Journal of Hazardous Materials, 7 (1982) 1—17
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

BURIED CONTAINER DETECTION USING GROUND-PROBING RADAR

JOHN J. BOWDERS, Jr., ROBERT M. KOERNER

Department of Civil Engineering, Drexel University, Philadelphia, Pennsylvania 19104 (U.S.A.)

and ARTHUR E. LORD, Jr.

Department of Physics, Drexel University, Philadelphia, Pennsylvania 19104 (U.S.A.)

(Received March 10, 1982; accepted April 21, 1982)

Summary

This paper contains the results of a continuing study to assess the capabilities and limitations of a ground-penetrating radar (GPR) system to detect and locate various subsurface anomalies — in this case, various size containers, both metal and non-metalic.This containers are located in various configurations at different burial depths. The site consisted of a relatively uniform sandy soil of low water content and represented nearly ideal conditions for the tests. The results show that steel drums are the most easily detected and located. Plastic drums, if empty, cannot be located; however, if liquid-filled they can be detected. Closely spaced drums cannot be resolved to determine the exact number of drums. Accurate depth predictions were made to all drums located using the GPR system.

I. Introduction

There are estimated to be 30000 to 50000 existing dump sites in the U.S.A. which contain various amounts and types of hazardous materials. Furthermore, many new sites are being discovered on a regular basis. One of the first pieces of information needed in the clean-up process is the physical extent of the dump size and resulting polluted area. This is very difficult to do when the hazardous materials are buried beneath the ground surface. There are a number of geophysical or nondestructive testing (NDT) techniques which can be used in the detection process and these have been elaborated on previously [1]. At a large number of the dump sites, the hazardous materials are placed in drums (steel or plastic) and buried. It is at such sites that ground-penetrating radar (GPR), an NDT technique, shows significant promise. Although several investigations of this type (using GPR) showing various degrees of success have been reported [2, 3, 4], there have been no studies to determine the accuracy ("ground truth") and limitations of such a system. The study to be described herein was undertaken to help satisfy this obvious need.

II. GPR overview

A considerable amount of subsurface probing at shallow depths has been based on the transmitting of pulsed RF waves in the frequency range of 1 MHz to 900 MHz. The transmitted pulse travels through the soil until it infringes upon an object or material with dissimilar electrical characteristics. Part of it is then reflected back to the ground surface where it is received and the time of travel is measured. The depth "d" to the interface is then calculated from $d=(vt)/2$ where "v" is the wave velocity (which is equal to $c/\sqrt{\epsilon_r}$, where "c" is velocity of light and "ϵ_r" is the relative dielectric constant of the material in which the wave is propagating) and "t" is the pulse travel time. The relative dielectric constant of numerous soils at different water contents has been evaluated by many investigators, including Okrasinski, et al. [5]. As shown in Table 1, this technique has been studied by many investigators.

TABLE 1

Details of ground-probing radar methods

Investigator(s)	Approx. freq. range (MHz)	Maximum depth (m)	Major application area
Cook [6, 7]	1—100	225	Locating faults, walls, holes
Rosetta [8]	100—200	15	Locating faults, caverns, water, utilities
Morey [9]	100—200	15	Locating faults, caverns, water, utilities
Dolphin et al. [10]	15—50	40	Locating rock cavities
Unterberger [11]	230	500	Salt thickness measurement
Harrison [12]	35	2000	Determining ice thickness
Rubin et al. [13]	100—200	10	Detecting subway tunnels
Rubin and Fowler [14]	100—200	15	Drilling guidance, subway tunnel monitoring, coal thickness
Benson and Glaccum [15, 16]	100—200	10	General subsurface probing, locate and follow pollutants in ground, detection of buried containers of industrial wastes
Sandness et al. [17]	100—200	10	General subsurface probing as described above
Alongi [18]	1000	3	Locating mines, pavement thickness, shallow voids, pipelines
Moffat and Puskar [19]	6000	3	Locating faults, joints, cavities, pipelines

Additional systems of a similar type as just described are also available at a higher frequency range, i.e., above 1 GHz. These are also listed in Table 1. They could, however, better be classified as microwave methods. The advantage of the higher frequency range is that a shorter wavelength gives greater definition to the subsurface object. However, the attenuation of the waves is higher, resulting in lower penetration depths [20].

The authors have adapted the pulsed radio frequency method generally called ground-probing radar (GPR) to the hazardous material/buried container problem. Using a commercially available system which transmits RF pulses in the 80—900 MHz frequency range and presenting the received signal in a real time printout, a visual subsurface profile is developed. Figure 1a illustrates an example of the GPR profile data and Figure 1b shows photographs of the

