of a suitable destructive test method. In this category are the following:

- test pits
- excavation trenches
- auger holes
- core borings
- observation wells

While one does indeed "see" the subsurface materials as they are excavated for ease of examination or subsequent testing, such methods are not without drawbacks in identifying and locating buried containers. Some disadvantages of destructive test methods for this purpose are:

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- The information obtained is discontinuous over the area investigated.
- Permission to enter the properties in question (and excavate therein) may be troublesome or impossible to obtain.
- Access for excavation equipment may not be available at the site in question.
- Costs are generally high, e.g., small amounts of excavation can easily be $200/cu. yd and boring costs of $10/ft are not uncommon.
- There is a danger to personnel from containers containing hazardous, toxic or radioactive materials which have been inadvertently ruptured or pierced by the excavations or borings.
- There is a danger to the environment due to such materials emptying out of the containers if they have been ruptured or pierced.

The second type of approach to identifying and locating buried containers is by use of a suitable non-destructive testing (NDT) method. Within this category are the following methods which have been used or seem to have applicability:

- seismic reflection
- seismic refraction
- electrical resistivity
- low frequency electromagnetic (conductivity)
- induced polarization
- eddy current (metal detector)
- magnetometer
- continuous microwave (CW)
- pulsed radio frequency (ground penetrating radar)
- infrared radiation
- sonar (pulse echo acoustics)

All of the above methods are not equally suited for identifying and locating buried containers, but many are, and the interest in these NDT approaches to the problem seems to be increasing. The major disadvantage at this time seems to be one of non-familiarity, a feature which this paper is aimed at overcoming.

The structure of the paper will be to present a brief survey of those NDT methods which have been used to date in identifying and locating buried containers, and then to present a few case histories showing the type of output each method generates. An extension into related problems, e.g., location of buried land mines and utilities, will also be included. Our conclusions will present an assessment of the current and potential advantages and disadvantages of each method for the identification and location of buried containers.

Current NDT methods used to detect buried containers

This section presents the basis of our findings on the subject of the identification and location of buried containers via NDT methods. As mentioned in the introduction there are indeed a wide variety of available NDT methods. So as not to bias the paper with any particular method, this section has been arranged in the order of the most widely used NDT method first, down to those methods which have been used only once. An example of each method accompanies the technical background material. Additional detail on fundamentals is given in Ref. [1] and on case histories in Ref. [2].

(a) Ground probing radar (GPR)

A short (~ 10^{-8} sec long) pulse of electromagnetic energy of "carrier" frequency about 300 MHz is sent into the ground. A reflection occurs when a medium of different dielectric constant is encountered, e.g., a buried metal drum or a very distinct water surface. The time it takes for the pulse to travel down and back gives an indication of the spatial extent of the sub-surface objects. Several systems are commercially available and surveys to a depth of about 10 feet (deeper in dry soils and shallower in saturated soils) can be made rather quickly over relatively large areas. The usual output gives the strength of the return echo as a degree of blackening on an Alden-type recorder, examples of which follow.

In connection with the recent fire and series of explosions at the Chemical Control Corporation's site in Elizabeth, New Jersey, Roy Weston Associates [3] was contracted by the U.S. Coast Guard to determine the location of 55

