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Project Summary

Electrical Resistivity Technique to Assess the Integrity of Geomembrane Liners

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An electrical resistivity survey technique has been developed and tested for assessing the integrity of geomembrane liner systems installed in fluid impoundments. Development of the technique included two-dimensional computer modeling and three-dimensional physical model testing. A 0.4-ha (1-acre) geomembrane-lined surface impoundment was used for full-scale testing of the technique. Tests were conducted to detect and locate single and multiple leaks of different sizes. Results indicate that the technique can be used to detect and locate single and multiple leaks as small as 2.5 cm (1 in.) in diameter within 1.5 m (5 ft) of the leak.

Though no full-scale tests were conducted with soil fill over the liner, scale model tests on a simulated landfill indicated strongly that the technique could be used to survey geomembranes installed at landfills.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, 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

Detecting and locating leaks in geomembrane liner systems at hazardous waste disposal and storage facilities is necessary to the performance of the liner system. Southwest Research Institute has developed an electrical resistivity technique to detect and locate leaks in these liner systems. The technique takes advantage of the high electrical insulating properties of a liner compared with the fluid contained above the liner and the soil under the liner.

Geomembrane liners made from impervious plastics and rubbers exhibit high electrical resistance. When a liner is installed in a landfill or surface impoundment, it effectively acts as an electrical insulator between the materials contained in the facility and the surrounding earth. If the liner is physically punctured or separated, conductive fluid flows through the leak and establishes an electrical shunt through the liner. The low-resistance shunt forms an electrically detectable region that is the basis by which a leak may be detected and located.

The basic electrical resistivity technique for detecting and locating leaks in a geomembrane liner (Figure 1) uses a current source to inject current across the boundary of the liner. The liner has an *electrical leak path, as shown.* When a voltage is applied between the source and remote current return electrodes, current flows through the leak as shown in the figure. If a soil cover were present over the edges of the liner, current would also flow through this soil cover to the remote current return electrode bypassing the liner. Potentials measured on the surface are affected by the current distributions near the leak and can be used to locate the leak.

Computer and physical modeling studies were performed to validate the electrical resistivity liner survey technique. These studies provided an opportunity to analyze the current distribution and surface potentials resulting from various leak configurations. This information was needed to develop field survey equipment.

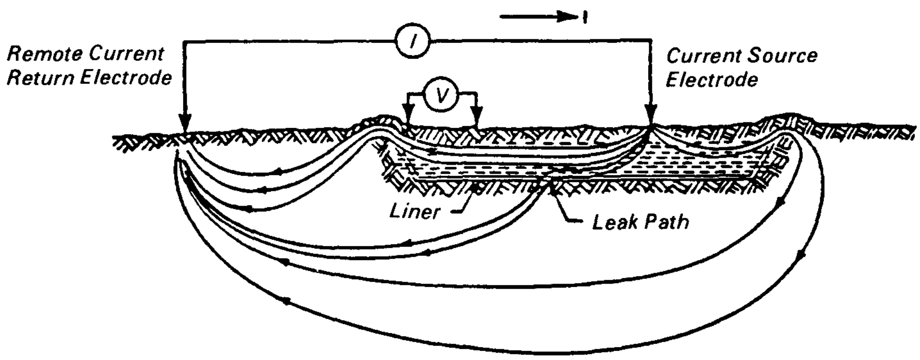

Figure 1. *Conceptual electrical resistivity testing technique applied to detect and locate leaks in a geomembrane liner system.*

Computer Modeling Studies

Model Design

Computer modeling studies with a two-dimensional resistive network were performed to predict the influence of an electrial current penetration through a geomembrane liner and associated surface potential voltages inside a landfill or fluid impoundment. The influences sought were the magnitude of the surface potentials at given locations for cases where fluid leaks or electrical current paths existed through the liner. The two-dimensional resistor network designed to simulate a liner was modeled using a general purpose curcuit simulation computer program called SPICE. This software allows simulation of circuits containing resistors, capacitors, inductors, and voltage and current sources. The resistivity of the fill inside the liner (either soil or fluid) and the earth surrounding the liner was modeled using a normalized resistance value of 1 ohm. The liner was characterized in the model by using parallel 1000-ohm resistors along the path of the liner (the solid line marked "liner" in Figure 2). To simulate a leak or conductive path through the line, one of the 1000-ohm resistors representing the liner was replaced by a 1-ohm resistor. As a result, the leak path has the same resistance as the earth. In effect, the liner is removed at that location.