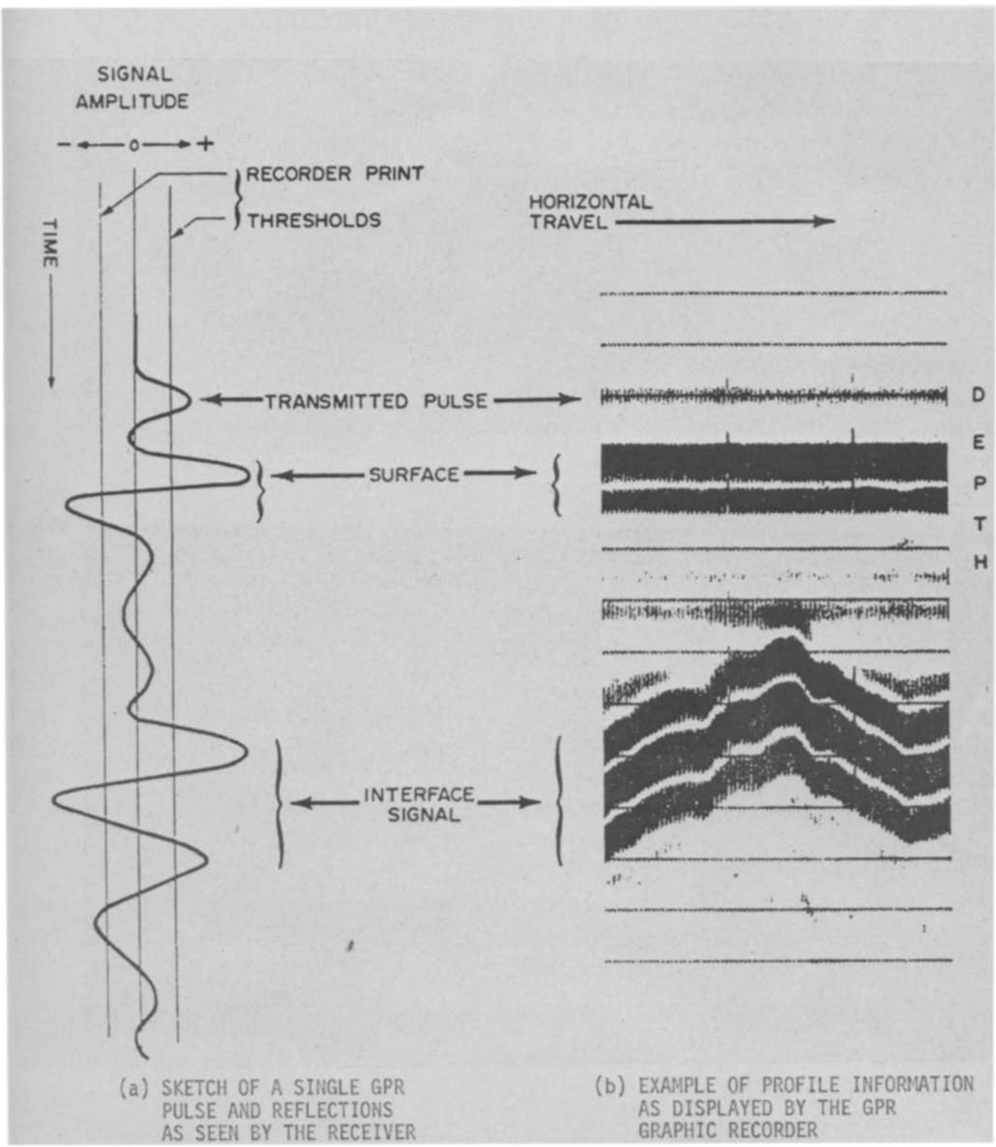
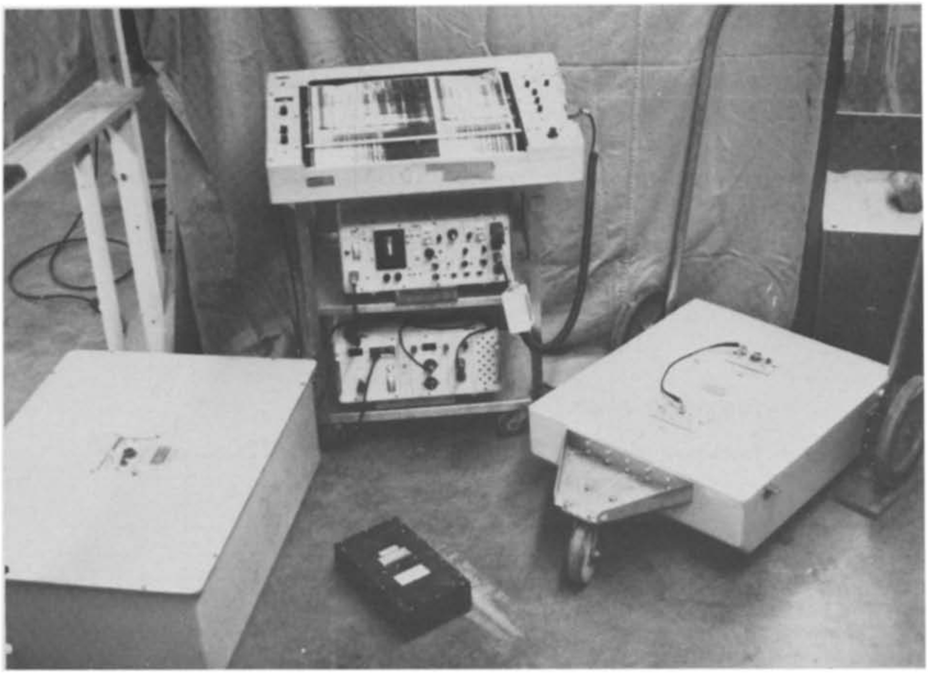


Fig. 1a. Example of GPR profile data, after ref. 21.



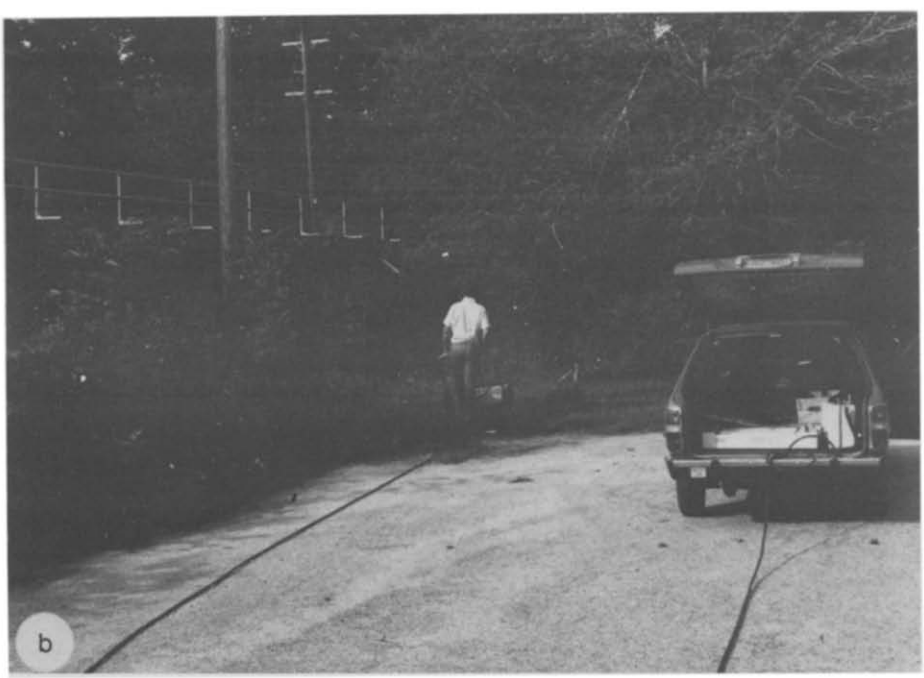


Fig. 1b. Photographs of GPR equipment.

equipment. Strong return signals appear as the black signals, while weak (or no) signals appear as white. Gray areas require appropriate interpretation. The particular system used in this study transmitted short (10^{-8} s long) pulses of carrier frequency damped to about 1—1/2 cycles at both 80 MHz and 120 MHz into the ground. Reflected patterns were recorded in real time printout as previously discussed. Maximum depth of penetration at the site under investigation was 11 ft (3.5 m). The goal of the study was to determine the detectability and limit of resolution of the buried containers at an ideal site, with regard to the following variables:

- container material (steel or plastic)
- container size (2 gal to 55 gal)
- container burial depth (1 to 11 ft below the surface)
- container orientation (0°, 45°, 90° with respect to the ground surface).

