# A. TOBLIN STAFF EXHIBIT 5

# NIRS/PC EC-1

# Detection and Location of Leaks in Geomembrane Liners Using an Electrical Method: Case Histories

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## ABSTRACT

A field-proven electrical technique, developed at Southwest Research Institute, San Antonio, Texas, is commercially available to detect and locate leaks in geomembrane liners. The electrical technique is used to inspect 100% of the geomembrane material that is covered by a conducting liquid. A voltage applied across the liner produces a uniform electrical potential distribution in the liquid or soil above the liner when no leaks are present in the geomembrane. If leaks are present, they are detected and located by searching for localized anomalies in the potential distribution caused by current flowing through the leak in the geomembrane liner. Sixty-one new or in-service geomembrane-lined waste storage facilities were investigated using the electrical leak location method. An average of 3.2 leaks per 10,000 ft$^2$ were located with a range of 0.3 to 5 leaks per 10,000 ft$^2$ of liner surveyed. Many leaks were located in new installations that had been tested using conventional inspection tests.

## INTRODUCTION

### Survey Method

Figure 1 shows a diagram of the Southwest Research Institute electrical leak location method which illustrates the technique described in this paper. When no leaks are present, the high electrical resistivity of the geomembrane liner material will prevent electrical current flow from the liquid in an impoundment to the earth ground or leak collection zone beneath the geomembrane liner. When a voltage is impressed across a geomembrane liner with no leaks, a relatively uniform potential voltage distribution is found in the liquid or soil cover above the liner. If a leak exists in the liner, conductive fluid will flow through the leak establishing a path for electrical current. An anomaly in the measured electrical potential is generated in the immediate vicinity of the leak through which electrical current is flowing. Leaks can be accurately located to less than 1 in. by searching for the point of highest electrical potential.

### Survey Equipment

The equipment used in a manual leak location survey consists of a DC power source, lightweight man-portable electronic detector, scanning probe and associated instrumentation as shown in Figure 2. The probe is most conveniently used while wading in the liquid. However, with an extension, it can be used from a floating platform in deeper liquid applications.

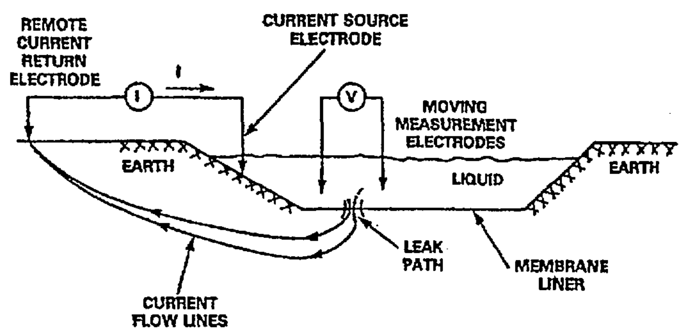


Figure 1
Diagram of the Electrical Leak Location Method

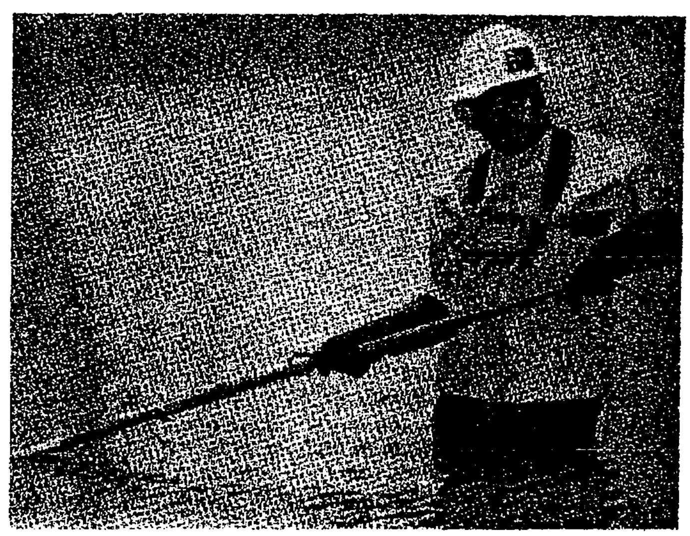

Figure 2
Manual Leak Location Equipment Consisting of an Electrode Probe and Electronics Unit

## MANUAL LEAK LOCATION SURVEY IN LIQUID IMPOUNDMENT

To conduct a manual leak location survey, a minimum of 12 in. of a conducting liquid and a maximum of 30 in. of conducting liquid (preferably fresh water) must cover the liner. Filling the impoundment to the operating depth with fresh water is recommended to hydrostatically load the liner prior to the leak location survey. Testing the liner after hydrostatically loading it is a valid method to determine if the liner will perform satisfactorily under the intended operating conditions. The water is then lowered in stages as the side slopes of the impoundment are electrically tested. After the water has been lowered to 30 in. in depth, the bottom floor area is surveyed.

