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USE OF A VERY-LOW-FREQUENCY ELECTROMAGNETIC METHOD AT 9.5 kHz TO DETECT BURIED DRUMS IN SANDY SOIL

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Summary

A detailed study of the very-low-frequency electromagnetic (VLF-EM) method was undertaken at a single field site where a prescribed distribution of buried metal (steel) and plastic containers had been placed. The site (which was quite free of interference) consisted of a relatively uniform sandy soil of low water content and represented nearly ideal conditions for the tests.

Results indicated that the technique will undoubtedly detect and delineate any typical dump site with predominantly metal (usually steel) drums. Single metal drums (55 gallon variety) can be detected with six feet of soil cover and isolated groups of metal drums to significantly greater depths.

Isolated plastic drums are very difficult to detect; however, a large group with highly conductive contents could probably be detected.

A quite unexpected result was that single, empty 40 gallon plastic drums can be detected to three feet of soil cover. Theoretical considerations indicate that these drums should be totally invisible to the technique.

It remains to show if these same conclusions will hold true in a more general soil type, one which contains a significant clay fraction.

Introduction

The dumping of all types of hazardous materials has been ongoing in most industrialized countries for hundreds of years. However, conditions seem to have accelerated in the past 40—50 years to the point where dangerous incidents are becoming common., e.g., Love Canal and Valley of the Drums in America and Lekkerkerk in Holland being prime examples. The problem is greatly aggravated when a soil covering is placed over the waste which is often placed in steel or plastic containers of various size, shape and orientation. This covering, or soil bury, is typically from a few inches to a few feet thick.

One of the first tasks in any remedial action is to delineate the physical extent of the sites and its encroachment into the surrounding area; this is

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especially true for totally covered sites. In this regard, both borehole drilling and excavation are very dangerous to workers and the environment and expensive and tedious to conduct. Conversely, non-destructive testing methods (NDT), have been used to detect buried drums, among which are ground probing radar, metal detectors, magnetometers and electromagnetic methods [1]. However, rarely have there been "ground truth" studies performed to determine the true capabilities of the methods used, i.e., the detectability limit, resolving ability, etc. In order to rectify this deficiency, a detailed study was performed at a site where a prescribed distribution of drums was buried. The general results of the study have already been reported in a somewhat abbreviated form [2].

It is the purpose of this paper (one of a series) to report in detail on the capabilities of one particular technique — an electromagnetic method called Very-Low-Frequency (VLF) — resulting from the general study.

Experimental approach

In general, electromagnetic methods cover a very wide frequency regime. Refer to Table 1 for a listing of methods and to reference [3] for further details. The particular methods which have been of definite use in locating buried objects on a small scale are VLF, pulsed radio frequency and continuous microwaves. This paper will deal with the VLF range of the electromagnetic spectrum and in particular a method which we will refer to as VLF-EM.

A commercially available VLF-EM unit operating at 9.5 kHz was utilized in this study. The unit used was similar to that used in another drum location and leachate plume detection study [4].

Figure 1 shows the details of the electromagnetic method. The transmitter coil (of size 10.5 inches × 1.5 inches) generates an electromagnetic field with a time variation of 9.5 kHz. The receiving coil (of the same size) placed twelve feet away from the transmitter detects this time-varying field essentially in two ways. One field arrives through the air and is little affected by the subsurface material. The field (both its phase and amplitude) arriving at the detector from the subsurface material is affected by the electrical conductivity and magnetic permeability of that material. Thus the total field arriving at the receiving coil can be very much affected by the nature of the subsurface material. The details of the electromagnetic method, both in theory and ap-

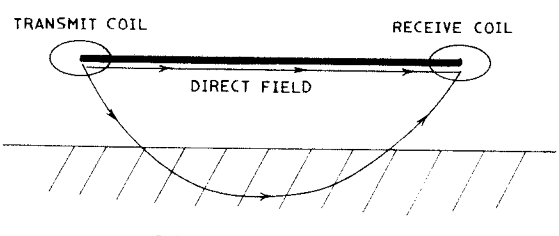
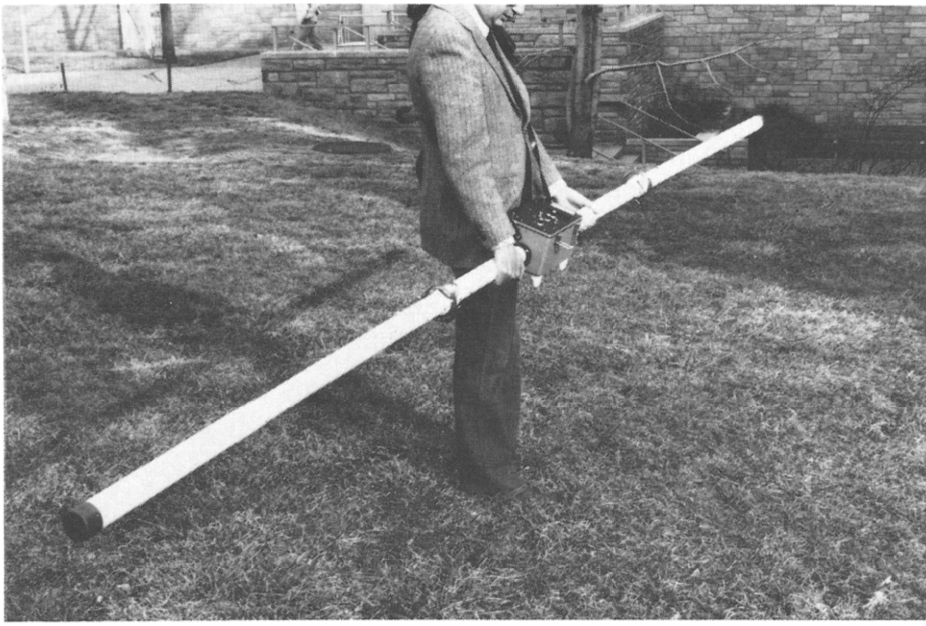


Fig. 1a. Schematic diagram of the measuring technique.