III. Site overview

The site where the containers were buried was in an abandoned sand quarry which was left in a level condition free of all vegetation and miscellaneous construction debris (Fig. 2). This site, near Gibbsboro, New Jersey, contained no pipelines, cables or overhead wires within 1000 ft of the study area. Thus, background noise from man-made objects was minimal.

Disturbed and undisturbed soil samples indicated that the site consisted of a very uniform poorly graded sand (specific gravity of 2.65, effective size of 0.18 mm, and coefficient of uniformity of 3.4). Its average in-situ density is 101 PCF (1.62 g/cm^3), the porosity is 0.40 and the relative density is 73%. For the purpose of this study, it is important to note that the in-situ water content is only 2%, which corresponds to a degree of saturation of 8%, i.e., the sand is almost dry.

The water table at the site was estimated to be 20 ft (6 m) below the ground surface and the sand, with essentially no capillary zone, proved to be nearly ideal for tests.

The containers were placed in hand- and equipment-excavated holes varying from 1 to 14 ft (0.3 to 4.3 m) in depth. The container burial configurations as shown in Fig. 3 were as follows:

- Four steel containers (2, 5, 30, 55 gal) buried at constant depths of 3.5 ft (1 m), i.e., 1 m of soil cover.
- Four 30 gal steel containers buried at 1, 3, 6, and 11 ft (0.3, 1, 1.8, 3.4 m) depths.
- Four 40 gal plastic containers (empty) buried at 1, 3, 6, and 11 ft depths.
- Two 40 gal plastic containers buried at 2 ft (0.6 m) depth, one filled with fresh water, the other with salt water.
- Three 30 gal steel containers buried at 3 ft (1 m) depth, but at various orientations, i.e., 0°, 45°, 90° to the ground surface.
- Four 55 gal steel containers buried at 4.5 ft (1.4 m) depth in two groups, one by itself, the other three side by side.

- A random burial site approximately 12 × 12 × 5 ft. deep, which contained 10 steel drums and 1 plastic drum in a random arrangement. (This pattern to be known as the "trash dump".)

All the patterns were separated by sufficient distance so that interaction between them was relatively unlikely.

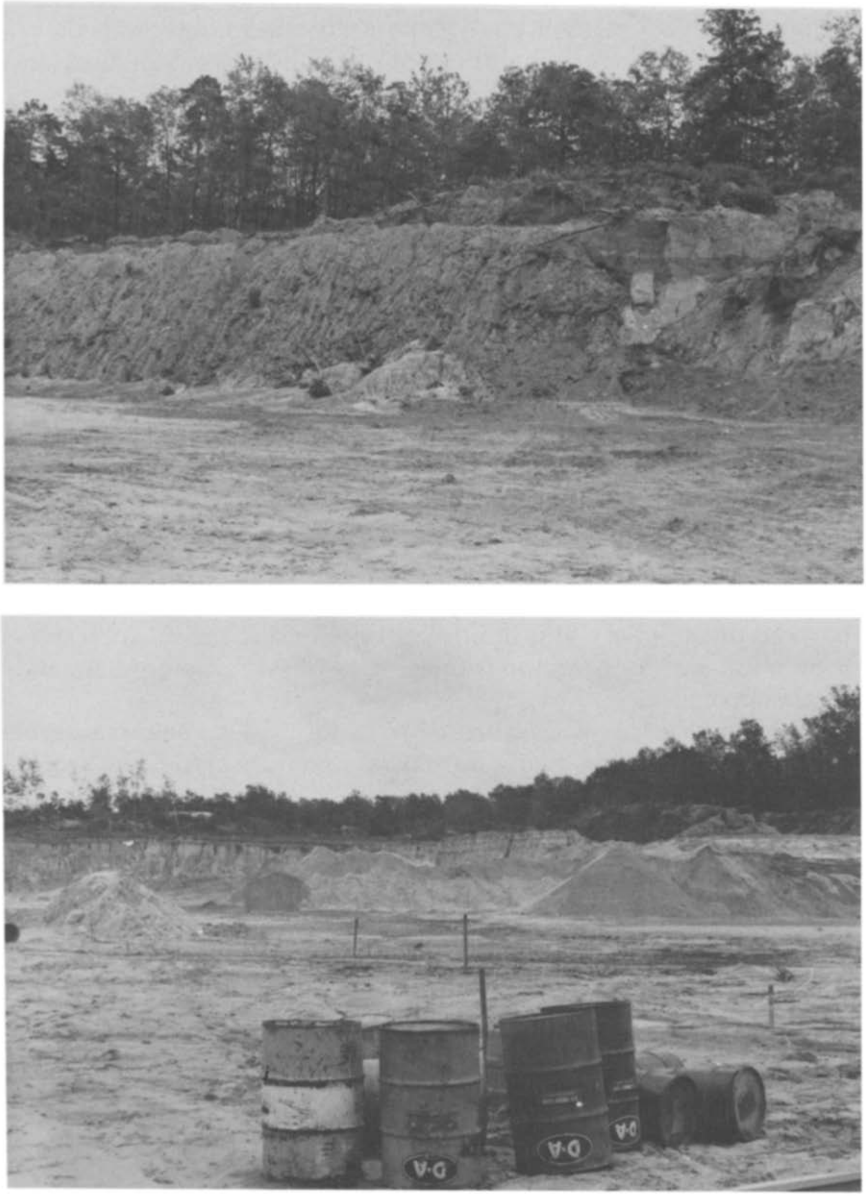


Fig. 2. Photographs of Gibbsboro site where numerous metal and plastic containers were buried at known locations and depths.

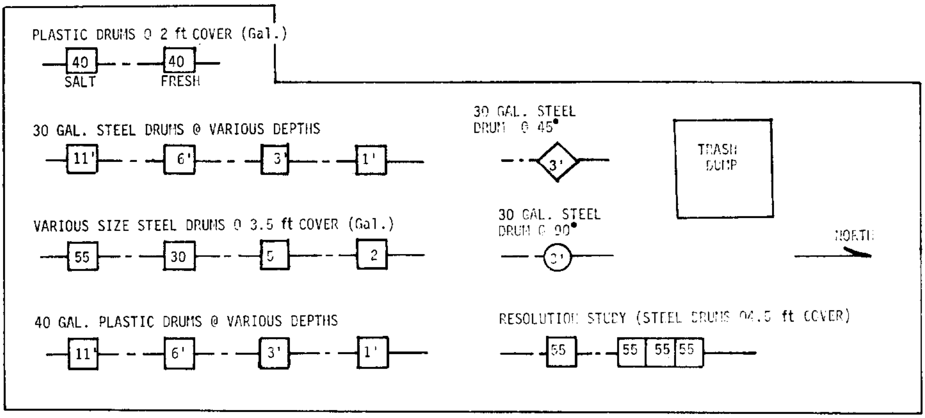


Fig. 3. Plan of buried container patterns at the Gibbsboro site (overall site dimensions are approximately 100 × 200 ft).