In surveying a double liner impoundment, provisions must be made to ensure that the material between the geomembrane liners provides electrical conduction to a return electrode placed in the leak collection zone. The test is best accomplished by flooding the leak collection zone with fresh water. To provide electrical contact to the leak collection zone, a stainless steel return electrode with connecting wire is placed in the zone prior to the installation of the primary liner. The return electrode also can be temporarily placed in the leak collection drain pipe if access is available. In both cases, the return electrode must be covered with water.

Air vents should be provided along the perimeter edges of the primary liner near the top of the berm to vent air trapped between the liners. This procedure will help prevent damage to the liner caused by trapped air floating the liner during flooding of the leak collection system. Impoundments that use sand as the material in the drainage layer usually do not require water flooding of the leak collection zone. This is because the sand contains sufficient residual moisture to allow electrical current flow in the sand drainage layer. However, a permanent stainless steel electrode placed in the sand drainage layer prior to the placement of the primary liner will greatly facilitate electrical leak location surveys.

Electrical conduction paths, other than leaks, such as steel piping, piers, fasteners and battens must be electrically isolated for best leak location results. Certain preparations such as rubber packers in inlet and discharge pipes will prepare most geomembrane lined impoundments for a successful leak location survey. The electrical leak location survey method can be most effectively and economically applied if the impoundment or landfill is designed such that electrical conduction paths between the liquid in the impoundment and the earth ground are eliminated or can be electrically insulated.

## SURVEYS OF SOIL-COVERED GEOMEMBRANES

A protective soil cover often is placed over the primary geomembrane liner of landfills to protect the liner from mechanical damage when placing the waste material in the landfill. In addition, a sand drainage layer often is used as the drainage medium in the leak detector zone of double liner installations. However, during the placement of the protective soil cover or the sand drainage layer, the liner can be damaged by the equipment used to place the soil cover, tools used to spread the material, sharp rocks in the soil or by a variety of other mechanical mechanisms. Often the mechanical damage to the liner is undetected and covered by the placing of the protective soil cover. The electrical leak location survey technique has been successfully adapted to locate leaks in geomembranes covered with up to 2 ft of a protective soil cover or sand drainage layer. Leaks were located and later verified beneath protective soil cover, sand drainage layers and thin sediment layers at several sites surveyed.

A protective soil cover or sludge cover over a geomembrane can decrease the effectiveness of a leak survey in three ways:

(1) The strength of the signal received may be reduced because of inhomogeneities in the soil cover or sand drainage layer
(2) The ability of the electrodes to detect leak signals is decreased because of the dissimilarity of the soil and water medium contacting the electrode, resulting in undesirable transient signals caused by polarization of the electrodes
(3) The scanning probe cannot be scanned close to the geomembrane liner

The first condition is solved by systematically conducting the survey on an established survey grid and recording the current signature every 24 in. The acquired data are analyzed in the field and a plot of anomalies is produced which allows for a resolution of the leak locations. The dissimilarity or polarization problem is overcome by using specially designed electrodes to eliminate electrode polarization.

## TYPES OF FACILITIES AND MATERIALS SURVEYED

### Facility Types Surveyed

The electrical leak location survey method was used to survey geomembrane lined facilities ranging in size from 970 to 584,800 ft$^2$. The facilities tested include:

- Primary and secondary liners at landfills
- Concrete vaults for solid waste storage
- Wastewater storage ponds for sewage treatment facilities
- Above ground steel tanks for storage of hazardous materials
- Brine storage impoundments
- Descaling ponds for natural gas transmission companies
- Cooling water ponds

### Materials Surveyed

Approximately 92% of all materials by area surveyed were high density polyethylene (HDPE). At installations lined with HDPE, the predominant material thickness was 60 mil. The remainder of the HDPE material had a thickness of 80 or 100 mils. The other liner materials were polyvinyl chloride (PVC), oil-resistant polyvinyl chloride (XR-5) and oil-resistant chlorosulfonated polyethylene (OR-CSPE). Generally, the seams at a given facility had been inspected using conventional inspection techniques such as visual inspection, air-lance, spark testing or vacuum box prior to the electrical leak location survey. After the electrical leak location survey was completed, the presence of the leaks detected and located by the electrical method was verified at several of the facilities using the vacuum box technique.

## DISCUSSION OF LEAKS DETECTED AND LOCATED

### Leak Statistics

Sixty-one sites with an approximate total area of 4,368,785 ft$^2$ of liner material have been commercially surveyed. Tables 1, 2 and 3 present a summary of all the commercial leak surveys conducted to date using the electrical method developed at Southwest Research Institute. A total of 1409 leaks were located at the 61 sites surveyed which equates to an average of 3.2 leaks/10,000 ft$^2$ of liner material inspected.