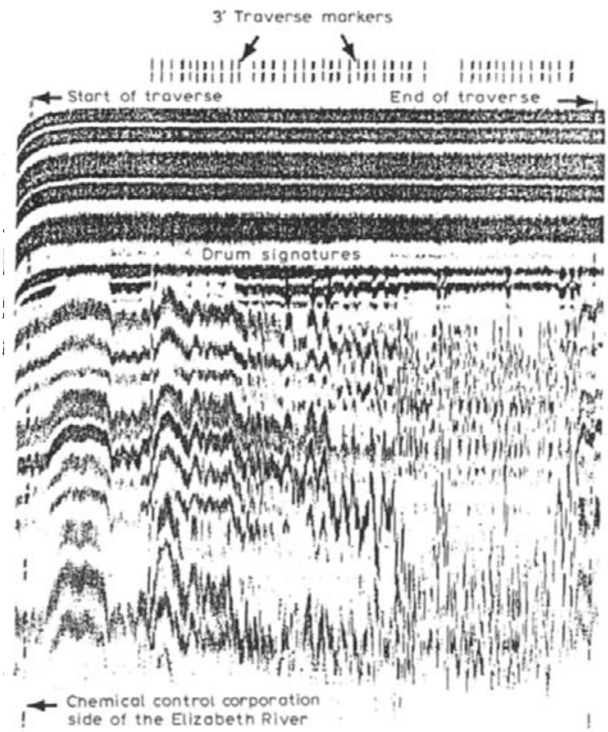

Fig. 1. Ground penetrating radar printout for traverse No. 39 in Elizabeth River, adjacent to Chemical Control Corporation Site, Elizabeth, New Jersey.

gal. steel drums suspected of being hurled into the adjacent Elizabeth River. A commercially available GPR system was adapted for river work by placing the antenna in a raft and pulling it by a small boat with the readout equipment on board. They performed 123 perpendicular traverses of the river at 10′ intervals and an additional 11 traverses at 10′ intervals parallel to the river flow. The object was to locate the drums which were on the river bottom, or embedded in the soft river silts and clays. The soft bottom sediment was estimated at 3′ to 5′ thick. The river depth ranged from 9′ to 13′.

The GPR traces showed a number of clear, unmistakable drum reflections, see Fig. 1. The carefully planned and executed GPR mapping of the site enabled the pinpointing of the location of many, or all, of the drums. Unfortunately, clean-up has not been initiated, so that "ground truth" has not been established.

Drexel University [4] is conducting ongoing research for EPA where steel drums are buried at known depths in various soil types (three sites; one a sand, one a river silt, and the third a silty clay) to determine the limitations of commercially available GPR equipment. The antenna used has a center frequency of 300 MHz and traverses are made at approximately one month intervals over the complete range of climatic conditions. To date, it has been found that:

- Traverses perpendicular to the drum axes are much more definitive than those parallel to the drum.
- Dry sand conditions show the best reflections.
- With soil at a high moisture content, as in a capillary zone, the reflections are very poor.
- When the water table is at the level of the top of the drum, the drum reflection is almost completely masked.
- Snow cover, or frozen ground, does not influence the readings.
- High moisture content of the upper soil (as immediately after a rain) limits the depth of the return signal.
- Ground vegetation limits the depth of the return signal.

Some examples of metal drums buried in sand at different depths traversed perpendicular to the axis and parallel to the axis are shown in Figs. 2 and 3, respectively.

(b) Metal detector (also called inductive or eddy current) method

This NDT method utilizes a search coil with an alternating current (a.c.) in it. It thereby produces an a.c. magnetic field which induces eddy currents in a nearby metallic object. These eddy currents produce a magnetic moment in the metal which then interacts back (via mutual inductance) on the search coil. The size of this mutual inductance is read out and gives an indication of the presence and size of the metallic object. This is the principle on which most metal detectors work. There are a wide variety of these relatively inexpensive metal detectors commercially available and they have been quite successful in detecting buried objects at relatively shallow depths. Penetration depth is obviously dependent upon the size of the buried object.

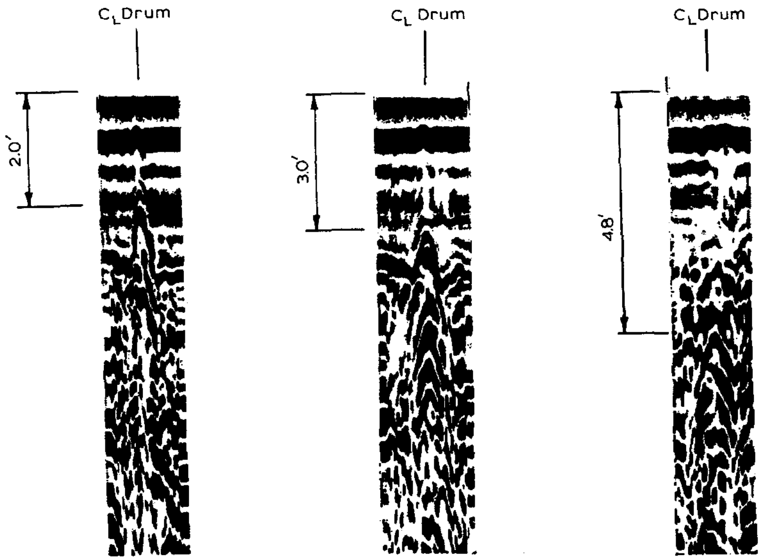

Fig. 2. Pulsed radar survey of buried metal drums in sandy soil at Wharton Site, surveyed by GPR traversed perpendicular to drum axis.