IV. Results

The real time printouts of each container burial configuration are shown in Figs. 4 through 10. Each are discussed in this section. It should be noted that no signal enhancement, other than what is built into the system, has been applied to these results.

The first pattern (Fig. 4) results from a series of various size steel drums buried beneath 3.5 ft (1 m) of soil. The drums include a 55 gal, 30 gal, 5 gal and 2 gal size from left to right on the figure. Each drum is characterized by a parabolic reflection which is the typical reflection from a buried cylindrical object when the antenna is moved perpendicular to the axis of the drum. The vertical scale adjacent to the printout reveals that the GPR accurately predicted the depths to the drums. This survey used a 120 MHz antenna.

The next pattern (Fig. 5) to be surveyed consists of 30 gal steel drums buried at various depths including 11, 6, 3 and 1 ft (3.4, 1.8, 1.0, 0.3 m) from left to right on the figure. All the drums are located and characterized by their parabolic reflection patterns. The drums at 11 and 6 ft (3.4, 1.8 m) (a and b, respectively) were surveyed with an 80 MHz antenna while those at 3 and 1 ft (1.0, 0.3 m) (c and d, respectively) were surveyed with a 120 MHz antenna. The reason for this frequency change being that the higher frequency (120 MHz) was not able to penetrate to the depth of the drums at 6 and 11 ft (1.8, 3.4 m) and the lower frequency (80 MHz) antenna is not capable of detecting near surface reflectors due to direct transmission of the signal from the transmitter to the receiver. This latter limitation results in a blind area as can be seen in Fig. 5 at drums a and b for a depth of approximately 5 ft (1.5 m). Again the vertical scale adjacent to the printout shows that the GPR accurately predicted the depths to the drums.

A series of empty heavy-duty plastic drums with a 40 gal capacity were buried at various depths (11, 6, 3 and 1 ft) (3.4, 1.8, 1.0, 0.3 m) as shown in

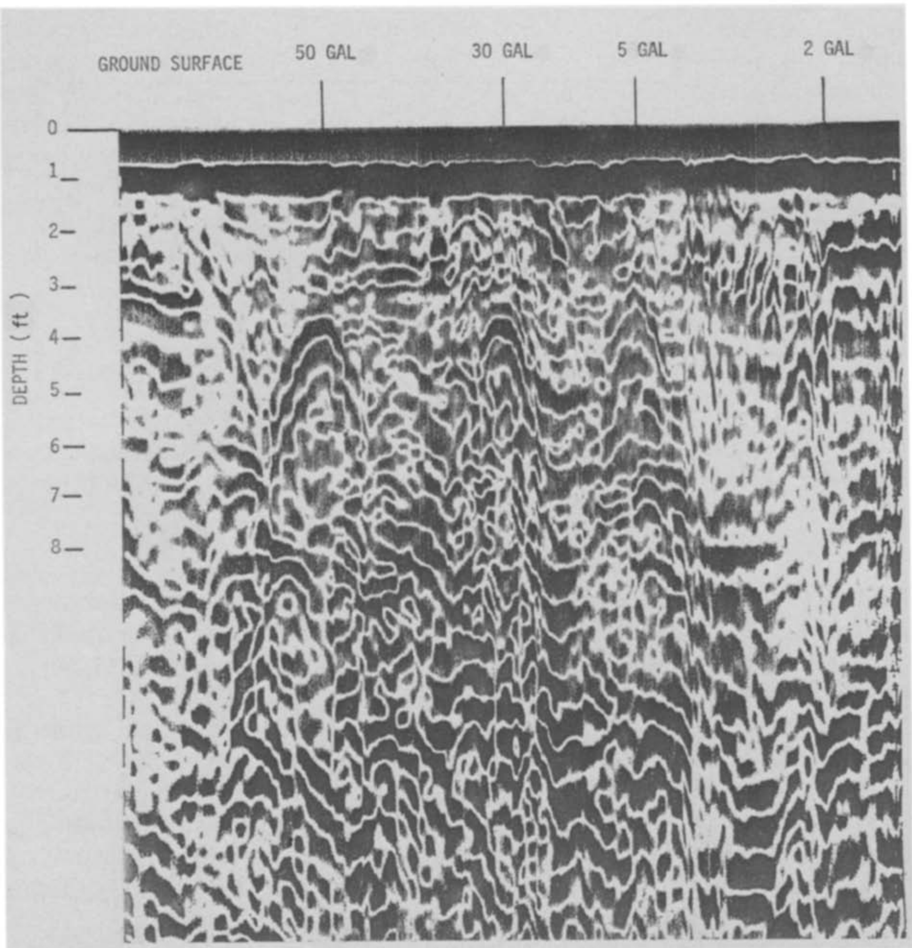


Fig. 4. GPR printout showing various size steel drums with 3.5 ft (1.1 m) of soil cover.

Fig. 6 from left to right, respectively. Since plastic is essentially transparent to the radar waves, there is an absence of reflections from the drums. Laboratory experiments have shown that small dielectric constant changes can be observed with the GPR equipment [22], however, for all practical purposes, the return signal from the plastic drums is too weak to be distinguished. Careful scrutiny reveals a faint signal from the drum buried at 3 ft (1.0 m); however, this was the only exception to the survey in which both 120 MHz (shown) and 80 MHz antennas were used. The drum at 1.0 ft (0.3 m) would probably have been detected; however, it was masked in the direct transmission of the signal from the transmitter to the receiver.

Since the plastic drums are essentially transparent to the radar signal, it may be possible to detect the drums due to the reflective nature of their contents. To examine this possibility, two plastic drums (identical to those previously discussed) were buried 2 ft (0.6 m) beneath the surface. One drum was filled with water and salt in a ratio of 1 lb salt/4 gal water. This simulated a highly ionic and conductive waste. The printout from this survey is shown in Fig. 7. Both drums are clearly evident. The fresh water drum (B) is slightly more pronounced due to the better reflecting ability (lower conductivity) of the fresh water as compared to the salt water drum.