Figures 3 through 7 are plots of the data as a function of the area surveyed and the leak location on seams or sheet, total number of leaks or area ratio of the leaks located. Figure 7 is a plot of the number of sites surveyed vs. the area ratio of the leaks located which indicates that there may be between 0.3 and 0.5 leaks/10,000 ft$^2$ of geomembrane liner.

### Leaks on Side Slopes

The side slopes were surveyed at approximately 25% of the liners surveyed. The majority of leaks on the side slopes occurred on the seams. At the facilities where the side slopes were tested, leaks on the side slopes comprised approximately 20% of the total leaks located.

### Leaks in the Bottom of the Liner

Leaks on the bottom of liquid impoundments were found in the parent material, field seams and factory seams. Eighty-seven

**Table 1**
**Leak Detection and Location Survey Data for Impoundment Where the Bottom Floor Area was Surveyed.**

| SURVEY NO. | SIZE SQ. FEET | TOTAL LEAKS | LEAKS LOCATED IN BOTTOM | SEAM | SHEET | LEAKS PER 10,000 SQ. FEET |
|---|---|---|---|---|---|---|
| 1 | 958 | 2 | 2 | 2 | 0 | 20.9 |
| 2 | 958 | 3 | 3 | 3 | 0 | 31.3 |
| 3 | 958 | 3 | 3 | 3 | 0 | 31.3 |
| 4 | 1,000 | 4 | 4 | 3 | 1 | 40.0 |
| 5 | 1,798 | 0 | 0 | 0 | 0 | 0.0 |
| 6 | 2,625 | 6 | 6 | 6 | 0 | 22.9 |
| 7 | 3,000 | 21 | 21 | 21 | 0 | 70.0 |
| 8 | 3,000 | 4 | 4 | 4 | 0 | 13.3 |
| 9 | 3,200 | 0 | 0 | 0 | 0 | 0.0 |
| 10 | 4,951 | 0 | 0 | 0 | 0 | 0.0 |
| 11 | 4,951 | 17 | 17 | 17 | 0 | 34.3 |
| 12 | 4,951 | 2 | 2 | 2 | 0 | 4.0 |
| 13 | 5,175 | 2 | 2 | 1 | 1 | 3.9 |
| 14 | 7,007 | 4 | 4 | 4 | 0 | 5.7 |
| 15 | 12,600 | 7 | 7 | 7 | 0 | 5.6 |
| 16 | 18,346 | 50 | 50 | 35 | 15 | 27.3 |
| 17 | 26,016 | 7 | 7 | 7 | 0 | 2.7 |
| 18 | 26,016 | 4 | 4 | 4 | 0 | 1.5 |
| 19 | 27,297 | 8 | 8 | 6 | 2 | 2.9 |
| 20 | 32,292 | 25 | 25 | 25 | 0 | 7.7 |
| 21 | 43,560 | 2 | 2 | 2 | 0 | 0.5 |
| 22 | 45,345 | 4 | 4 | 4 | 0 | 0.9 |
| 23 | 50,000 | 6 | 6 | 6 | 0 | 1.2 |
| 24 | 50,400 | 193 | 193 | 188 | 5 | 38.3 |
| 25 | 54,500 | 29 | 29 | 18 | 11 | 5.3 |
| 26 | 55,025 | 12 | 12 | 12 | 0 | 2.2 |
| 27 | 58,900 | 8 | 8 | 6 | 2 | 1.4 |
| 28 | 62,500 | 21 | 21 | 19 | 2 | 3.4 |
| 29 | 64,583 | 29 | 29 | 21 | 8 | 4.5 |
| 30 | 65,340 | 56 | 56 | 55 | 1 | 8.6 |
| 31 | 65,369 | 6 | 6 | 6 | 0 | 0.9 |
| 32 | 65,369 | 7 | 7 | 5 | 2 | 1.1 |
| 33 | 65,369 | 5 | 5 | 3 | 2 | 0.8 |
| 34 | 65,500 | 7 | 7 | 5 | 2 | 1.1 |
| 35 | 65,500 | 5 | 5 | 3 | 2 | 0.8 |
| 36 | 74,088 | 20 | 20 | 19 | 1 | 2.7 |
| 37 | 82,500 | 18 | 18 | 15 | 3 | 2.2 |
| 38 | 87,120 | 8 | 8 | 7 | 1 | 0.9 |
| 39 | 87,120 | 17 | 17 | 17 | 0 | 2.0 |
| 40 | 99,050 | 18 | 18 | 14 | 4 | 1.8 |
| 41 | 135,036 | 17 | 17 | 16 | 1 | 1.3 |
| 42 | 150,781 | 64 | 64 | 46 | 18 | 4.2 |
| 43 | 152,460 | 2 | 2 | 2 | 0 | 0.1 |
| 44 | 152,460 | 7 | 7 | 7 | 0 | 0.5 |
| 45 | 157,584 | 12 | 12 | 10 | 2 | 0.8 |
| 46 | 164,085 | 18 | 18 | 16 | 2 | 1.1 |
| 47 | 362,690 | 51 | 51 | 37 | 14 | 1.4 |
| TOTALS | 2,769,336 | 811 | 811 | 709 | 102 | 2.9 |