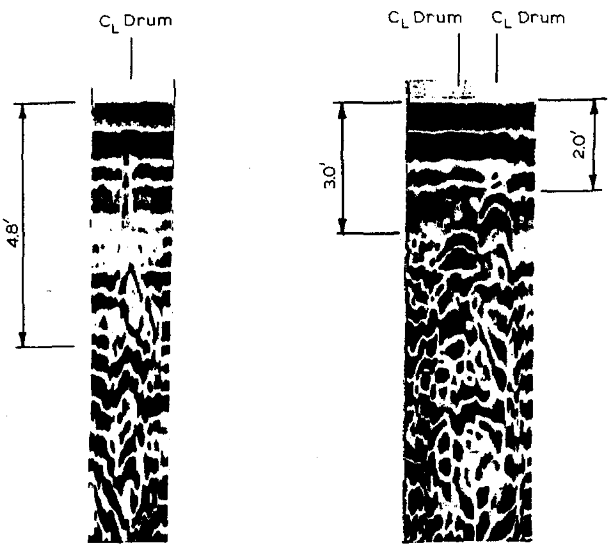

Fig. 3. Pulsed radar survey of buried metal drums in sandy soil at Wharton Site, surveyed by GPR traversed parallel to drum axis.

In conducting a survey over the location of a cluster of buried steel drums, Benson and Glaccum [5] show a clear metal detector reflection for the entirety of the 5 meter ($\simeq 15'$) wide area, see Fig. 4. The return signal rises sharply above background on one side of the location of the drums, stays high, and

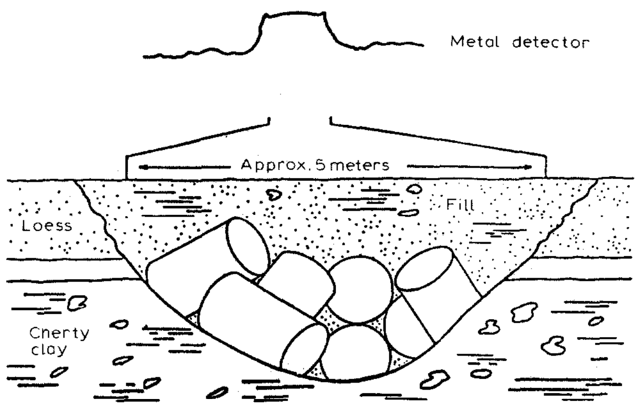

Fig. 4. Results of metal detector survey over buried container area [5].

then abruptly falls off as the traverse leaves the vicinity. The topmost portion of the drums were covered with about two feet of soil, which is apparently shallow enough so that changes in conductivity can be easily sensed by the metal detector. The authors state that in comparison to other NDT methods used at this site, "the metal detector provides a sharper response at the edge of the trench, resulting in better spatial definition of the drum boundaries".

(c) Magnetometer

A magnetometer is a device which measures very minute changes in the earth's magnetic field. Any magnetic object, e.g., an iron ore deposit, buried steel object, etc., will alter the earth's magnetic field locally and thus can potentially be detected. The most common magnetometer today uses proton nuclear magnetic resonance, called proton precession, while another type uses cesium vapor. The nuclear spin of the proton can be made to flip in a radio frequency (r.f.) field. When the frequency of the r.f. field and the d.c. magnetic field have appropriate values, there is a maximum flip rate and hence maximum energy absorption.

The proton magnetometer has the frequency set in such a way that maximum absorption is occurring under the normal magnetic field of the earth. If a magnetic object is encountered, the frequency goes out-of-tune and the frequency change one needs to bring it back into tune is a very precise measure of the change in magnetic field due to the magnetic object. A new, very sensitive magnetometer based on the superconducting Josephson effect, and called SQUID, is now commercially available.