The following pattern to be discussed consists of 30 gal steel drums placed

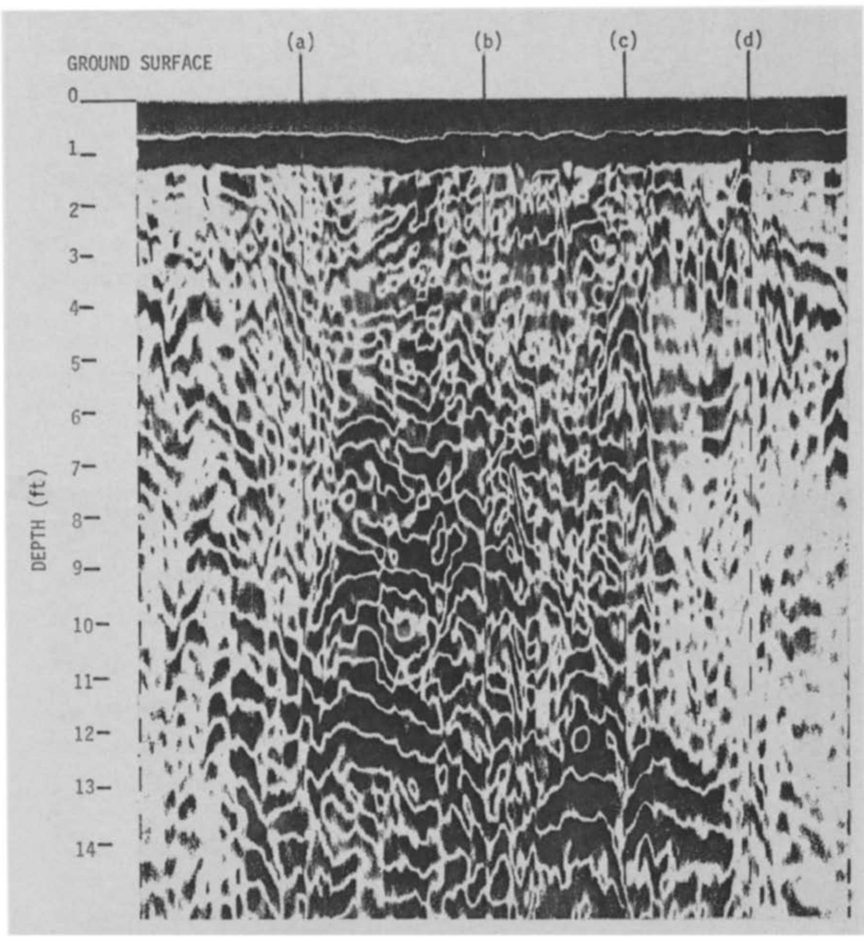


Fig. 5. GPR printout showing survey of 30 gal steel drums (empty) at various depths:

Location	Depth (ft. (m))	Antenna (MHz)
(a)	11 (3.4)	80
(b)	6 (1.8)	80
(c)	3 (1.0)	120
(d)	1 (0.3)	120

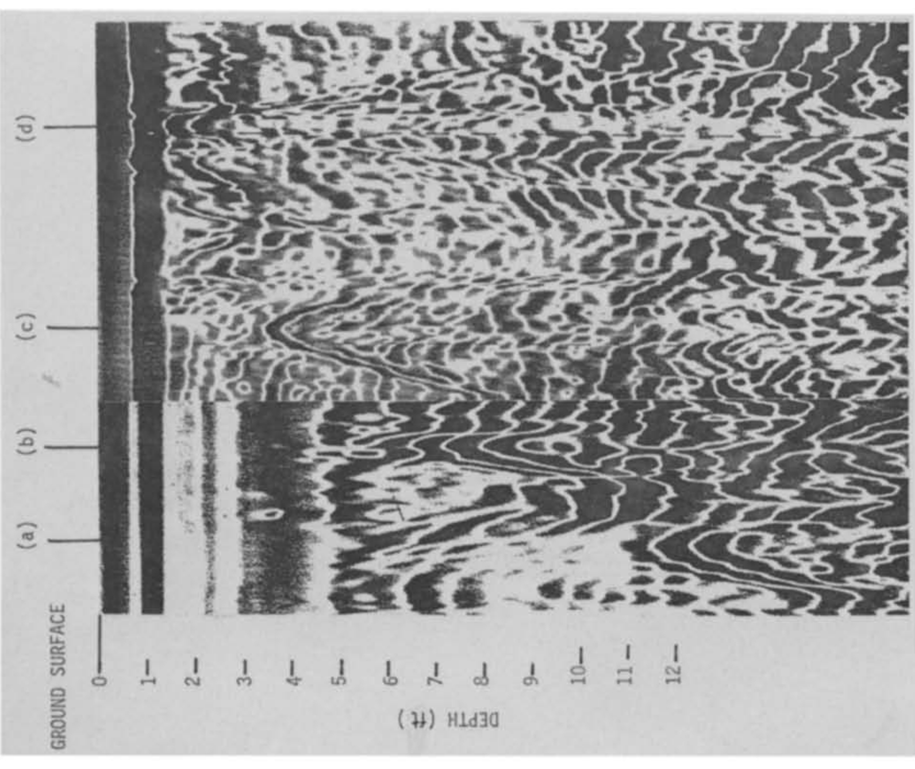

GROUND SURFACE
(a)
(b)
(c)
(d)
DEPTH (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 6.

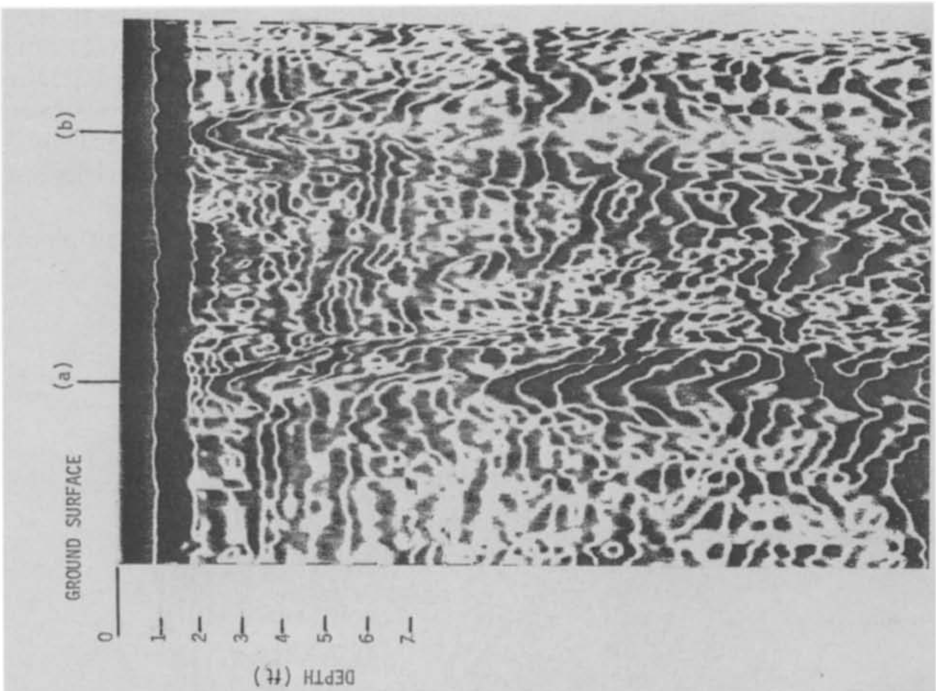

GROUND SURFACE
(a)
(b)
DEPTH (ft)
0
1
2
3
4
5
6
7

Fig. 7.