Computer Results

Figure 2 illustrates the results of one of the computer-generated, two-dimensional analyses of a liner having a leak in the bottom. This figure represents a two-dimensional cross-section through the liner and surrounding earth. The outline of the liner has been sketched in the figure and is represented by the three-sided trapezoidal figure in the center of the plots. The equipotential lines in the figure are generated and plotted automatically by the computer program described earlier. The equipotential lines showing the voltage distribution patterns were computer generated. The current flow paths are at right angles to the equipotential lines and were sketched in by hand.

This figure shows that, as predicted, when a leak has penetrated the liner, current flow between electrodes located inside and outside the liner will follow two paths, namely, through the leak and over the buried edges of the liner. Note the nonsymmetry of the equipotential lines terminating on the surface of the facility above the liner. The voltage gradient is clearly steeper along the surface on the left side of the current injection electrode above the leak. This voltage gradient is due to more current flow in the direction of the leak.

Physical Scale Modeling Studies

After completion of the computer modeling studies, a three-dimensional physical scale model was designed and constructed. The objectives of using this model were to: (1) observe the surface voltage distribution patterns created by a fixed liner geometry, injection current location, fill material inside the liner, and leak configuration; (2) test the system instrumentation and assess its suitability for full-scale testing; and (3) determine the accuracy of the technique in locating a leak.

Model Design

The model is designed to study how accurately the technique could locate a leak in the liner. Outside dimensions were established at 3.05 m (10 ft) on each side, for a total lined floor area of 9.3 m² (100 ft²). Maximum depth was established at 1 ft, allowing variation of water depth during the experiments. A black polyethylene sheet 6 mils thick was selected as the geomembrane. A sand bed was placed below the liner. The moisture level of the sand was typical of that of the surrounding soil in the area.

Results

Surface potential measurements were made with 0.1 m (0.33 ft) of water in the model. Figure 3 presents a polar coordi-

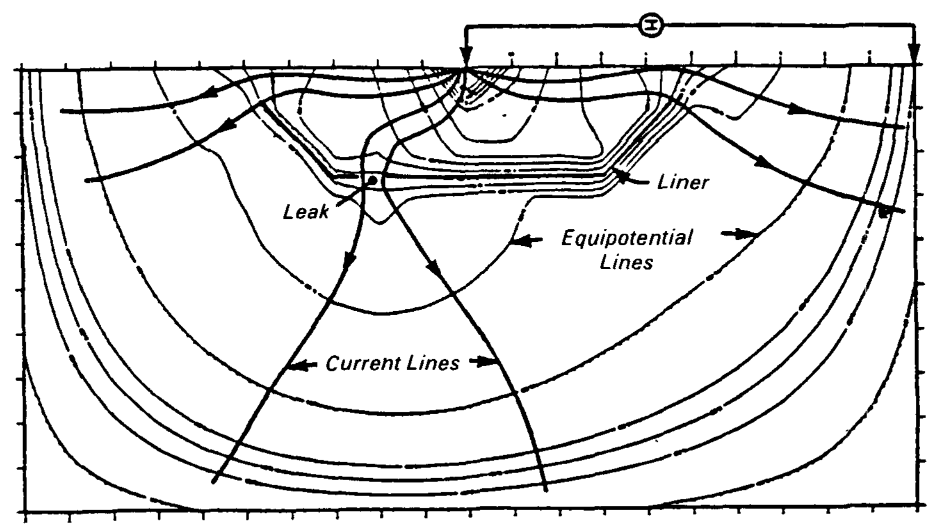

Figure 2. *Two-dimensional computer model of a liner with a leak. Equipotential lines at the top are nonsymmetrical, indicating the presence of a leak.*