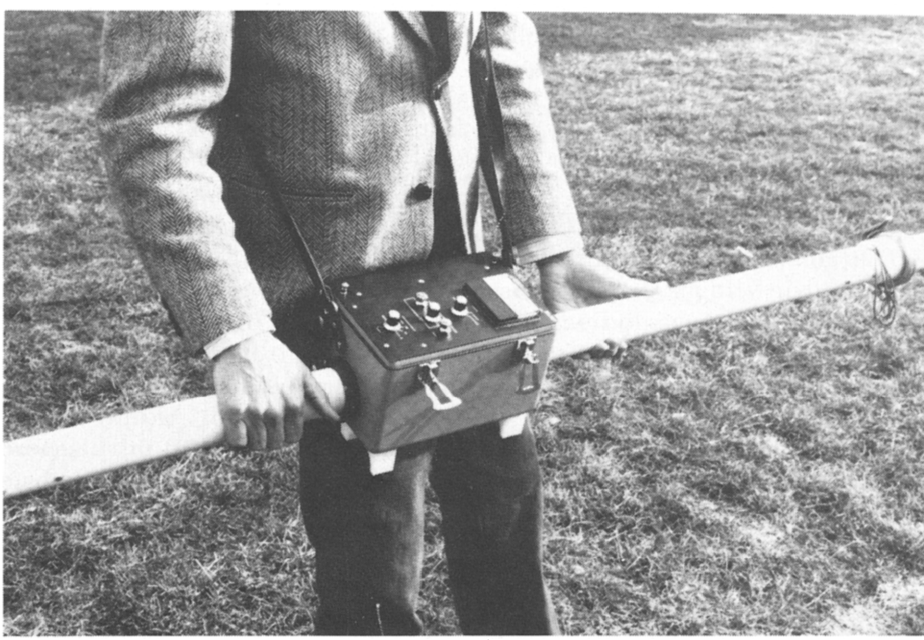


Fig. 1b. Photographs of the actual apparatus used in this study.

TABLE 1

Electromagnetic methods
The given frequency ranges are somewhat arbitrary; there is no official frequency breakdown

Method	Approx. frequency range
Electrical resistivity	≃ dc
Extremely low frequency (ELF)	1–100 Hz
Very low frequency (VLF)	100–10,000 Hz
Pulsed radio frequency (pulsed RF)	1 MHz–200 MHz
Pulsed microwave (pulsed μ-wave)	1 GHz–8 GHz
Continuous wave radio frequency (CWRF)	0.05 MHz–600 MHz
Continuous wave microwave (CW μ-wave)	0.2 GHz–8 GHz
Infrared	about 10^{14} Hz
Optical	about 10^{15} Hz

plication can be found in references [5] and [6], and a recent report written by the authors [7].

The particular unit used is calibrated to read the conductivity of a uniformly conducting subsurface in ohm^{-1} $meter^{-1}$. Thus the readings to be presented (taken over a drum(s)/soil situation) should only be considered relative values and may at times bear no direct relationship to the conductivity of the soil.

Site details

An abandoned sand quarry was available where drums could be buried permanently. The quarry was located at a somewhat remote location; the nearest road and utilities being 1000 feet from the test site. Thus, background disturbances from man-made objects were minimal. The soil was mainly uniform sand with a water table much deeper than the maximum depth of bury. The lack of stratified layers in the soil proved most ideal for the type of work performed. Details of the exact nature of the soil can be found in reference [2].

The containers were placed in hand-excavated and equipment-excavated holes varying from 1 to 14 ft in depth. Containers placed in the excavations varied in size from 2 gallons to 55 gallons and were made from both steel and plastic. The container burial patterns were as follows:

1. Three 30 gallon steel containers buried at 3 ft depth, but at different orientations, 0°, 45°, 90°.
2. Four 55 gallon steel containers buried at 4.5 ft depth in two groups, one by itself, the other three side by side.
3. Four steel containers of various sizes (2, 5, 30, 55 gal) buried at constant depths of 3.5 ft (i.e., 3.5 ft of soil cover).
4. Four 30 gallon steel containers buried at 1, 3, 6 and 11 ft depths.
5. A random burial site approximately 12 × 12 × 5 ft deep, which was

filled with 10 steel drums and 1 plastic drum of various sizes. (This pattern was called the "trash dump.")

6. Four 40 gallon plastic containers buried at 1, 3, 6 and 11 ft depths.
7. Two plastic containers buried at 2 ft depth, one filled with fresh water, the other filled with salt water.

All patterns were separated by sufficient distance so that interaction between them was relatively unlikely, and within each pattern sufficient distance was allowed for the same reason.

VLF-EM surveys were performed with the long axis of the unit both perpendicular and parallel to the traverse direction.

Theoretical considerations

General theory of response of a buried dipole

The general theory of the apparent resistivity of various materials or objects placed in the subsurface region is quite complicated. The complications arise mainly due to the shape of the buried object(s). Often, considerable information can be obtained by approximating the actual shape to some idealized geometrical shapes or by model studies. One particular problem that is quite useful to the study of an isolated small buried object is to approximate the field induced in the buried object to that of a dipole. The validity of this approximation improves as the dimensions of the object become smaller in comparison to its depth of burial.

First consider a magnetic dipole (current loop) situated in air as shown in Fig. 2. The magnetic field at P will be given by [8]

$$\vec{H_t} = \vec{H_\theta} + \vec{H_r} \tag{1}$$

where H_r is the radial component and H_θ is the tangential component. In the near zone, $|kr| \ll 1$, where k is the wave propagation constant, the two field components are given by

$$H_r = 2m \cos\theta / r^3 \tag{2}$$

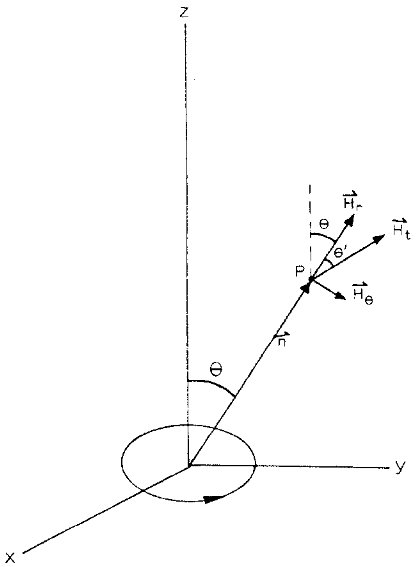
$$H_\theta = m \sin\theta / r^3 \tag{3}$$

where m is magnetic moment of the dipole and equals the product of the area of the current loop and the current flowing through it.