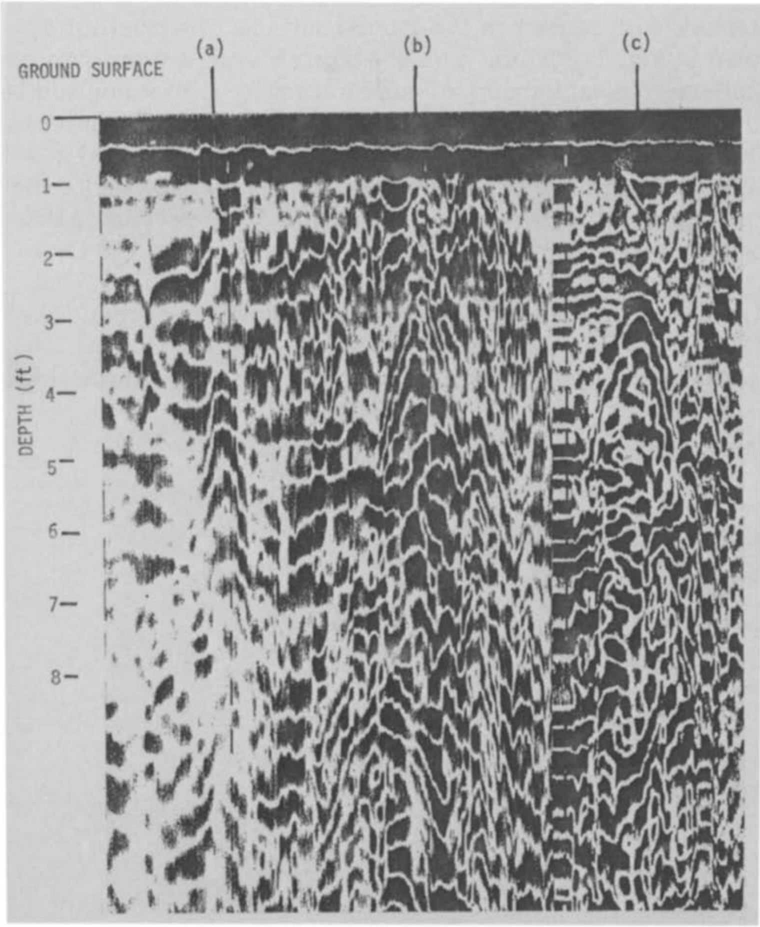


Fig. 8. GPR printout showing survey of 30 gal steel drums at various orientations buried 3 ft (1.0 m) beneath the surface.
(a) Drum standing on end.
(b) Drum at 45° angle to ground surface.
(c) Drum buried horizontal to ground surface.

Fig. 6. GPR printout showing survey of 40 gal plastic drums (empty) at various depths. All drums surveyed with 120 MHz antenna, burial locations and depths same as Fig. 5.

Fig. 7. GPR printout showing survey of 40 gal plastic drums buried 2 ft (0.6 m) beneath the surface (120 MHz).
(a) Salt water filled.
(b) Fresh water filled.

at various orientations with respect to the ground surface. The printout of the results is shown in Fig. 8. Position a on the figure reveals a drum standing on its end. The reflection is no longer parabolic but rather abrupt and similar to passing over a flat steel plate. Signals are reflected only while the antenna is directly above the drum. Position b on the figure shows a drum buried at a 45° angle to the ground surface. Although the reflection is parabolic, due to the angle of the return signals, the reflection is not as refined or obvious as that of the drum in a horizontal orientation as shown in position c on the figure.

To examine the resolution abilities of the GPR, a pattern of four 55 gal steel drums was arranged with three drums adjacent to one another and the fourth drum 12 ft (3.6 m) away, all buried at a depth of 4.5 ft (1.4 m). The printout for this survey is shown in Fig. 9. The separation between the single

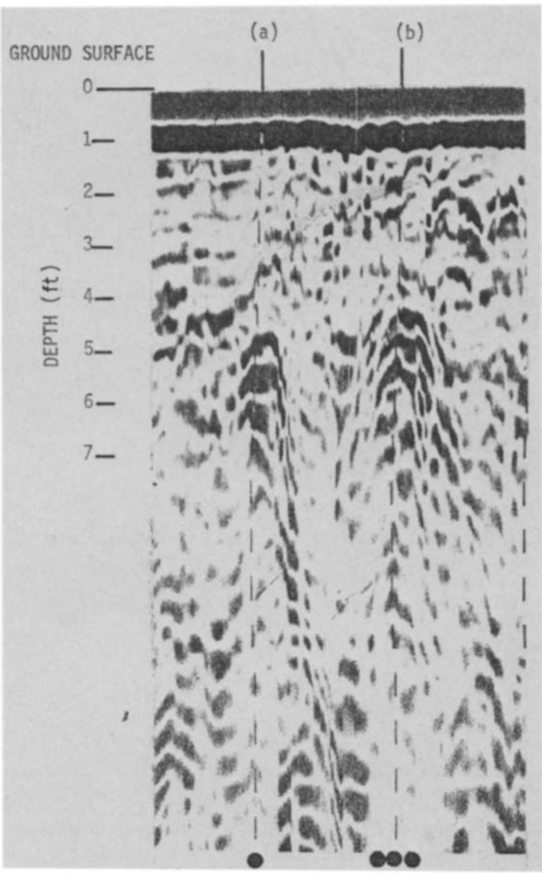


Fig. 9. GPR printout showing survey of resolution study of 55 gal steel drums, buried 4.5 ft (1.4 m) beneath the surface.
(a) Single drum.
(b) Three drums adjacent to each other.