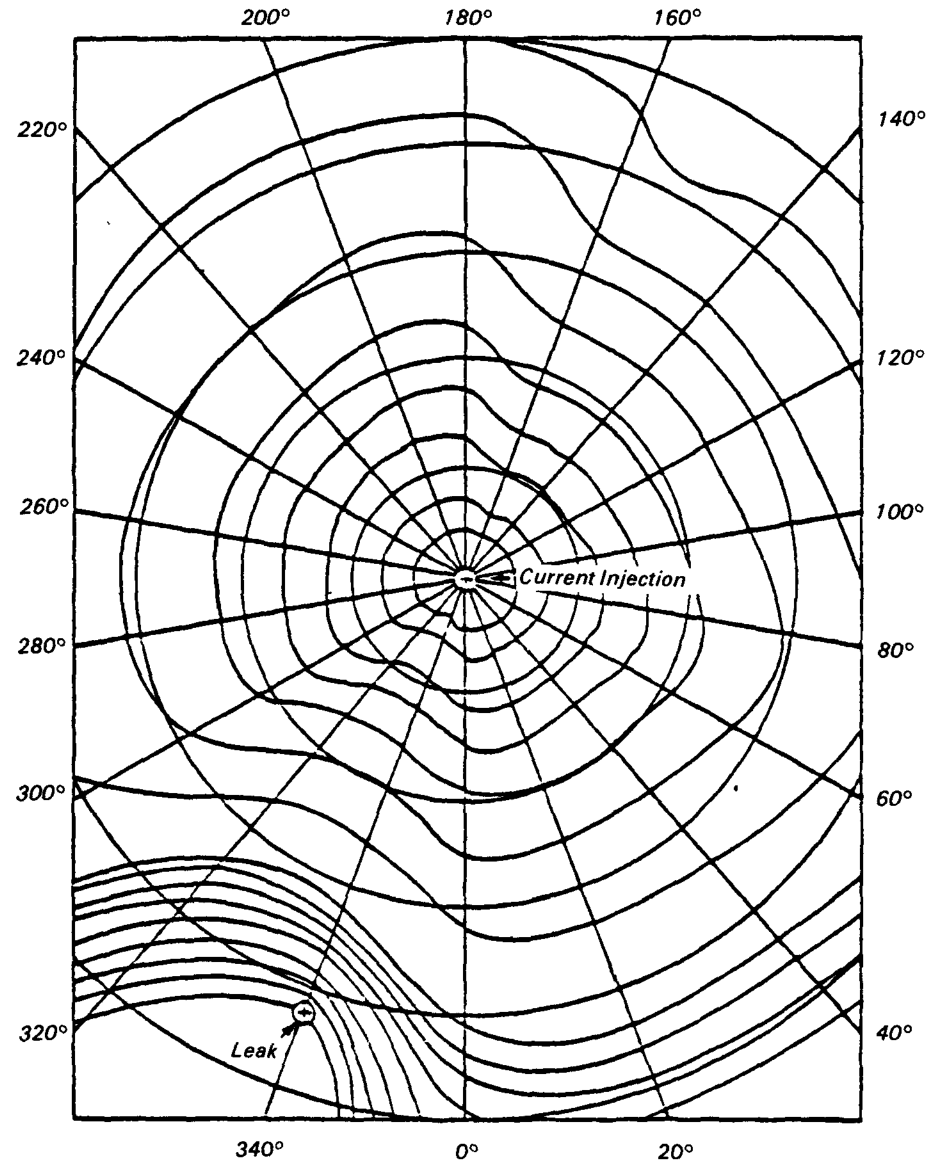

Figure 3. *Equipotential plot of voltages on the surface of the water with a single leak.*

nate equipotential plot of the measured data from one experimental configuration. The current injection electrode is shown in the center of the plot. A leak is shown on the 340° radial. The distortion of the equipotential lines indicates increased flow of current around the leak.

Testing on the water-filled model (simulating a fluid impoundments) confirmed that leaks can be detected and located by this technique. To determine whether the system would achieve the same performance on a simulated landfill, the water in the model was replaced with soil. Figure 4 presents the results of a test with 0.06 m (0.22 ft) of soil in the model and one leak. The current injection electrode is shown in the center of the plot. The equipotential contours are distorted in the area of the leak as with the water-filled condition.

These studies further demonstrated the fundamental concepts of the approach, which were first defined by the computer modeling efforts. Based on these results, the measurement equipment, data processing software, and electrodes were specified for full-scale testing at a 0.4-ha (1-acre) lined facility located on Institute grounds. Testing at this scale was performed to measure the performance of the technique at full-scale conditions that more accurately simulate actual field conditions.

Full-Scale Studies

The electrical resistivity leak detection technique was tested at a 0.4-ha (1-acre) lined, water-filled impoundment. The overall goal of the testing program was to determine how well the technique worked in a field environment under full-scale conditions. To accomplish this goal, the instrumentation required to apply the electrical resistivity technique was assembled. A 100-mil geomembrane liner made of high-density polyethylene was installed in a 1-acre impoundment. Controllable leaks were installed in the liner for detection and location studies. Experiments were then performed to evaluate the technique and the instrumentation.