**Table 2**
**Leak Detection Data for Impoundment with the Side Slopes and Bottom Floor Area Surveyed.**

| SURVEY NO. | SIZE SQ. FEET | TOTAL LEAKS | LEAKS LOCATED IN BOTTOM | SEAM | SHEET | SIDE SLOPE | LEAKS PER 10,000 SQ. FEET |
|---|---|---|---|---|---|---|---|
| 1 | 9,620 | 16 | 12 | 14 | 2 | 4 | 16.6 |
| 2 | 12,540 | 16 | 12 | 12 | 4 | 4 | 12.8 |
| 3 | 24,000 | 40 | 33 | 33 | 7 | 7 | 16.7 |
| 4 | 24,272 | 47 | 31 | 46 | 1 | 16 | 19.4 |
| 5 | 25,000 | 22 | 10 | 15 | 7 | 12 | 8.8 |
| 6 | 25,000 | 15 | 7 | 10 | 5 | 8 | 6.0 |
| 7 | 35,291 | 42 | 31 | 33 | 9 | 11 | 11.9 |
| 8 | 42,022 | 14 | 7 | 12 | 2 | 7 | 3.3 |
| 9 | 50,000 | 4 | 4 | 3 | 1 | 0 | 0.8 |
| 10 | 51,000 | 20 | 13 | 19 | 1 | 7 | 3.9 |
| 11 | 62,500 | 50 | 26 | 44 | 6 | 24 | 8.0 |
| 12 | 130,680 | 192 | 183 | 183 | 9 | 9 | 14.7 |
| 13 | 522,720 | 41 | 31 | 31 | 10 | 10 | 0.8 |
| 14 | 584,804 | 79 | 54 | 61 | 18 | 25 | 1.4 |
| TOTALS | 1,599,449 | 598 | 454 | 516 | 82 | 144 | 3.7 |

**Table 3**
**Survey Data for All Impoundments Inspected.**

| | SITES | TOTAL AREA | TOTAL LEAKS | LEAKS LOCATED IN BOTTOM | SEAM | SHEET | SIDE SLOPE | LEAKS PER 10,000 SQ. FEET |
|---|---|---|---|---|---|---|---|---|
| BOTTOM AREA ONLY | 47 | 2,769,336 | 811 | 811 | 709 | 102 | N/A | 2.9 |
| BOTTOM AND SIDE AREA | 14 | 1,599,449 | 598 | 454 | 516 * | 82 | 144 | 3.7 |
| TOTAL | 61 | 4,368,785 | 1,409 | 1,265 | 1,225 | 184 | 144 | 6.7 |