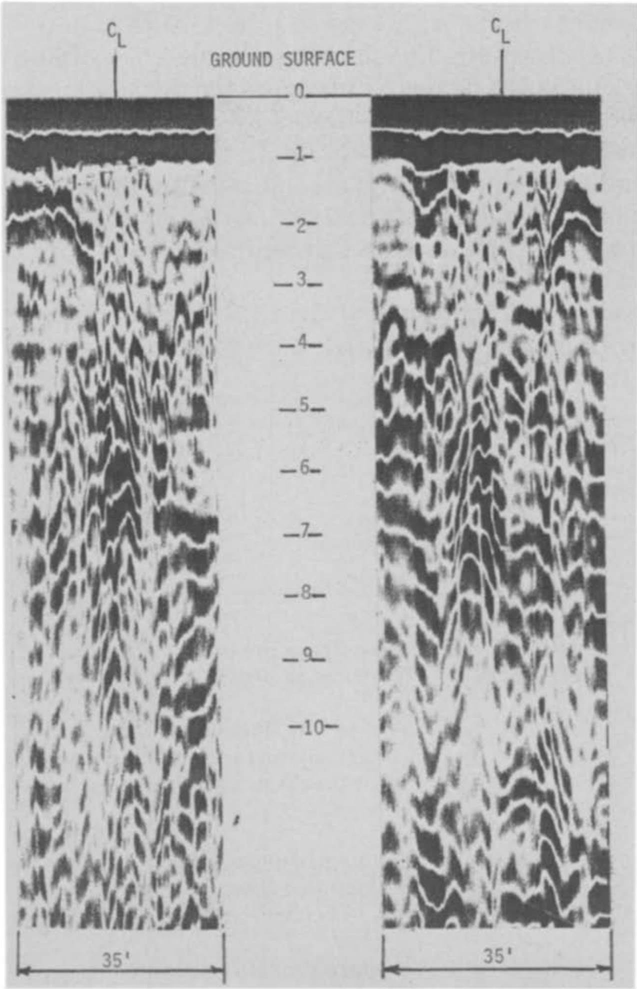


Fig. 10. GPR printout showing two surveys over the trash dump (120 MHz).

and group of three drums is obvious, however, it is difficult to differentiate between the three adjacent drums. The double peaks at the three drums do indicate a larger reflecting object than the single parabolic peak at the single drum. The 120 MHz frequency was used to locate these drums and comparison with the adjacent depth scale shows that the depth was accurately predicted.

The final pattern to be examined was an excavation approximately 12 × 12 ft (3.6 × 3.6 m) by 7 ft (2 m) deep. Placed in the excavation were ten steel drums and one plastic drum in a random arrangement. This was covered by approximately 5 ft (1.5 m) of soil. The pattern simulates on a small scale a typical waste dump site. The printouts from two surveys over the site are shown in Fig. 10. The center of the dump is indicated in each printout. Both surveys show a heavy black reflection at the center of the dump, however, it is not possible to resolve the individual drums within the site itself. Note in both surveys that the limits of the excavation, i.e., the trench boundaries, can be approximated. The survey on the left of the figure shows the distinct location of the left-most boundary of the trench. It is indicated by the abrupt ending of the black horizontal band at the 2 ft (0.6 m) depth. In the survey on the right of the figure, both limits of the excavation are indicated by the abrupt end and start of the black horizontal band at the 2 ft (0.6 m) depth. The survey was conducted using a 120 MHz antenna and resulted in good approximation of the depth to the buried drums.

To provide a concise summary of the results of the GPR surveys of each drum burial configuration, Table 2 has been added. Each pattern is listed and results are given followed by a brief comment.

TABLE 2

Summary of results from all drum burial patterns

Pattern	Resolution of return signal	Comments
Steel drums		
Various depths (30 gal)	Excellent	Very strong parabolic reflections
Various sizes (55, 30, 5, 2 gal at 3.5 ft cover)	Excellent	Very strong parabolic reflections
Various orientations (at 3 ft cover)	Excellent	Best results when drum is horizontal and antenna is moved perpendicular to the drum axis
Plastic drums		
Various depths (40 gal—empty)	Minimal	Only one drum was barely discernable in one of several surveys
Various contents (2 ft cover)		
salt water	Good	Average strength reflection
fresh water	Good	Strong parabolic reflection
Resolution		
55 gal steel drum at 4.5 ft cover	Good	Could not resolve three adjacent drums
Trash dump	Minimal	Could not resolve individual drums, located boundaries of the excavation

V. Conclusions

Several major conclusions can be drawn from this study using GPR to detect buried containers:

- For steel drums, the maximum detection depth is a function of drum size (a 30 gal steel drum can be detected at a depth of 11 ft (3.4 m)).

- Steel drums at various orientations (other than horizontal) are detectable; however, the interpretation of the results is difficult.
- Adjacent or closely spaced drums cannot be resolved, making it difficult to determine the exact number of drums in a dump site; however, in some instances the boundaries of the excavation can be identified thereby providing an indication of the extent of the problem.

Although the GPR performance was very good overall, there are several drawbacks that should be noted. GPR has very poor lateral scan sensitivity, and it can only detect drums that are passed over by the antenna. Drums adjacent to the path of the antenna are out of the penetrating signals' path and can be easily missed, e.g., see Fig. 11. Also, plastic drums are not nearly as detectable as steel drums, nor are drums located in salt water versus fresh water.

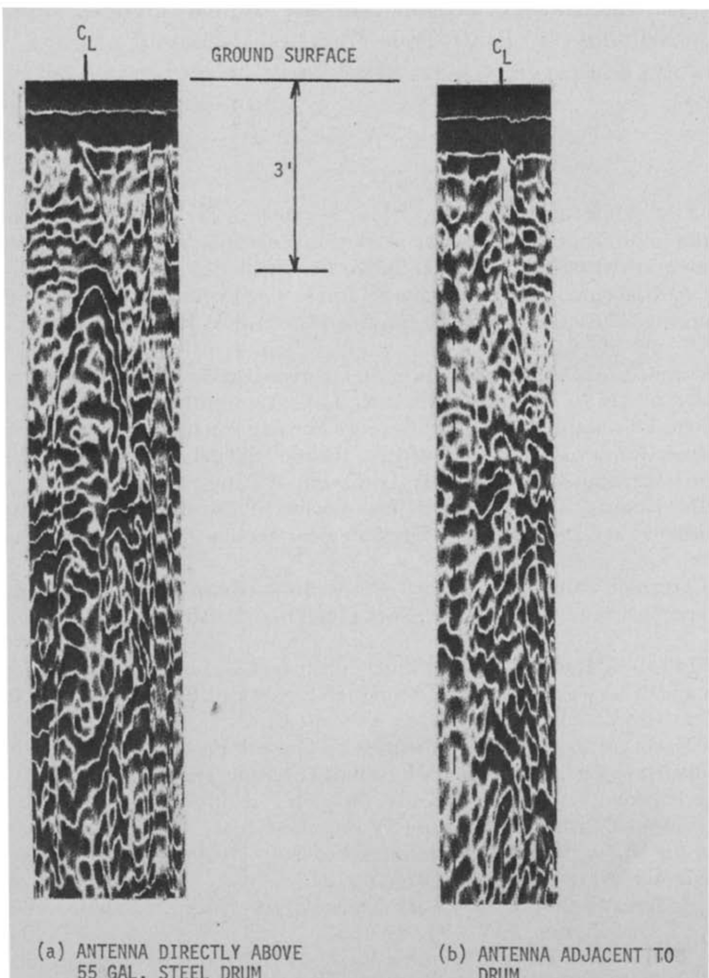


Fig. 11. GPR printout showing spatial sensitivity of the system, 120 MHz antenna.