Impoundment Design

A 0.4-ha (1-acre) impoundment was used to test the liner assessment technique. The facility was designed to accommodate up to 2 m (6.5 ft) of water. Overall dimensions were approximately 65.8 m^2 (216 ft^2) from the top of the berms. Side slopes were approximately 3 to 1. An access road around the facility allowed for vehicular traffic during testing. A 100-mil high-density polyethylene liner was installed in the facility to serve as the test liner. The liner was anchored at the top of the berm in a 0.6-m (2-ft) deep trench. The trench was backfilled with soil.

Leaks had to be constructed in the liner to facilitate testing of the leak detection technique. Five pipes, each 0.3 m (1 ft) in diameter and 0.1 m (4 in.) long, were installed through the floor of the liner. The pipes were installed with 0.05 m (2 in.) above the liner and 0.05 m (2 in.) below the liner. Each pipe was made of high-density polyethylene (HDPE) to allow the liner to be welded to the pipe, creating a water-tight seal. A cap was constructed to fit over this pipe. The cap was made from two polyvinyl chloride (PVC) rings that were bolted together. To create various leak sizes, disc-shaped HDPE inserts with holes of various sizes were placed between the rings. The rings were bolted and placed over the top of the pipe. These leak points allowed control of leak location during the performance tests.

Full-Scale Measurements

Figure 5 shows a conceptual drawing of the full-scale test impoundment and operation of the equipment. All measurements were taken along radial lines 5° or 10° apart, beginning at the current source electrode and continuing out to markings on the berm. The logging cable was

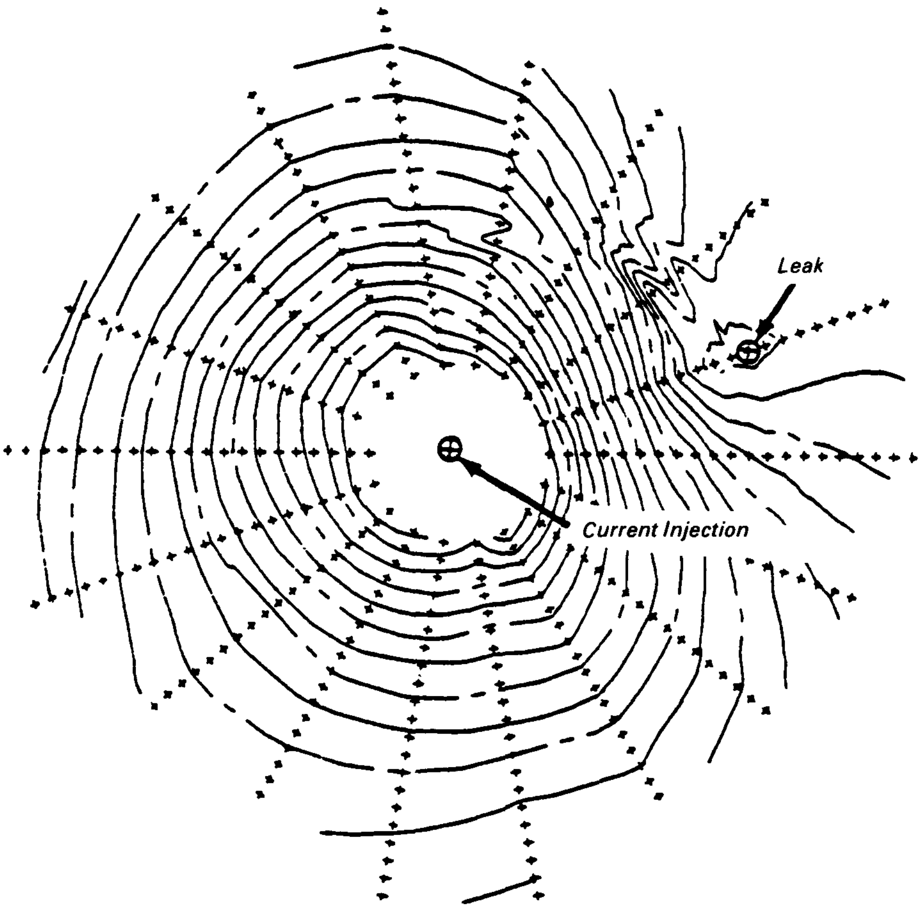

Figure 4. *Equipotential plot of voltages on the surface of the soil with a single leak.*