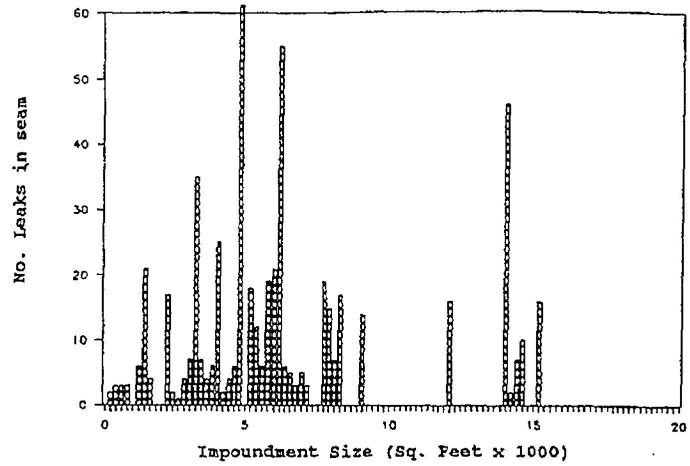


Figure 3
Histogram of Total Leaks Located vs. Bottom Floor Area Surveyed

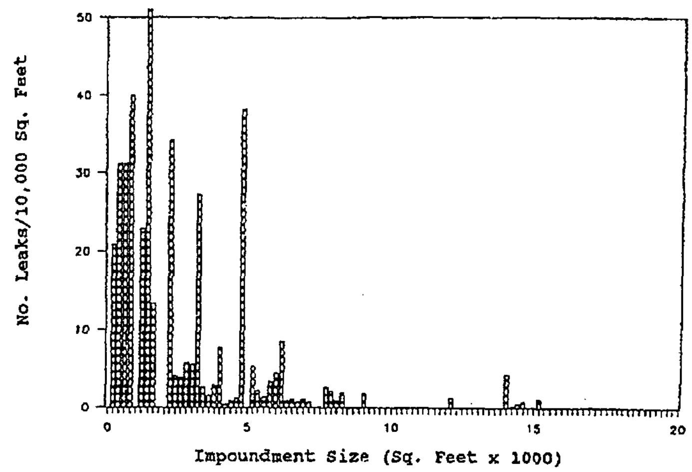


Figure 4
Histogram of Leaks per 10,000 ft² of Liner Surveyed

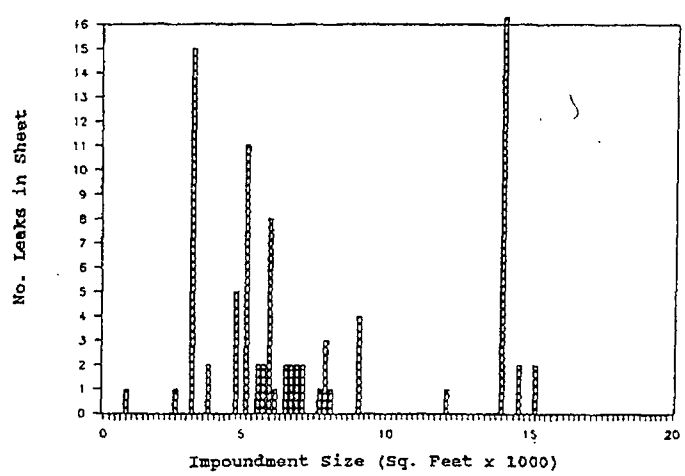


Figure 5
Histogram of Leaks in the Parent Material vs. Impoundment Size

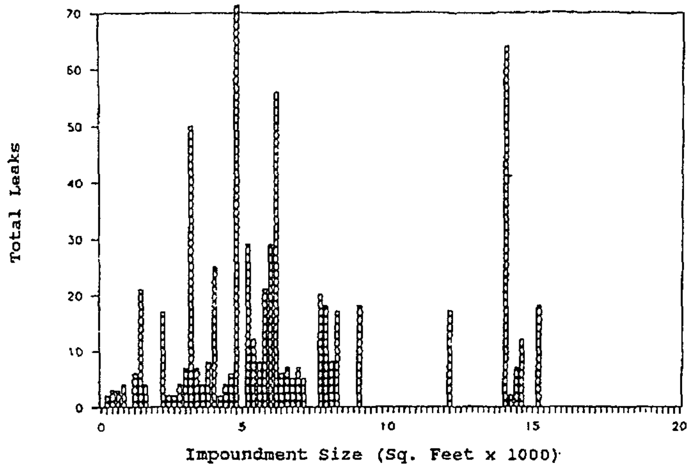


Figure 6
Histogram of Leaks in Seam vs. Impoundment Size

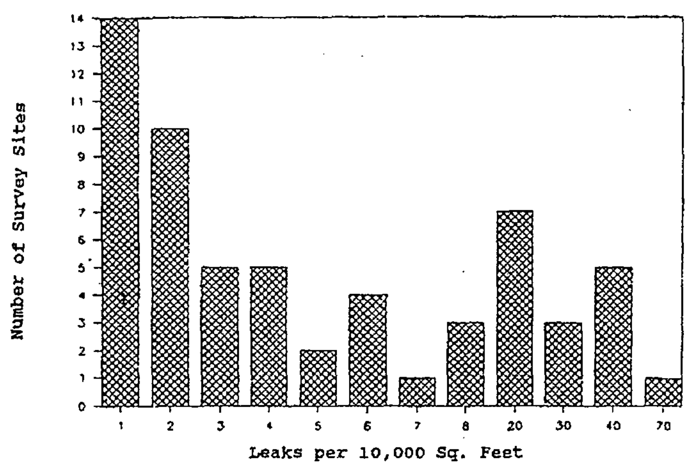


Figure 7
Histogram of Number of Sites Surveyed vs. Number of Leaks Located per 10,000 ft² of Geomembrane Liner

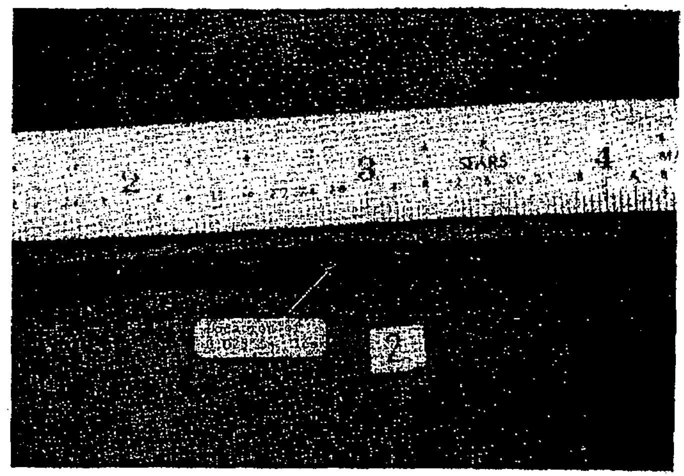

Figure 8
Leak in HDPE Seam. Approximate Leak Size 0.025 In.
(Note: Leak not apparent in reproduced photograph.)