Finally, GPR is very sensitive to soil conditions. This study was conducted under near ideal conditions in relatively dry sandy soil. Studies using GPR in clays and silts have met with less success [21].

The next phase of this project is to use the same GPR system on similar buried container patterns in saturated fine-grained soils (silts and clays) to see if the conclusions presented herein hold or if they require modifications.

Acknowledgements

The authors would like to thank Mr. Bernie Sharpe and Mr. Stephen Sahns for allowing us access to the site and providing equipment and logistical support. Their help was indispensable. Thanks are also due to EPA Municipal/ Environmental Research Laboratory, Edison, New Jersey, for financial support under Cooperative Agreement No. R-804763. The encouragement of our Project Officer, Dr. John E. Brugger was, as usual, most helpful.

References

1 A.E. Lord, Jr., S.D. Tyagi and R.M. Koerner, "Non-Destructive Testing (NDT) Methods Applied to Environmental Problems Involving Hazardous Material Spills," Proceedings, 1980 Conf. on Control of Hazardous Material Spills, Louisville, KY, pp. 174—179.

2 E.C. Benson and R.A. Glaccum, "Site Assessment: Improving Confidence Levels with Surface Remote Sensing", Proceedings, 1980 Conf. on Control of Hazardous Material Spills, Louisville, KY, pp. 59—65.

3 W.M. Leis and K.A. Sheedy, "Detailed Location of Inactive Disposal Sites", Proceedings, 1980 Conf. on Control of Hazardous Material Spills, Louisville, KY, pp. 116—118.

4 H.J. Yaffe, N.L. Cichowicz and P.J. Stoller, "Remote Sensing for Investigating Buried Drums and Subsurface Contamination at Coventry, Rhode Island", Proceedings, 1980 Conf. on Control of Hazardous Material Spills, Louisville, KY, pp. 239—249.

5 T.A. Okrasinski, R.M. Koerner and A.E. Lord, Jr., "Dielectric Constant Determination of Soils at L-Band Microwave Frequencies", Geotechnical Testing Journal, ASTM, 1 (1979) 134—140.

6 J.C. Cook, "Seeing Through Rock with Radar", Proceedings of the North American Rapid Excavation and Tunneling Conference, Port City Press, Baltimore, 1972, pp. 89—101.

7 J.C. Cook, "Ground Probing Radar", Proceedings, Subsurface Exploration for Underground Excavation and Heavy Construction, American Society of Civil Engineers, New York, 1974, pp. 172—194.

8 J.V. Rosetta, Jr., "Detection of Subsurface Cavities by Ground Probing Radar", Symp. on Detection of Subsurface Cavities by Surface Remote Sensing Techniques, U.S. Army Waterways Experiment Station, Vicksburg, MS, 1977, 120—127.

9 R.M. Morey, "Continuous Subsurface Profiling by Impulse Radar", Proceedings, Subsurface Exploration for Underground Excavation and Heavy Construction, American Society of Civil Engineers, New York, NY, 1974, pp. 213—232.

10 L.T. Dolphin, R.L. Bollen and G.N. Oetzel, "An Underground Electromagnetic Sounder Experiment", Geophysics, 39 (1974) 49—55.

11 R.R. Unterberger, "Overview of Electromagnetic Methods in Geophysics and Application of Radar to Detection of Cavities in Salt", Symposium on Detection of Subsurface Cavities by Surface Remote Sensing Techniques, U.S. Army Waterways Experiment Station, Vicksburg, MS, 1977, p. 119.

12 D.H. Harrison, "Reconstruction of Subglacial Relief from Radio Echo Sounding Records", Geophysics, 35 (1970) 1099—1115.
13 L.A. Rubin, J.N. Griffin and W.L. Still, "Subsurface Site Investigation by Electromagnetic Radar, Phase I Report: Feasibility", Report NSF/RA-76-0187, ENSCO, Inc., Springfield, VA, March 1976.
14 L.A. Rubin and J.C. Fowler, "Ground-Probing Radar for Delineation of Rock Features", Engineering Geology, 12 (1978) 163—170.
15 R.C. Benson and R.A. Glaccum, "Remote Assessment of Pollutants in Soil and Ground-Water", Proceedings, 1979 Conference on Hazardous Materials Risk Assessment, Disposal and Management, Information Transfer, Inc., April 1979, Miami Beach, FL, pp. 188—194.
16 R.C. Benson and R.A. Glaccum, "Radar Surveys for Geotechnical Site Assessment", Proceedings, Conf. on Geophysical Methods in Geotechnical Engineering, Atlanta, Oct. 23—25, 1979, Preprint #3794.
17 G.A. Sandness, G.W. Dawson, T.J. Mathieu and J.L. Rising, "The Application of Geophysical Survey Techniques to Mapping of Wastes in Abandoned Landfills", Proceedings, 1979 Conference on Hazardous Materials Risk Assessment, Disposal and Management, Information Transfer, Inc., April 1979, Miami Beach, FL.
18 A.V. Alongi, "Pavement Thickness Measured, Voids Detected by Downward-Looking Radar in New York Test", Industrial Research News, (Fall, 1973) 36—39.
19 D.L. Moffat and R.J. Puskar, "A Subsurface Electromagnetic Pulse Radar", Geophysics, 41 (1976) 506—518.
20 A.E. Lord, Jr., R.M. Koerner and J.S. Reif, "Determination of Attenuation and Penetration Depth of Microwaves in Soil", Geotechnical Testing Journal, ASTM, 2 (1979) 77—83.
21 Geophysical Survey Systems, Inc., Hudson, New Hampshire, 03051, product literature.
22 J.J. Bowders, R.M. Koerner and A.E. Lord, Jr., "Sensitivity Determination of a Ground Probing Radar System", Geotechnical Testing Journal, ASTM, to be published in the September 1982 issue.
23 R.M. Koerner, A.E. Lord, Jr. and J.J. Bowders, "Utilization and Assessment of a Pulsed RF System to Monitor Subsurface Liquids", Proceedings, Conf. on Management of Uncontrolled Hazardous Waste Sites, HMRI, Washington, DC, October 28—30, 1981, pp. 165—170.