If a horizontal receiver coil of area, A is placed at P, the magnetic flux ϕ through it will be given by

$$\phi = H_t A \cos(\theta + \theta') \tag{4}$$

Now, if the current in the loop changes with a frequency f, the induced emf in the receiver coil will be proportional to $f\phi$. In the VLF-EM survey instrument used in this study, the situation is depicted in Fig. 3. The transmitter, T, induces a dipole moment in an object O, which in turn produces a signal at the receiver as discussed above. The signal, S, at the receiver can be shown to be



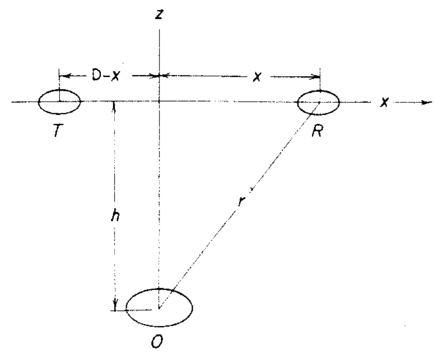


Fig. 2. Coordinates used for dipole model calculations.

Fig. 3. Model of VLF-EM unit used for calculation.

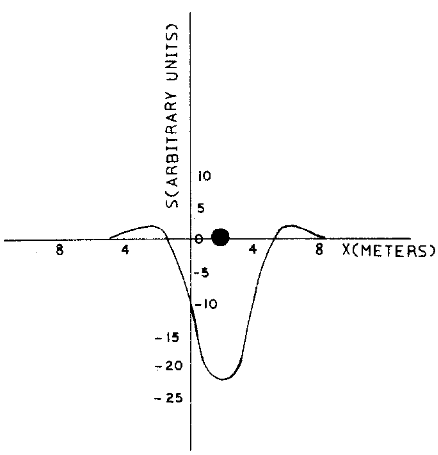


Fig. 4. Theoretical results for scanning over a conducting drum with the VLF-EM unit, according to eqn. (5); h = 5 m, D = 3.75 m.

$$S = C \frac{(h^2 - x^2)[h^2 - (D-x)^2]}{\{(h^2 + x^2)[h^2 + (D-x)^2]\}^{5/2}} + S_1 + S_2 \qquad (5)$$

where C is a constant and depends on the area and number of turns of the transmitter, receiver and cross-sectional area of the object perpendicular to the Z-axis. It further depends on the operating frequency of the instrument, the current in the transmitter coil, and the conductivity of the buried object.

The signal at the receiver will be further modified by a constant signal S_1 due to the direct coupling between the transmitter and receiver, and by S_2, the signal due to the uniformly conductive medium in which the object is buried. Thus, the first term in eqn. 5 gives the variation of the signal level in arbitrary units. In a VLF-EM survey for buried objects, it is the variation in S that is important and not the absolute value of S. A plot of eqn. 5 for h = 5 m and D = 3.75 m is shown in Fig. 4.

Response of a buried, conductive drum

The scale on the commercially available unit is calibrated according to the following equation [9]

$$\sigma_a = K\, H_s/H_p \tag{6}$$

where H_s and H_p are, respectively, the secondary and the primary magnetic fields at the receiver coil, and $K = 4/\omega\mu_0 D^2$ for the instrument placed over a homogeneous half space where, $\omega = 2\pi \times$ frequency; μ_0 = permeability of free space (= $4\pi \times 10^{-7}$ kg m s^{-2} A^{-2}); D = intercoil spacing.

This value of K is obtained under the assumption that the skin depth of the electromagnetic waves at frequency f is much larger than the intercoil spacing. Equation (6) can be suitably modified for cases where the half space under the instrument consists of layers of different conductivities [9].

Here two things should be mentioned in regard to eqn. (6). First, for shapes other than the homogeneous (or layered) half space, the instrument scale calibrated by using eqn. (6) cannot be used for quantitative analysis. Second, an equation similar to eqn. (6) for shapes such as cylinders, spheres, spheroids, etc., is very complicated, see Wait [10] for details.

The form of eqn. (6) for a sphere of radius R is discussed below as an illustration. Consider a sphere of conductivity σ_1 = 0, and magnetic permeability μ_1 situated in a medium of σ_2 = 0 and magnetic permeability μ_2. The following equation for the ratio of the z-components (along the direction of the primary field) of the secondary and the primary field can be obtained [10]

$$\left|\frac{H_s}{H_p}\right|_{\max} = -\frac{3R^3}{z^3}(M + iN) \tag{7}$$

where z is the distance measured from the center of the sphere and

$$M + iN = -\frac{2}{3}\left[\frac{2\mu_1(\sinh\alpha - \alpha\cosh\alpha) + \mu_2(\sinh\alpha - \alpha\cosh\alpha + \alpha^2\sinh\alpha)}{2\mu_1(\sinh\alpha - \alpha\cosh\alpha) - 2\mu_2(\sinh\alpha - \alpha\cosh\alpha + \alpha^2\sinh\alpha)}\right] \tag{8}$$

$$\alpha = (i\mu_1\sigma_1\omega)^{1/2}R \tag{9}$$

The functions M and N are usually plotted as function of α for various values of μ_1/μ_2. Thus using eqns. (7)—(9) it is possible to estimate the magnitude of the conductivity anomaly and compare it to the experimentally observed value to obtain a conversion factor between the instrument scale and the theoretically estimated anomaly. However, in cases where only the location of a buried object is of interest, it is the existence of an anomaly rather than its magnitude which is of importance.

A rough estimate of the magnitude of the conductivity anomaly due to a metal sphere can be obtained via the method obtained via the method obtained in references [9] and [11]. The result obtained in this way is in order-of-magnitude agreement with the experimental results.

Response due to an air void

The signal due to an air cavity, e.g., an empty plastic drum, in a uniformly conductive soil can be obtained by using a model depicted in Fig. 5. The cavity is treated as the absence of a dipole from the uniform earth. The variation of the signal with distance along the survey will be similar to that of a metallic drum buried in earth, but the contribution will be in the opposite direction to that of a metallic drum.

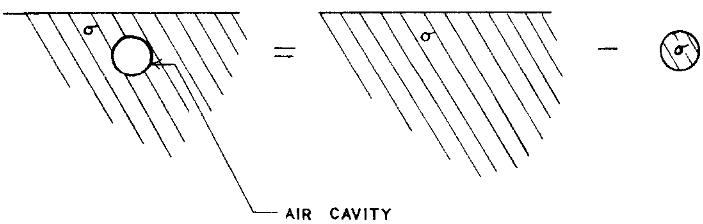


Fig. 5. Model for conductivity anomaly due to a void.