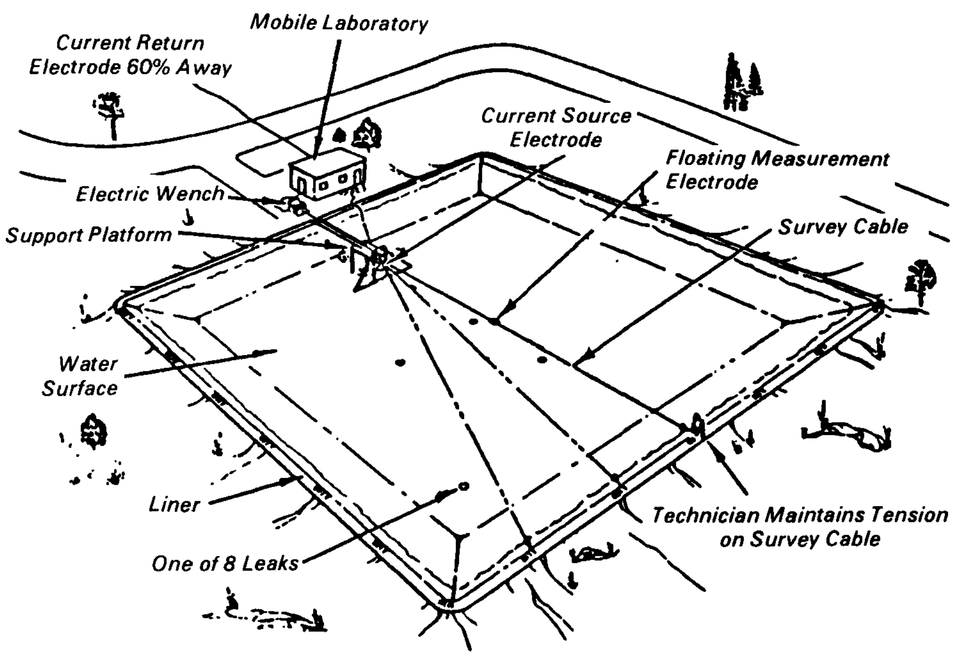

Figure 5. *Conceptual drawing of the test impoundment and operation of the test equipment.*

positioned on these marks during data acquisition runs. The location of any anomaly such as a leak could be calculated from the radial and the odometer data. The odometer, located on the electric winch, established the exact location of the measurement electrode with respect to the current electrode. To establish a baseline condition, the entire surface of the pond was surveyed with all leaks closed.

The various leaks were opened by removing the caps previously described. Potential measurements were then taken over the surface of the water. Soil moisture conditions below the liner were not measured. A contour plotting computer program was used to produce equipotential contour plots of the no-leak and leak data.

No-Leak and Single-Leak Results

A contour plotting computer program was used to produce an equipotential contour plot of the voltages measured over the surface of the water in the no-leak case (Figure 6). The X and Y axes define the approximate north and east water level boundaries of the impoundment. The angles of the radials are indicated. Voltage measurements were taken at 0.3-m (1-ft) increments along each radial. The current source electrode is identified by a dot above the X axis at the 28-m (92-ft) point. The water was approximately 1.5 m (5 ft) deep.

The equipotential contour lines in Figure 6 show insignificant distortions of the surface potentials across the water surface. The results are similar to the no-leak contour plots of data taken with the physical scale model. The contour lines tend to be concentric semicircles close to the current injection point. Moving away from this region, the contour lines begin to straighten out due to the effect of small amounts of current flow across the liner. Part of this current flow is due to the capacitive effects of the liner. Overall, this plot indicates no sudden, unexpected changes or perturbations in the current flow on the surface of the water.

To determine whether the survey technique could detect and locate a single leak, a 0.3-m (1-ft) diameter leak was opened. The surface potentials were measured and the results plotted as before. An examination of the equipotential contour plot in Figure 7 shows that the contour lines close around the location of the leak. This indicates that the flow of current converges in the area of the leak, shown by the "bull's-eye"