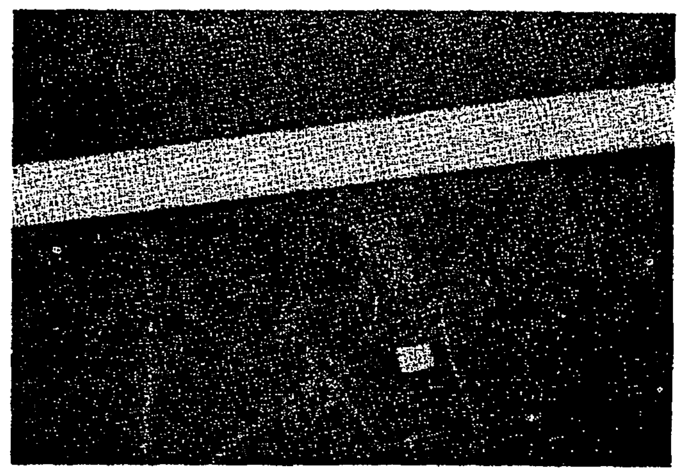

Figure 9
Leak in Parent Material

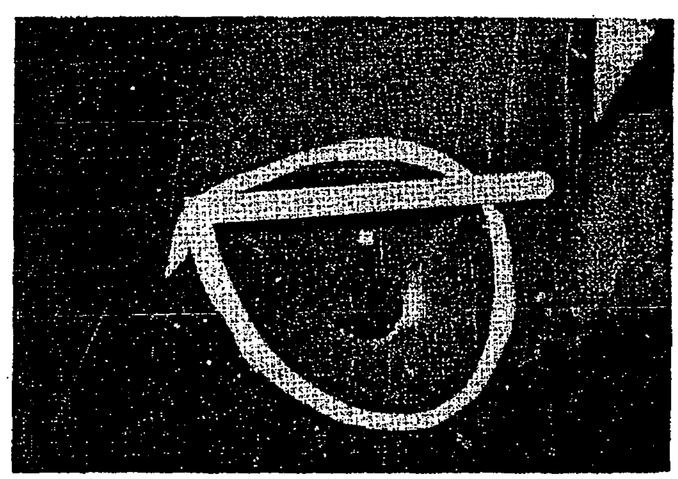

Figure 10
Large Leak in HDPE Parent Material

percent of the leaks were in seams, and the remaining 13% were in the parent material. Figures 8 and 9 show examples of seam leaks detected with the Southwest Research Institute electrical leak location system. Leak sizes and shapes ranged from relatively circular holes from less than 0.025 to 1 in. in diameter, to slits from 0.25 to 12 in. long, to gashes and gouges up to 6 by 8 in., to evidently tortuous paths through seam welds.

**Leaks in Parent Material**

The leaks in the parent material generally can be attributed to accidental damage from equipment or tools, crescent-shaped cracks due to equipment being dropped, slits due to razor-edged tools cutting the liner, burns from cigarettes, gashes and gouges. Figures 10 and 11 show typical leaks in the parent material. Some of the leaks in the parent material probably were caused by improper material handling or wind buffeting. Many leaks in the parent material of installations with a protective soil cover appeared to have been created during the application of soil cover over the liner.

The observed ratio of parent material leaks to seam leaks may be slightly less than actual because the seams are double-checked during the leak location survey process. While rechecking the seams, the search probe tip is scanned within 1 in. from the leaks in the seams. However, during the general survey of the geomembrane, the parent material is swept at 12 in. intervals placing the electrical probe as much as 6 in. from a potential leak point. Because the probe tip is approximately six times closer to potential leaks when surveying the liner seams, it is probable that very small leaks found in the seams are not detected in the parent material.