The authors found no reasonably accessible solution for the response of a sphere of low conductivity material, as is needed for the solution of the air void problem. However, using the method of references [9] and [11], a rough estimate can be made of the magnitude of the response of the instrument to an air void of the size produced by an empty 40 gallon plastic drum. The magnitude turns out to be some three orders-of-magnitude smaller than what is observed experimentally. More will be said concerning this point in the Discussion.

Effect of drum inclination

If the drum axis is inclined with respect to the Z-axis (vertical), then the effective area of the current loop (Fig. 6) will increase and the signal should increase accordingly. (This effect has been observed experimentally and will be seen in later figures.)

Experimental results

Steel drums, pattern 1. Figure 7 shows the results of a survey performed with the shaft connecting the transmitter and receiver perpendicular to the traverse for a 30 gallon steel drum buried upright with 3 feet of soil cover. The position indicated on the abscissa is the mid-point between the two coils. Figure 8 indicates the results when the shaft is parallel to the traverse. The

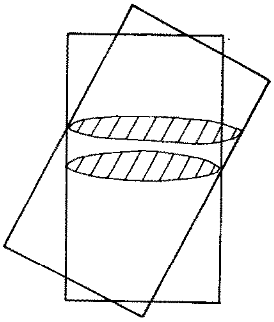


Fig. 6. Projected area differences for inclined drum.

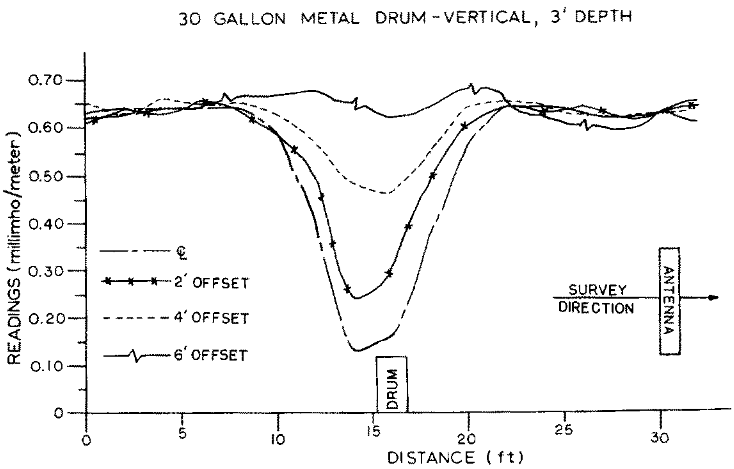


Fig. 7. Results of VLF-EM scans over single upright steel drum (antenna ⊥ to scan direction).

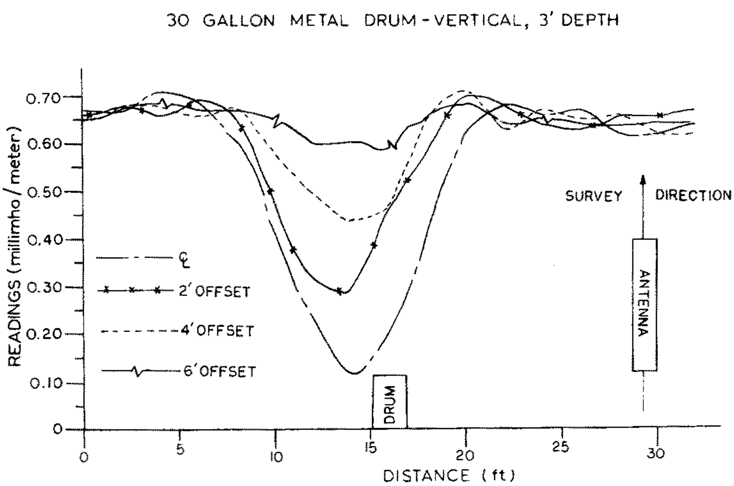


Fig. 8. Results of VLF-EM scans over single upright steel drum (antenna ∥ to scan direction).

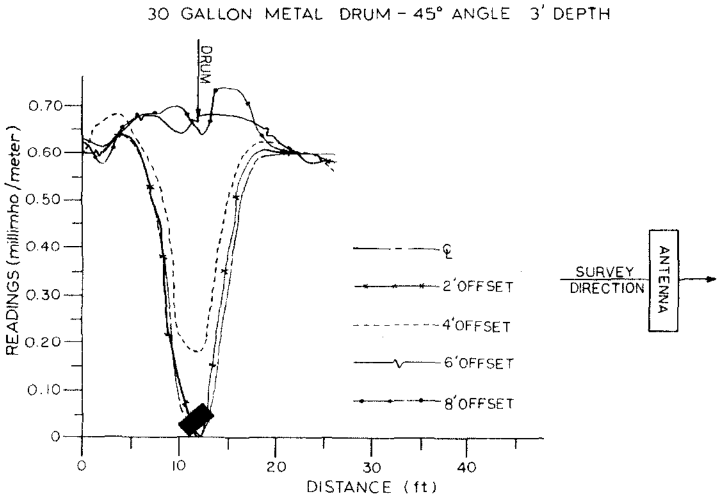


Fig. 9. Results of VLF-EM scans over single inclined steel drum (antenna ⊥ to scan direction).

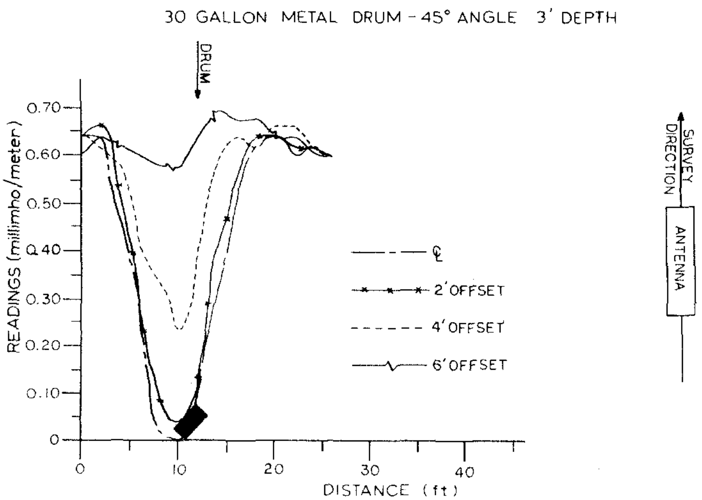


Fig. 10. Results of VLF-EM scans over single inclined steel drum (antenna || to scan direction).

dip predicted by theory is present; it is most pronounced when the traverse passes directly over the drum and decreases as the traverse moves farther (perpendicularly) from the center line (2 ft offset, 4 ft offset, etc.). Figures 9 and 10 show that essentially the same response occurs when a similar drum is positioned at an angle of 45°, with the larger response coming possibly from the inclination effect (see: Theoretical considerations — Effect of drum inclination).