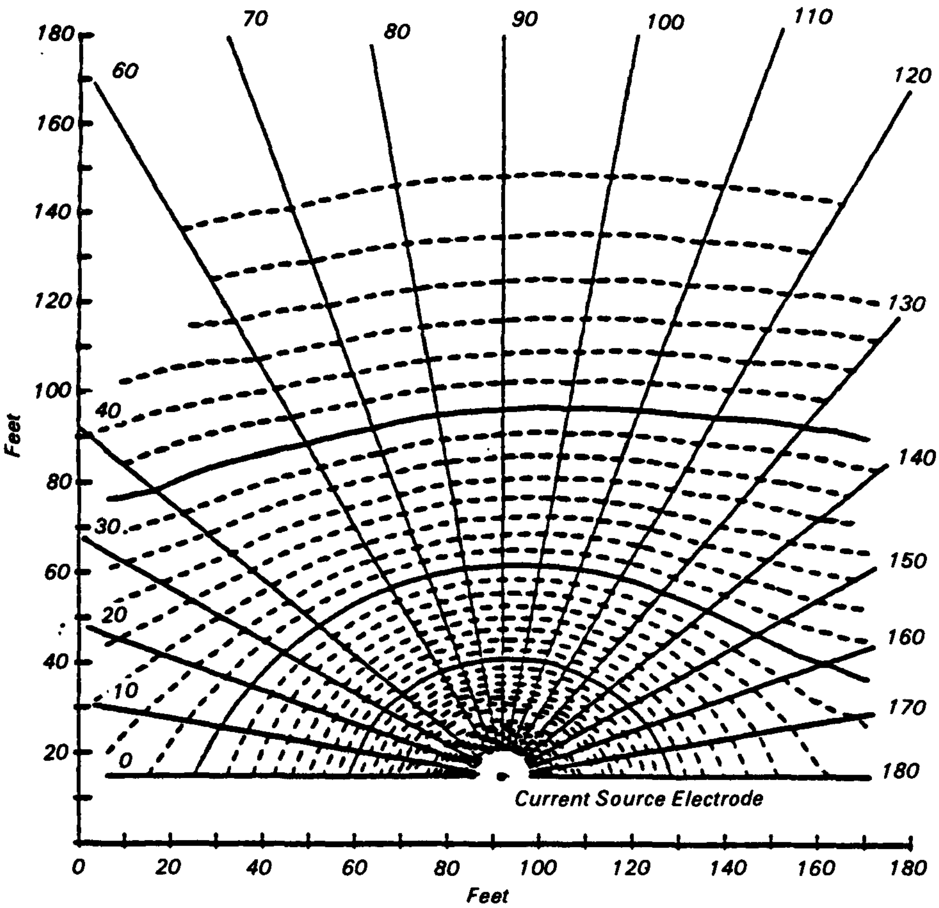

Figure 6. *An equipotential contour plot of no-leak measurements.*

pattern centered on the leak. The bull's-eye potential pattern located on the surface of the water serves to graphically reveal the location of the leak. The plots of the data for each radial along with the equipotential contour plots serve as excellent analytical tools to detect and locate a leak.

To determine whether the technique could detect and locate a smaller leak, 2.5-cm (1-in.) diameter leak was installed on the 90° radial 22 m (72.3 ft) from the current electrode. Surface potential measurements were taken at 0.3-m (1-ft) increments along the 60° through 120° radials. The equipotential contour of these data (Figure 8) indicates a significant distortion on the 90° radial in the proximity of the true leak location. The results of this test indicate that the electrical resistivity technique can be used to detect and locate a 0.02-m (1-in.) diameter leak in approximately 3716 m^2 (40,000 ft^2) of liner surface area to an accuracy of 1 ft. This accuracy is obtainable when the contour plots are used together with the raw data (not shown). The contour line shifts along the 100° radial in Figure 8 do not indicate an anomaly, since the shift is consistently of the same magnitude.

Multiple Leak Results

Multiple leak configuration experiments were performed to determine the leak signatures and sensitivity of the electrical resistivity technique. An experiment was performed in which three 1-ft-diameter leaks were detected and located. These leaks were established at locations 01, 04, and 05. Surface potential measurements were at 1-ft (0.3-m) increments along the 70° through 125° radial lines. Voltage peaks occur directly over each of the three leaks. The equipotential contour plot (Figure 9) clearly shows the presence of each leak.

Conclusions

Full-scale tests have demonstrated the ability of the electrical survey technique to detect and locate single and multiple leaks in geomembrane liner systems installed in water-filled impoundments. For all tests, the technique detected the presence of a leak. The accuracy of leak location ranged from within 0.3 m (1 ft) to 1.5 m (5 ft), depending on the location of the leak with respect to the current source electrode and the total number of leaks present. Although full-scale tests of the technique with soil fill over the liner were not conducted as part of this project, the results of model scale tests strongly indicate that the technique can be used to survey geomembranes installed at landfills.