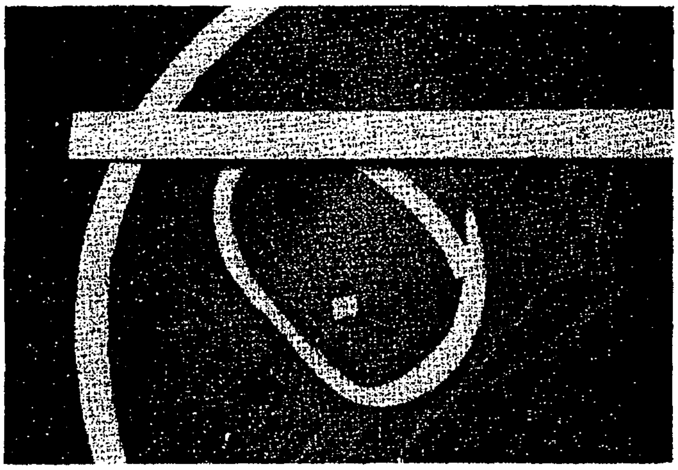

Figure 11
Cut in HDPE Parent Material

**Leaks in Seams**

Inadequate field seaming appears to be the primary cause of leaks in geomembrane lined impoundments. Eighty-seven percent of the total number of leaks were in field welded or bonded seams. Many of the leaks occurred at T-joints, patches and at seams in highly-stressed areas such as at the base of the sideslope. Some leaks were found in seams which previously had been repaired and tested. Figures 12, 13 and 14 show typical leaks located in seams. Leaks may not develop in the seams until a hydrostatic load is placed upon the liner. Cases were documented where obviously poor seaming techniques resulted in seams failing indiscriminately after repair and hydrostatic loading. In such cases, it is suggested that the entire liner installation be redone.

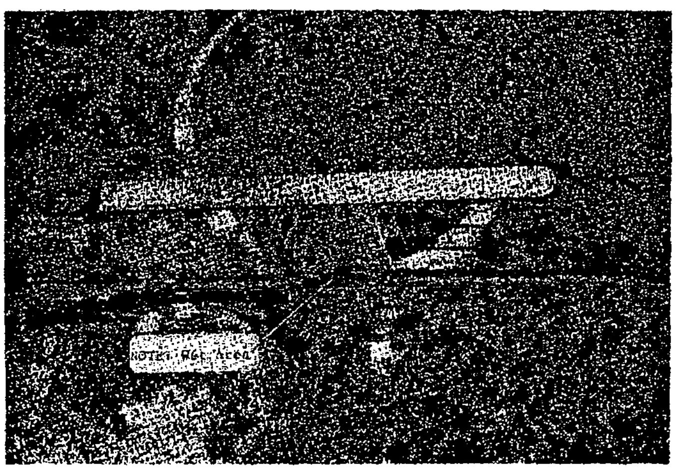

Figure 12
Leak in Seam

**Leaks Associated with Penetrations and Structures**

In some facilities, numerous leaks were found around penetrations or structures in an otherwise excellent field installation. Many designs incorporate complex seam requirements when attempting to isolate drainage cribs, separation walls, concrete sumps, concrete pads and other structures. Where such structures are necessary, the electrical method may be the only method which can be applied to test for leaks.

**Leaks Associated with Material Types**

Because of the limited use of materials other than HDPE in the

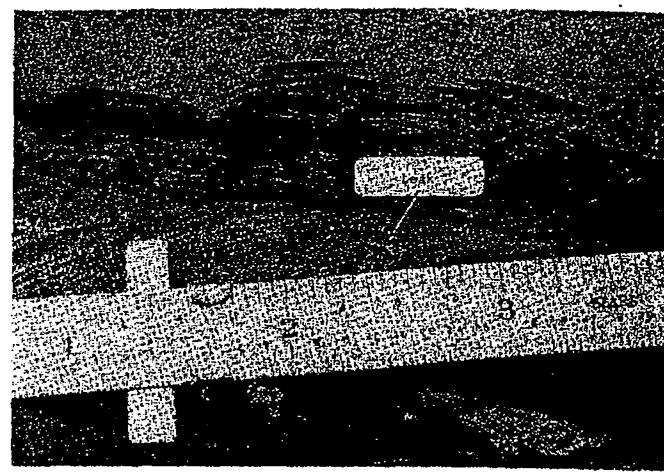

Figure 13
Leak in Seam After Grinding, Just Prior to Repair

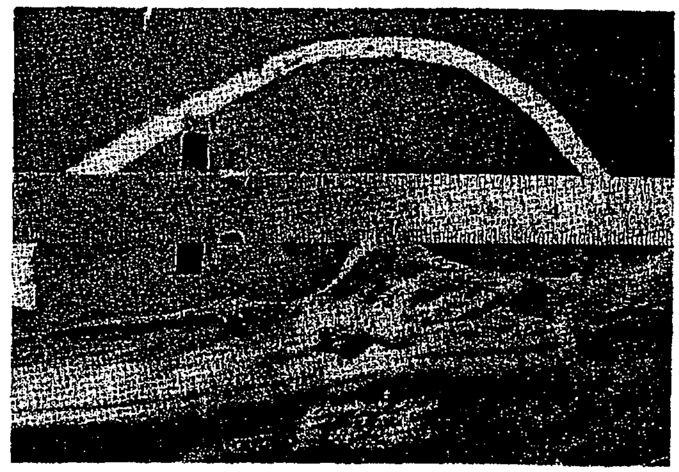

Figure 14
Leak in Seam Where Seaming Material Did Not Bond to Sheet

facilities tested by the Southwest Research Institute electrical method, it is not possible to formulate any valid conclusions on the relationship of material type to numbers and types of leaks.