Recognizing that the magnetometer detects only ferrous materials, but to a greater depth than metal detectors, Sandness et al. [6] developed a vehicle mounted cesium vapor magnetometer which was digitally interfaced to a microprocessor for data acquisition purposes. For the particular survey described, however, they used a commercially available proton precession magnetometer. Using three spherical steel sources (drums?) in the Hanford, Washington area

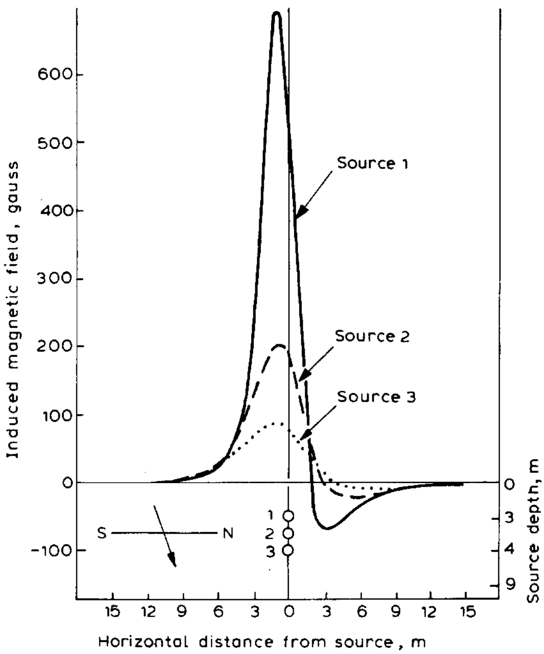

Fig. 5. Induced magnetic field from three buried containers at varying depths [6].

at depths of 3.0, 4.5 and 6.0 m, they found the response shown in Fig. 5 and drew the following conclusions.

- The earth's gravitational field pulled the maximum anomaly south of the source.
- The width of the anomaly is related to the source depth.
- The amplitude of the negative part of the anomaly is 10% of the positive part.
- The anomaly is small at burial depths greater than three times the source dimensions.

Magnetometers of several types are commercially available and are used a great deal in geophysical prospecting. An example of typical output using a proton precession magnetometer is shown in Fig. 6 which presents the results of a magnetometer field survey from a burial site consisting of dry soil. The zones of converging magnetic anomalies show where the buried objects are located.

(d) Electrical resistivity

This geophysical method applies current to the ground through electrodes and depends, for its operation, on the fact that any subsurface variation in conductivity alters the form of the current flow within the earth. Therefore, the distribution of electric potential is affected. The degree to which the potential measured at the surface is affected depends on the size, shape, loca-