Steel drums, pattern 2. In order to test the resolving power of the electromagnetic method, traverses were made over a pattern consisting of a single 55 gallon steel drum and three 55 gallon steel drums buried on their sides and 16 feet apart. There was 4.5 feet of soil cover over all drums. The results are shown in Figs. 11 and 12. The figures indicate that the single drum is certainly resolvable from the three drums. It should be noted that the upward lobe of the 3-drum pattern almost spreads to the single drum, indicating

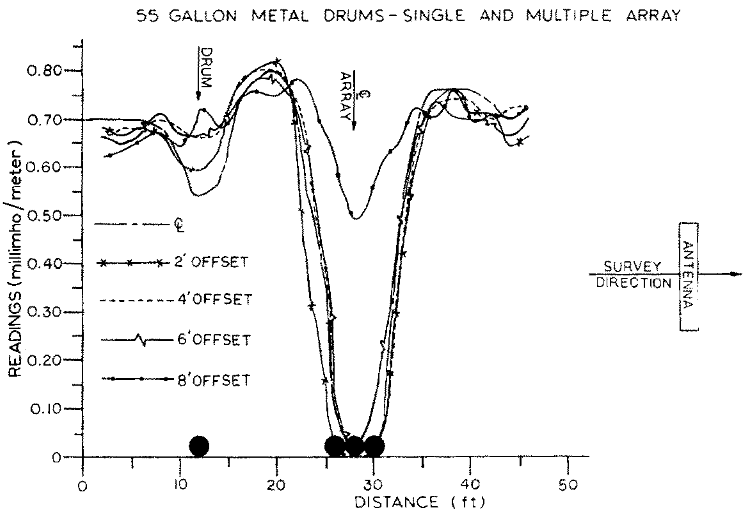


Fig. 11. Results of VLF-EM scans over one and three drum pattern (antenna ⊥ to scan direction).

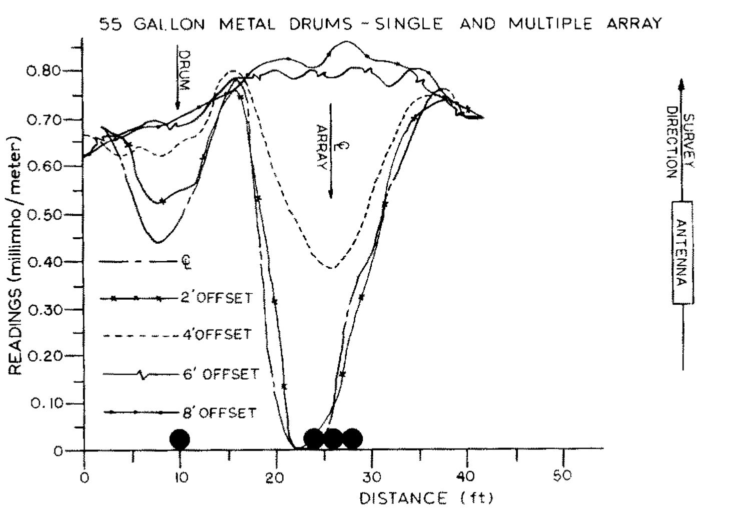


Fig. 12. Results of VLF-EM scans over one and three drum pattern (antenna ∥ to scan direction).

that for this particular pattern of drum burial, 16 feet is about the resolving power. Of course, the resolving power will depend on the actual distribution of drums (number and depth); the smaller the number of drums, the greater the resolving power.

Steel drums, pattern 3. Figures 13 and 14 show the results of traverses (surveys) made over individual steel drums of various sizes, all with 3.5 feet of soil cover. Each drum was clearly detectable and resolvable. These results again

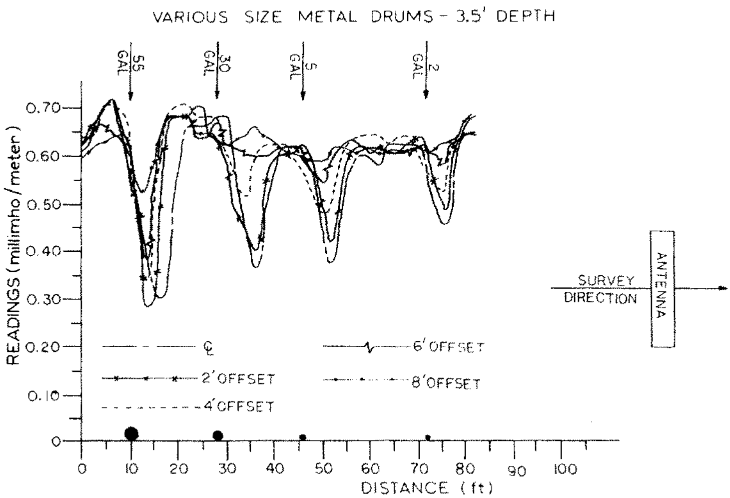


Fig. 13. Results of VLF-EM scans over variable size steel drum pattern (antenna ⊥ to scan direction).

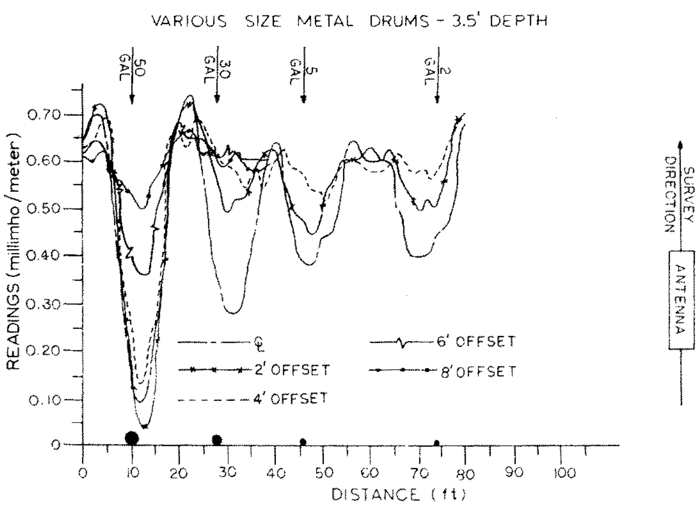


Fig. 14. Results of VLF-EM scans over variable size steel drum pattern (antenna || to scan direction).

indicate that for essentially single drum burial distributions, the resolving power is of the order of 15 feet or less. (The resolving power is determined by the spread of the upward lobes.)