The technique will not damage the geomembrane liner, and instrumentation and hardware for applying the technique are portable. Experiments using conductive metal cans close to a leak path indicate that the performance of the technique is not diminished by the presence of such potentially interfering objects.

The approach to finding leaks when their location is unknown would be the same as that used at the SWRI test impoundment. Modifications to the survey approach, such as moving the position of electrodes, can easily be accomplished if necessary. Modifications might be called for if, for example, the leaks are not along a radial traverse.

The water depth and leak size and shape will probably influence leak signatures. Though the exact relationships are not known at this time, increasing depth appears to reduce the magnitude of the signature. Depth will become a limiting factor only if the signature strength falls below the background noise of the instrumentation. Background noise will be a site-specific characteristic and therefore cannot be predicted.

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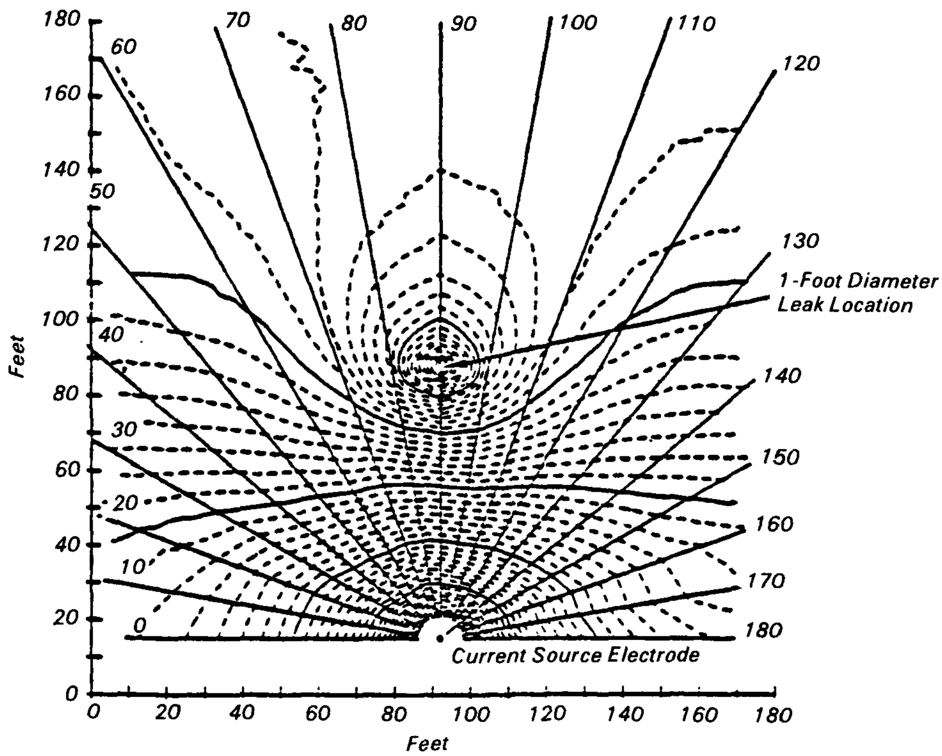

Figure 7. An equipotential contour plot showing the distortions from a 1-foot diameter leak on the 90° radial.