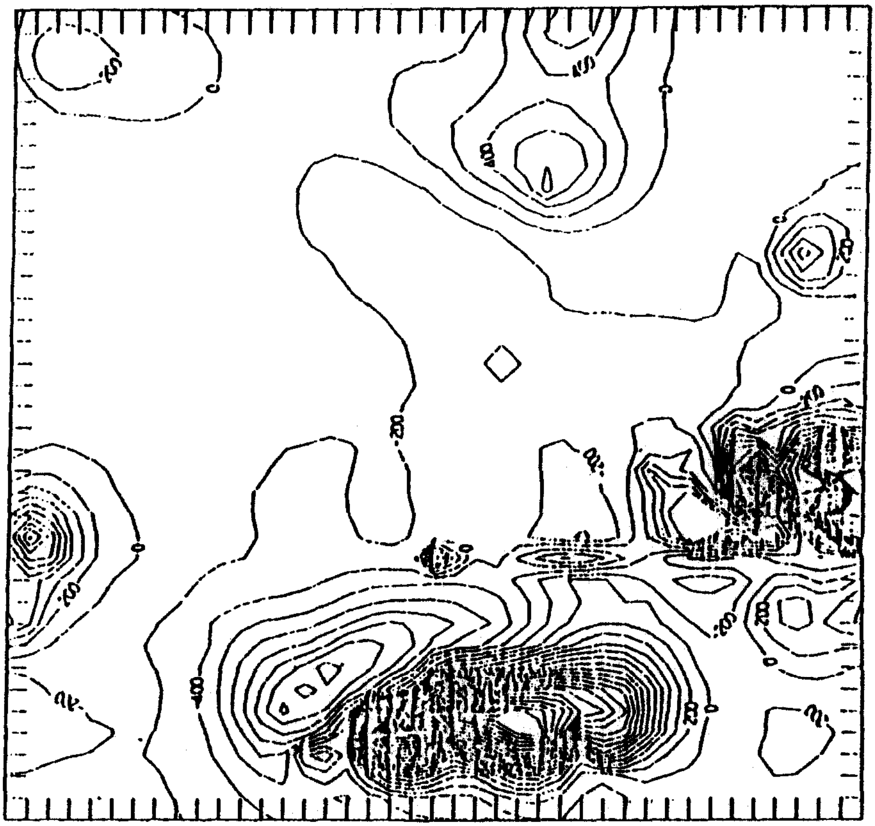

Fig. 6. Contour plot of magnetometer field survey data from a dry burial area.

tion and electrical resistivity of the sub-surface mass. It is therefore possible to obtain information about the sub-surface distribution of various bodies or the tracing of sub-surface seepage plumes from potential measurements made at the surface. This method is used extensively in the oil and mineral prospecting area, but has not been widely used in shallow monitoring for small buried objects. It has seen some use for tracing sub-surface liquids. There are many commercial sources of equipment to choose from.

At the Coventry, Rhode Island, site, the Mitre Corporation [7] used electrical resistivity as a seepage plume detection method. As various traverses were made, the area of buried drums was encountered and resistivity measurements were made. The high drum concentration was probably responsible for the extremely low resistivity values; see Fig. 7 which shows the results of a number of resistivity traverses in which the fourth was made in the vicinity of the buried drums. The high density of drums probably resulted in a large volume of highly conductive chemicals which would result in a strong effect on resistivity measurements. It should be mentioned, however, that the Mitre report does not dwell on the use of electrical resistivity to locate buried drums.

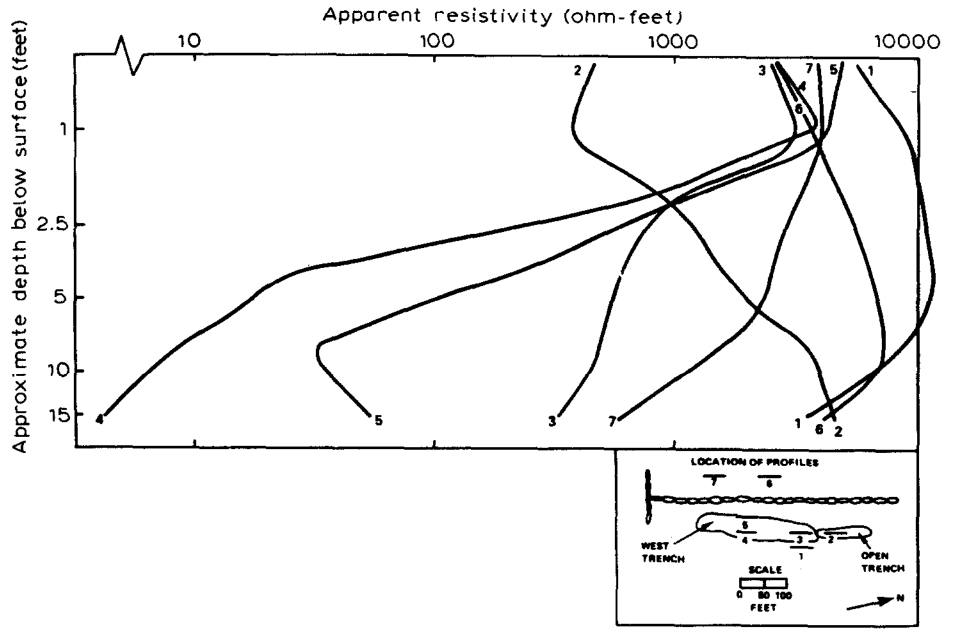

Fig. 7. Apparent resistivity depth profiles at Coventry, Rhode Island [7].