Steel drums, pattern 4. Figures 15 and 16 show the results for 30 gallon steel drums buried under various soil covers. It is observed that a 30 gallon steel drum is barely detectable under 6 feet of soil cover with the present technique. Of course, any known dump site has a great many drums, so this is not the practical limit of detection, but does indicate the single drum detection limit.

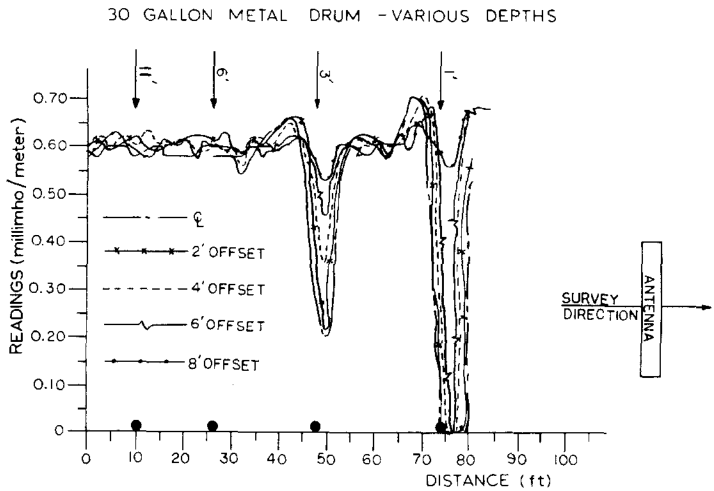


Fig. 15. Results of VLF-EM scans over variable depth steel drum pattern (antenna ⊥ to scan direction).

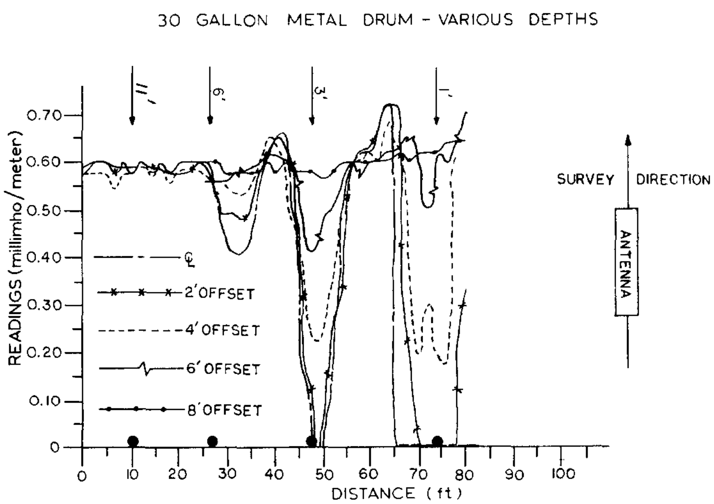


Fig. 16. Results of VLF-EM scans over variable depth steel drum pattern (antenna || to scan direction).

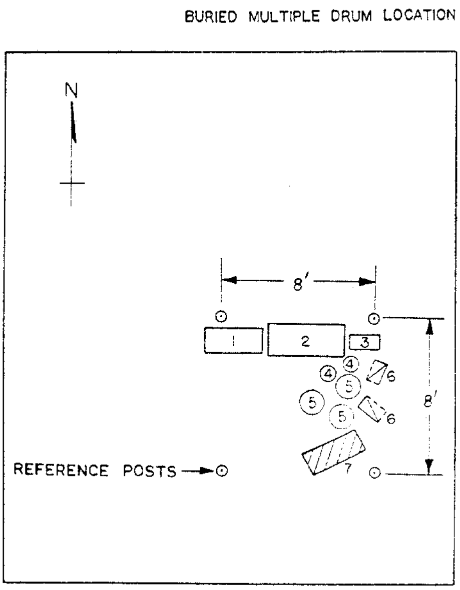


Fig. 17. Distribution of objects in "trash dump" (pattern 5).
Key: metal drums: 1 : horizontal, 30 gal; 2: horizontal, 55 gal; 3: horizontal, 5 gal; 4: vertical, 5 gal; 5: vertical, 30 gal; 6: 45° angle, 5 gal; plastic drum: 7: horizontal, 30 gal.

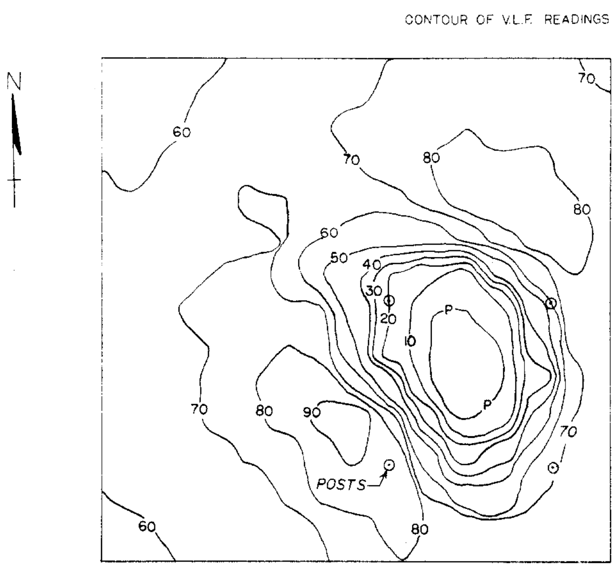


Fig. 18. Conductivity contours in vicinity of "trash dump" determined by VLF-EM technique (pattern 5).

Steel and plastic drums, pattern 5. A very small dump site was approximated by digging a 7 feet deep hole, 12 × 12 feet in area. Various steel drums and one plastic drum were "dumped in" the hole and covered with 5 feet of soil. Figure 17 indicates the disposition of the drums and Figure 18 gives a conductivity contour map as determined with the VLF-EM method from a 2 × 2 ft grid spacing (P indicates pegging of the conductivity reading on the low side). The position of the main metal in the "dump" is quite well determined from the conductivity readings; the lowest readings indicating the highest density of drums.