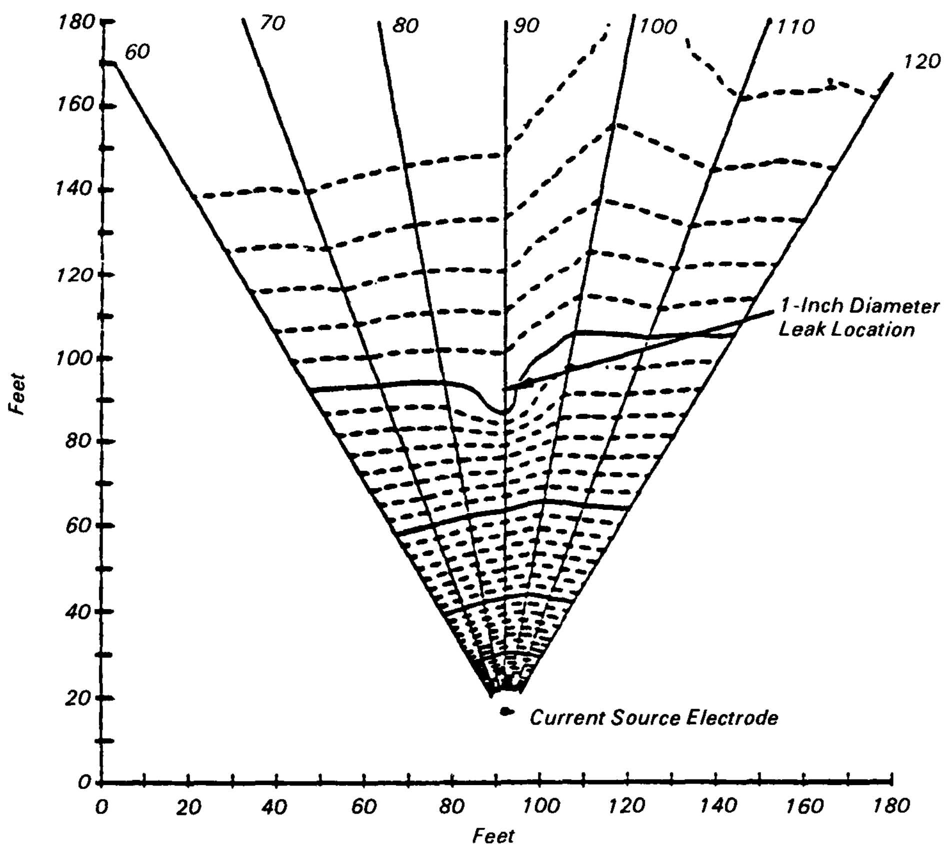

Figure 8. An equipotential contour plot showing the distortions from a 1-in.-diameter leak.

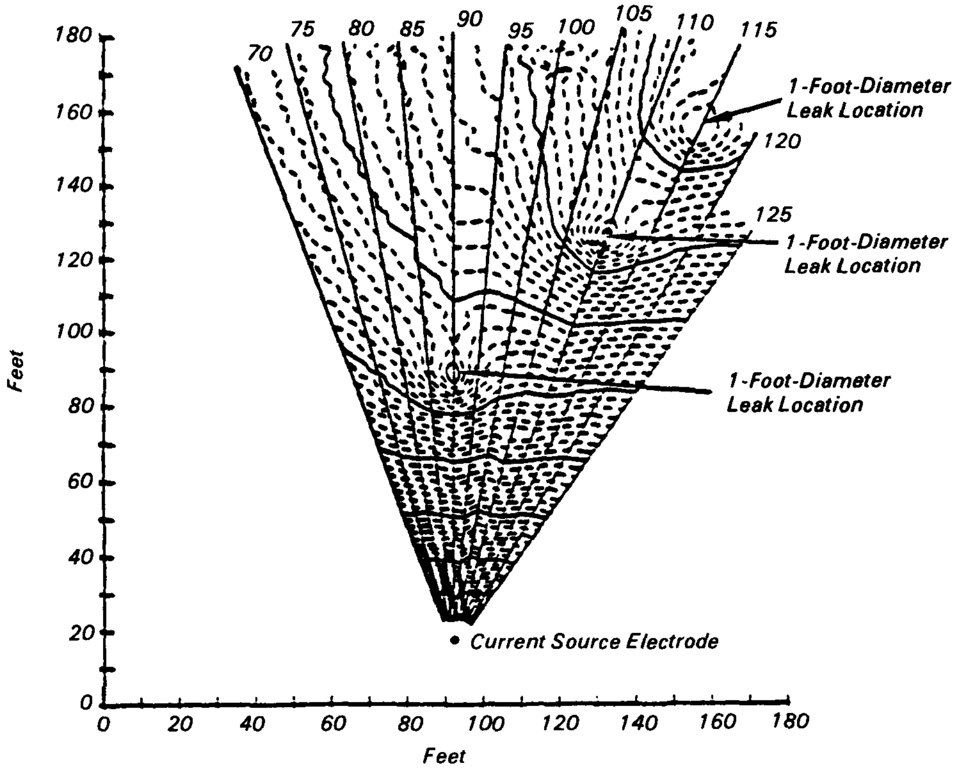

Figure 9. *An equipotential contour plot showing the distortions from three 1-ft-diameter leaks on different radials.*

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***Carlton C. Wiles** is the EPA Project Officer (see below).*

The complete report, entitled "Electrical Resistivity Technique to Assess the Integrity of Geomembrane Liners," (Order No. PB 85-122 414; Cost: $11.50, subject to change) will be available only from:

National Technical Information Service
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