(e) Low frequency (VLF) electromagnetic

Electromagnetic methods utilize the measurement of secondary electromagnetic fields generated by induction in sub-surface conductors. The primary energy sources are electromagnetic fields generated by U.S. Navy VLF transmitting stations or fields generated during the study from a separate coil or line. That is, the transmitted waves induce currents in sub-surface conductors as the waves pass through them. The currents are formed in accordance with the laws of EM induction and conduction. The currents are then sources of new waves which radiate from the conductors and are detected at the surface. Inhomogeneities in the electromagnetic field observed at the surface indicate variations in conductivity of sub-surface features which are picked up with the receiver at the surface. This method is probably the most recently employed of those mentioned in tnis paper. Thus, its use in detecting small buried objects is largely unknown.

Benson and Glaccum [5] used the VLF—EM method to locate buried drums under approximately 2 feet of soil and were quite successful in doing so. The trench where the drums were buried was about 5 meters (15 feet) wide and the method showed the trench boundaries quite well, see Fig. 8. The general response from a number of parallel traverses made over the site is shown as a composite diagram in the corner of Fig. 8. Note that individual drum locations within the soil mass cannot be distinguished, but general boundaries are quite easily seen. Since the VLF—EM method responds to the conductivity of the drums, the high density of metal apparently eliminates resolution of individual behavior.

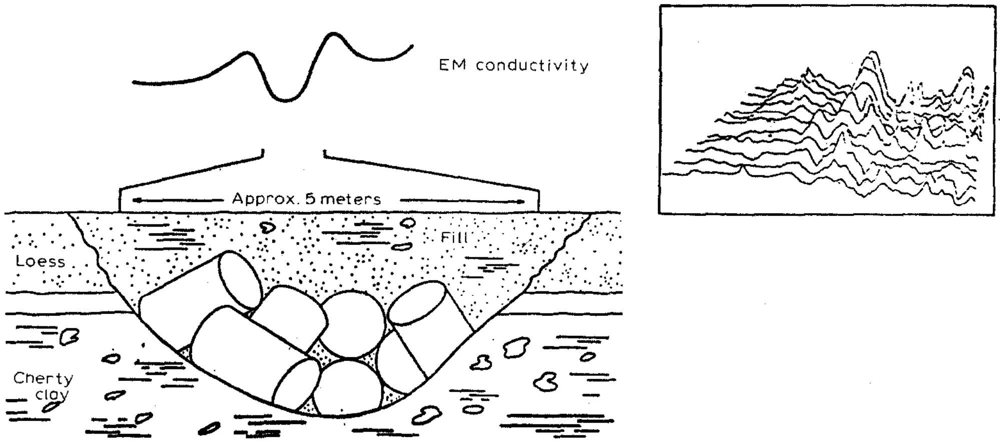

Fig. 8. Results of a VLF—EM survey of a buried container site showing one traverse and a series of parallel traverses over an area of fractures in soluble rock [5]. Eleven continuous and parallel EM conductivity lines clearly reveal size, location and periodicity of fracture trends in soluble rock to a depth of 6 meters. Line length is approx. 800 meters and line spacing is 15 meters.

(f) Seismic refraction [2]

In this well-established geophysical method, a seismic impulse (a hammer blow or explosive charge) is applied to the ground and the time to reach a transducer is measured for varying distances between the impulse and the transducer. The time is plotted as a function of distance and, if there is a well-defined layer beneath the surface, a characteristic break in the curve is found from which the depth to the layer can be determined. This method has not been used to detect small objects, but is widely used in the oil and mineral prospecting area, and can be used to determine generalized topography at a dump site.

(g) Sonar (pulse echo) acoustics [2]

This method is in principle similar to ground probing radar (GPR). A pulse of acoustic energy of a few kHz carrier frequency is beamed from a water surrounded source into the soil. A reflection occurs when the wave encounters a medium of different acoustic impedance (e.g., an air void or a metal plate). The time it takes for the echo to return gives an idea of the depth of the reflecting object. Lateral surveying will indicate the extent of the object. The trade off between resolution (high frequencies) and low loss (low frequencies) involves frequencies such that the usefulness of the technique is at most a few feet of probing into the soil. Coupling of the transducers to the soil presents a real problem. A somewhat higher frequency (12 kHz) unit has been used to probe the bottom of water bodies.