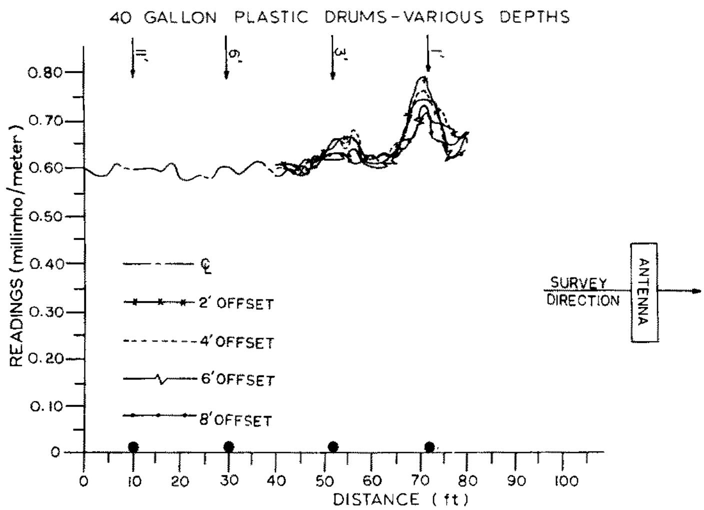


Fig. 19. Results of VLF-EM scans over variable depth plastic drum pattern (antenna ⊥ scan direction).

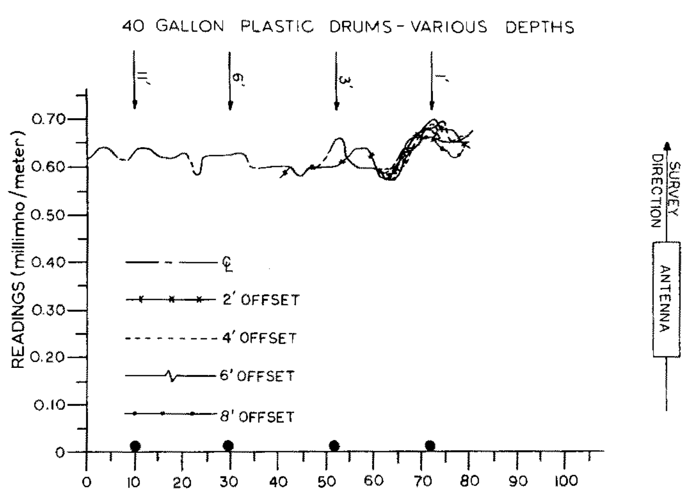


Fig. 20. Results of VLF-EM scans over variable depth plastic drum pattern (antenna ∥ scan direction).

Plastic drums, pattern 6. Figures 19 and 20 show the traverses over empty 40 gallon plastic drums buried under various depths of soil cover. The drum under 1 foot of soil cover is easily discernible while the drum under 3 feet is barely detectable. The deeper ones are "invisible" to the VLF-EM technique.
Plastic drums, pattern 7. A traverse was also made with a 40 gallon plastic drum filled with fresh water and a similar drum filled with salt water (1 lb salt/4 gal water); both were under 2 feet of cover. Neither drum could be detected. It seemed, therefore, that single plastic drums filled with any liquid, conducting or non-conducting will be most difficult to detect with the electromagnetic method. If, however, a large group of plastic drums filled with conductive liquids was present in a dump, the large conducting mass might be detectable, but the present work was not extensive enough to ascertain this possibility.

Discussion

The results obtained for the single steel drums buried at various depths allows a simple theory to be developed to estimate the number of drums detectable as a function of depth of bury.

The dipole model used is shown in Fig. 21. Again the results of Wouch and Lord [11] are utilized. The transmit coil acts as a dipole and produces at the sphere of radius a a magnetic field H_0 of magnitude C_1/r_3, where C_1 is a constant. This induces a magnetic moment, M_{EC}, due to eddy currents in the conducting sphere of magnitude $C_2 a^3/r^3$. This moment, acting as a dipole, produces a magnetic field at the receive coil, H_{EC} of size M_{EC}/r^3 or $C_2 a^3/r^6$. This quantity a^3/r^6 will now be used, together with the experimentally-determined detectability limit (for our particular situation) to estimate the size of a conducting sphere that could be detected versus depth of bury.

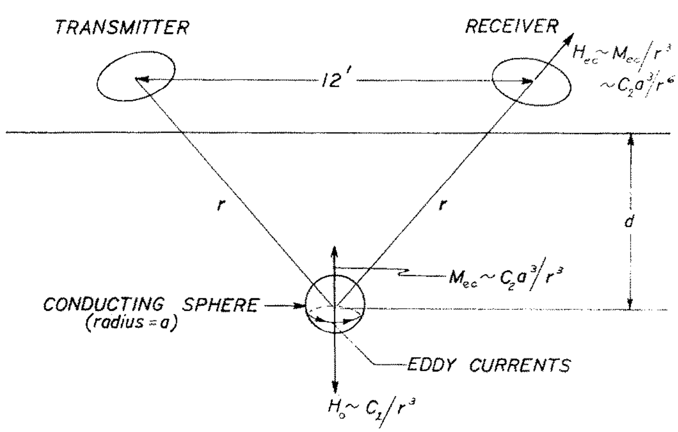


Fig. 21. Dipole model used for calculation of number of drums detectable versus depth of bury.