**Leaks Beneath Soil Covers and Sludge**

The Institute has successfully located leaks beneath installed soil cover up to 2 ft thick. Leaks have been found beneath chemical precipitate sludges, but the application of the electrical method in the sludge environment is extremely tedious and demanding. The leaks found beneath soil covers have included seam leaks and leaks in the parent material apparently caused by the heavy equipment which was placing the protective soil cover material. Figures 15, 16 and 17 show leaks located under 2 ft of sand place over the primary geomembrane liner. No significant numerical relationships between leaks, leak occurrence and types of leaks can be developed on leaks discovered beneath soil covers because of the limited field testing experience in such environments.

## CONCLUSIONS

The electrical leak location method is a very sensitive, accurate and valid method for locating leaks in geomembrane liners. Leaks were found in every liner surveyed except for three liners that were less than 500 ft$^2$ in area. Leaks were located in liners that had been rigorously tested using one or more of the conventional methods for testing geomembrane liners.

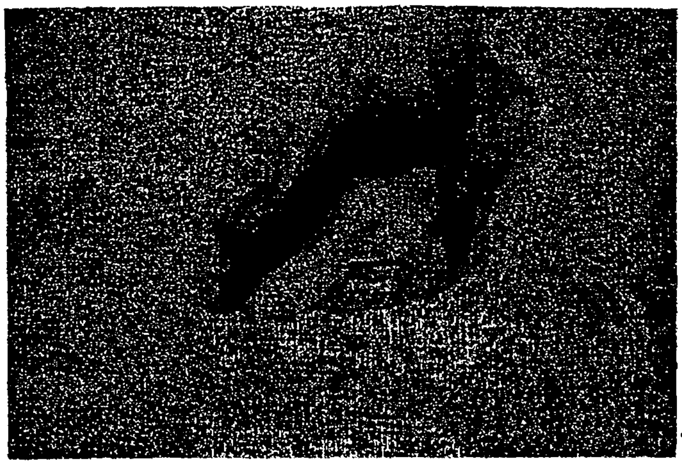

Figure 15
Leak Under 2 ft of Protective Sand Cover

Figure 16
Mechanical Damage to Liner Under 2 ft of Sand Cover

The number of leaks per 10,000 $ft^2$ of surveyed area typically ranged from 0.3 to 5 with an average density of 3.2 leaks/10,000 $ft^2$ of geomembrane liner. Several liners had greater than 20 leaks/10,000 $ft^2$ of area surveyed.

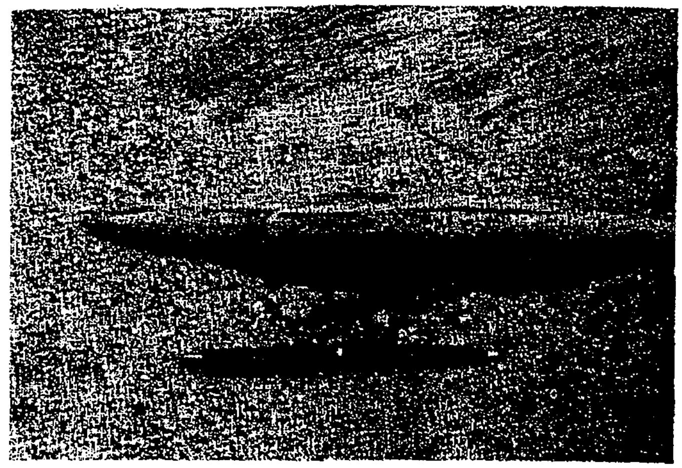

Figure 17
Tear in Liner Covered with 2 ft of Sand

The density of leaks generally decreases as the liner size increases. Possible explanations for this are:

- Smaller installations have proportionally more complex features such as corners, sumps and penetrations
- Small installations tend to have higher proportions of hand seaming
- Larger installations tend to have better QA/QC programs
- Larger installations generally receive proportionally less traffic

From our experience, and knowledge of the history of some of the liners surveyed, the major factors for minimizing the number of leaks in geomembrane liners in the general order of importance are: the professionalism and skill of the seaming machine operator; environmental factors such as moisture, temperature and wind; simplicity of the liner design; thickness and weldability of the liner material; and liner care and handling procedures.

The electrical leak location method has demonstrated that geomembrane installations can benefit from an electrical method leak location survey as a part of the construction quality assurance program. Pre-service testing of new installations using the electrical leak location method will enhance the overall performance of the containment facility.

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