(h) Infrared radiometry [2]

The method utilizes thermal radiation from a surface which is measured by an infrared radiometer. The heating can be either active or ambient. The radiation pattern reveals heat generation and heat flow anomalies caused by variations in the materials being investigated. The method is a highly refined NDT method. Much commercial equipment is available and has been used to determine water flow profiles (in dams), heat escaping from uninsulated houses, heat from vegetation, etc. Its use in picking up buried drums and related problems has not been reported. A major drawback of the technique is the cost of the equipment ($10,000 to $20,000 for a two-dimensional scanning unit).

(i) Nuclear (high energy particles) method [2]

There has been an effort to detect land mines with high energy particles. High energy particles (x-rays, neutrons, etc.) are beamed into the ground and if a metal mine is present more of the particles are back-scattered to the detector. The range of travel of the particles is very limited in soil.

(j) Continuous wave (CW) microwaves [2, 8]

This method is similar to ground probing radar except that a continuous wave (CW) is used. The CW is swept in frequency and the wave from the ground surface and the wave from a subsurface reflection interfere with each other. The spacing (in frequency) between interference maxima (or minima) as the frequency is swept gives the depth of the reflecting surface. Some systems of this type are in an advanced research stage; however, they are not available commercially as far as the authors are aware.

Conclusions

In assessing the current status of identification and location of buried containers using NDT methods, it is seen that a variety of techniques has been attempted. By categories these vary from traditional geophysical methods:

- seismic refraction
- electrical resistivity
- magnetometry

to more recent NDT methods (adapted from various technologies studying close-range problems):

- ground probing radar
- metal detector
- VLF (electromagnetic)
- sonar (pulsed echo acoustics)
- infrared
- nuclear — high energy
- continuous wave microwave

Threaded throughout the review of the literature and our personal experiences

TABLE 1

Assessment of most widely used NDT techniques for identification and location of buried containers

Method	Equipment cost	Field deployment	Data inter-pretation	Container detail	Maximum penetration depth (approx.)
Ground probing radar	$35,000	moderate	moderate	excellent	4′—15′
Metal detector	500	easy	simple	poor	2′—5′
Magnetometer	4,000	easy	moderate	poor	4′—30′
Resistivity	2,000	moderate	difficult	poor	2′—50′
VLF (EM)	7,000	moderate	moderate	poor	2′—20′
Refraction	5,000	moderate	moderate	poor	2′—100′
Sonar (pulse echo acous.)	10,000	difficult	moderate	good	1′—3′
Infrared	15,000	moderate	moderate	moderate	1′—5′
Nuclear—high energy	30,000	difficult	moderate	moderate	1′—2′
CW microwave	10,000	moderate	moderate	moderate	2′—12′

was an underlying theme that the geophysical methods (with the possible exception of magnetometry) were not sensitive enough to detect containers buried at shallow depths of the type generally encountered. We are in general agreement with this conclusion.

In order to rate, and compare, the remaining methods to one another, Table 1 has been assembled. Upon reviewing this information, we feel confident in making the following conclusions:

(1) Metal detectors should be the first method used for exploratory work. Since the majority of containers are steel and buried under from a few inches to a few feet of soil, one would be remiss in not first attempting to use this method. It is simple to use, gives straightforward results and is the least expensive of all NDT equipment to purchase and maintain.

(2) If the drums are shallow, but not of steel, we feel that the sonar—pulse echo acoustics method is best for soils of high saturation (> 50%) and the continuous wave microwave method is best for dry or partially saturated (< 50%) soils. However, both of these methods are still in a development stage and further research is necessary.

(3) For drums buried deeper than 5′ and in soils of high saturation (> 50%), the magnetometer seems best suited although individual drum definition is not particularly clear. The equipment is of moderate cost and many consulting firms have such services available.

(4) For drums buried deeper than 5′ in dry or partially saturated (< 50%) soils, GPR seems well suited. Here, more than other techniques, the individual containers can be identified and quantified. The equipment, however, is quite expensive and therefore only a limited number of consultants have such a service available.

(5) The other NDT techniques noted in the literature require much more field (and laboratory) development before they can be recommended for routine field investigation. For most of them, "ground truth" experiments under a wide variety of field conditions seem justified.

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