The detectable limit was found to be a 30 gallon steel drum at 6 feet of cover. The drum will be approximated by a sphere of radius one foot, hence the center of the sphere is seven feet below surface, and ten feet below coil and transmitter (assuming coil and transmitter are three feet above the surface). Thus for the detectable limit, with

$$r_6 = \sqrt{6^2 + 10^2} = 11.66 \text{ ft}$$

$$\frac{a_6^3}{r_6^6} = \frac{1^3}{11.66^6} = 4 \times 10^{-7} \text{ ft}^{-3}$$

At twelve feet of bury $r_{12} = \sqrt{6^2 + 16^2} = 17.09$ ft, and

$$\frac{a_{12}^3}{17.09^6} = 4 \times 10^{-7} \text{ ft}^{-3}$$

Thus,

$$a_{12}^3 = 10 \text{ ft}^3$$

The volume of this large sphere is equal to the volume of n individual spheres (Fig. 22) with

$$(4/3)\pi a_{12}^3 = n\,(4/3)\pi a^3$$

Using

$$a = 1 \text{ ft}, n = a_{12}^3 \qquad (13)$$

Thus, if the large sphere is replaced by n spheres, the detectability limit is about 10 spheres (drums) at 12 feet of cover. This replacement of one large sphere with a large number of small conducting spheres has been looked into [12] and found to be a reasonable approximation in certain cases. This same

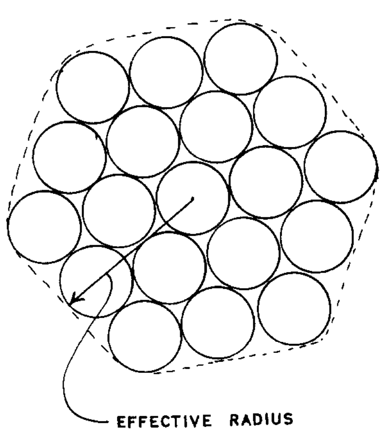


Fig. 22. Schematic diagram indicating replacement of one large drum by many drums of same total volume.

procedure gives the following detectable limits:

a_{18}^3 = 56 drums at 18 feet of cover;

a_{30}^3 = 674 drums at 30 feet of cover.

Even though the numbers cannot be taken too literally, the calculation does indicate that a typical dump site (a great many steel drums buried under a few feet of soil cover) will always be detectable with the VLF-EM technique. It also appears promising to use the technique to look for small, isolated deep bury dumps — say, 10 drums buried at 10 feet of cover.

It was indicated in the Theory section that a single empty plastic drum (approximated by a small air void) would produce far too small a magnetic moment to be detectable with the present technique. However, as seen in Figs. 19 and 20, a 40 gallon plastic drum buried under 1 foot of soil is definitely observable. The reason for this anomaly is unclear. It is interesting, however, to look at a simple, infinite layer model to gain insight into the air void anomaly.

The model is shown in Fig. 23. This is a three-strata model, each strata being of infinite lateral extent.

The apparent conductivity of the three-strata situation is [9]

$$\sigma_a = \sigma_1 [1-R_v(z_1)] + \sigma_2 [R_v(z_1)-R_v(z_2)] + \sigma_3 [R_v(z_2)]$$

where σ_1 is the conductivity of the top layer; σ_2 is the conductivity of the middle layer; σ_3 is the conductivity of the lower layer; $R_v(z) = 1/(1+4z^2)^{1/2}$; z_1 is the thickness of the top layer; z_2 is the thickness of the middle layer. If $\sigma_2 = 0$ (i.e., assuming a very low conductivity media such as air) and $\sigma_1 = \sigma_3 = \sigma$, then

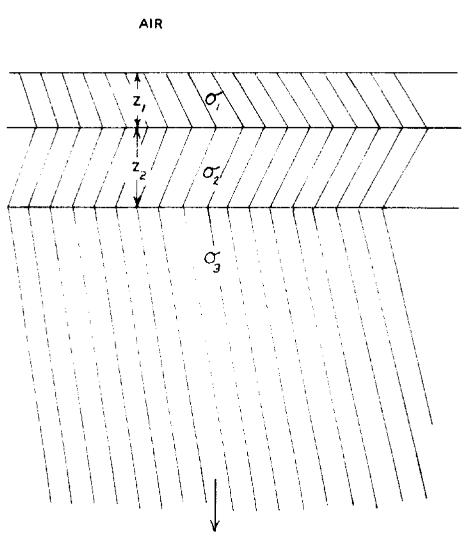


Fig. 23. Diagram of model used in layered model of soil.

TABLE 2

Calculated anomalies in conductivity resulting from air layers of two feet thickness at different depths

Depth of air layer	Decrease from σ (%)
1	10
3	12
6	11
11	6

$$\sigma_a = \sigma \{1 - [R_v(z_1) - R_v(z_2)]\}$$

The percentage change (from the σ value) is

$$\frac{\sigma_a - \sigma}{\sigma} \times 100 = -[R_v(z_1) - R_v(z_2)] \times 100$$

The anomalies given by this simple model due to an air layer of two feet thickness are given in Table 2. The values at 1 and 3 feet are close to that observed for the empty plastic drums. However, the values at 6 and 11 feet are certainly much larger than those observed experimentally.

It must be realized that these values are for a layer of infinite lateral extent. Hence, many of the field lines from the transmitter have a chance to interact with the "anomaly" and produce a reasonable-sized magnetic moment. In the case of the small single sphere discussed in the theory section, only a small number of the field lines interact with the sphere and hence the magnetic moment produced is quite small.

The great discrepancy between the theoretical and experimental value of observed apparent conductivity for the 40 gallon plastic drums at shallow bury still is completely unclear. The effect should be investigated further to ascertain if the VLF-EM method does indeed ferret out voids.

Conclusions

The results of this study strongly indicate that a commercially available VLF-EM method will detect steel drums in almost any dump site distribution imaginable. The meter will peg when in the immediate vicinity of large quantities of buried metal, hence it will be impossible to determine quantitatively how much metal is present. The lateral delineation of the site will be determined by the extent of the lobes of the pattern of the edge drums, but for practical purposes, the delineation should be sufficient for large and small dump sites. Isolated steel drums can also be delineated to depths of approximately 6 feet.

Plastic drums will be essentially impossible to locate, unless there is an extremely large number of them with strongly conducting ingredients. An interesting finding is that air voids equivalent in volume to 40 gallon containers can be detected in a sandy soil at shallow depth of bury (1—3 ft).

The above very positive findings for location of steel drums using the VLF-EM method must be tempered, however, by two practical considerations. These are the effects of nonhomogeneous and fine grained soils (silts and clays), and the effect of high background noise areas. Each of these considerations are currently under investigation, their effects being unknown at the moment.

Comparison of the VLF-EM method should be made with the metal detector (MD), which is discussed in a companion paper [13] (the same site was used for both techniques). The VLF-EM technique is considerably more sensitive, especially in what is called "lateral scan sensitivity," i.e., the metal drums can be detected much better with the VLF-EM technique if one is displaced laterally from the center line directly over the drums. Also the shallow bury plastic drum could be detected with the VLF-EM while not with the MD.

However, the relative costs (~$8,000 for VLF-EM and ~$500 for MD) and adequate sensitivity make MD undoubtedly the first choice technique for almost all suspected dump sites.

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