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Field Evaluation of Plastic Film Liners for Petroleum Storage Areas in the Mackenzie Delta

Economic and Technical Review
Report EPS-3-76-13

Environmental Conservation Directorate
October 1976

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Cat. No.: En 46-3/76-13
ISBN 0-662-00261-X

FIELD EVALUATION OF PLASTIC FILM LINERS FOR PETROLEUM STORAGE AREAS IN THE MACKENZIE DELTA

D.E. Thornton
Environmental Emergency Branch
Environmental Protection Service
Edmonton, Alberta

P. Blackall
Environmental Protection Service
Yellowknife, N.W.T.

EPS 3-EC-76-13

REVIEW NOTICE

ABSTRACT

An inspection tour was made of seven petroleum storage areas in the Mackenzie Delta area to study the use of artificial liners employed at each site to enhance the spill retention capabilities of these tank lots. Of the six types of membranes viewed by the inspection party, polyurethane (20 mil.) prestressed laminated polyethylene, and fibre-reinforced polyurethane appeared to show promise as lining materials. It was noted that bedding preparation is important if the membrane has a low puncture resistance, and also that an adequate thickness of protective overburden is desirable, as exposed membranes invariably become damaged. It was concluded that carefully chosen and properly installed plastic membranes can be effective and economical for artificially enhancing the spill retention properties of petroleum storage areas in the Arctic. In particular, plastic membranes appear applicable for buried installation in permanent tank lots during the initial foundation construction, but not suited for improving existing installations.

RÉSUMÉ

On a effectué une tournée d'inspection de sept aires de stockage du pétrole dans la région du delta du Mackenzie afin d'étudier l'emploi qu'il y est fait de membranes artificielles pour améliorer l'étanchéité des réservoirs. Parmi les six types de mambranes étudiés, le polyuréthane de 20 milliémes de pouce d'épaisseur, le poléthylène laminé précontraint et le polyuréthane renforcé par fibres ont semblé les plus prometteurs. On a pu constater que la préparation du lit est importante si la membrane an une faible résistance aux perforations et qu'une couche protectrice d'une bonne épaisseur est souhaitable puisque les membranes exposées sont immanquablement endommag'es. On a conclu que les membranes de plastique choisies avec soin et convenablement installées peuvent être efficaces et économiques pour améliorer de façon artificielle la résistance aux fuites des aires de stockage du pétrole dans l'Arctique. En particulier, elles semblent applicables aux installations souterraines de groupes de réservoirs permanents lors de la construction des fondations, mais ne semblent pas convenir à l'amélioration des installations existantes.

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1 INTRODUCTION

The harsh climate, and general lack of stable, impermeable fill material in northern regions has created problems for the adequate design, construction and maintenance of spill containment dykes. Consequently, a review of dyking practices and procedures in the western Arctic was performed using a questionnaire approach in 1974. (Auld et al., 1974).

One of the most promising methods, pioneered by the oil industry, to enhance product containment in the event of a spill is the emplacement of plastic lining materials on or in dyke walls and storage area floors. The review in 1974 indicated that the oil industry has been rapidly gaining experience with this technique in the North, but found that there were many films which were not suitable for the subject application. An approximate evaluation of six generic types of film based upon laboratory work by Imperial Oil Ltd. (IOL) was included in the review. The films were evaluated in regard to their resistance to attack by liquid fuels, ductility at low temperatures, puncture resistance, resistance to weathering and ability for solvent or adhesive bonding.

In order to assess the field performance of some liners in the North, an inspection tour of fuel storage locations in the Mackenzie Delta area was carried out during the last week of August, 1975. Seven lined sites were visited and six types of liners viewed.

Three unlined petroleum storage sites, belonging to government agencies and crown corporations were also visited during the inspection tour. The government agencies have now begun to build dykes for their storage facilities and to incorporate liners in these dykes. All the sites discussed in this report on liners are oil industry sites.

This report, then, presents the findings of the tour, including discussion of lined sites. In addition, some of the technical comments and conclusions are reproduced from a technical report by IOL (Marion, 1974) which resulted from a tour of IOL fuel storage depots in the western N.W.T. in June, 1974. Most of the problems identified at the IOL sites have since been rectified, but the experience gained by this company is worthy of dissemination. Access to this material hereby is acknowledged gratefully.

2 IOL INSPECTION TOUR, 1974

The objectives of the inspection tour in 1974 by IOL personnel was to evaluate provisions for spill containment in the western Arctic. Particular attention was given to (30 mil.) oil resistant PVC membranes installed during the summer of 1973. At that time oil PVC membranes had been installed partially or completely at six IOL sites: Hay River, Aklavik, Bar-C, Yellowknife, Tuktoyaktuk, and Inuvik. Liners were installed only in the dykes at the latter three locations, being anchored into the relatively impermeable permafrost at Yellowknife and Inuvik and into a substrate layer of clay at Tuktoyaktuk. In addition, a 7 mil. polyethylene derivative membrane (Marlex) had been installed during the winter of 1972/73 at a small weather data transmitter on Hooper Island.

The lowest temperature for making field seams with oil PVC adhesive was thought to be around 10°C, so installation procedures were terminated near or just below this temperature. Laboratory tests had indicated that the material remained ductile above -18°C, but field experience showed that brittle fractures were inflicted at temperatures as high as 5°C. The apparent reason for this discrepancy is a shift in the ductile-brittle transition temperature caused by increased strain rates. The membrane was simply not handled as rigorously in the laboratory tests as it was during field installation.

During the inspection of the sites, performed by carefully clearing small areas of the protective overburden, limited evidence was noted at some sites of damage caused to the membranes during installation. This damage comprised occasional brittle fractures and flaws apparently not caused by subsequent operations. A metal ground rod was also found protruding through the soil beneath the liner. Such carelessness was interpreted to be caused by a decrease in quality of work during installation once temperatures began to drop to more uncomfortable levels.

Most of the flaws noted after removal of the overburden were apparently caused by sharp-edged rocks or sand particles in the foundation or overburden pressing into the membrane. Such damage was deemed to be caused by inadequate preparation of the gravel beddings or cover, and/or excessive aggregate size.

Although at all the sites inspected the membranes were protected by covers of fill material of varying thickness and type, at certain sites small areas of the liners were exposed. Failures of the oil PVC films at these points were common, almost exclusively caused by brittle fractures attributable to human activity during low ambient temperatures.

Deterioration of the Marlex liner was observed wherever it was not protected by a gravel covering. In this case damage was caused by summer sunlight and arctic winds. Prior to emplacement of the liner it was recognized that this material deteriorated when exposed to the elements. However, at the time of installation the transmitter site was intended to be temporary and only subsequently had acquired an air of permanence. Hence, the material had been selected primarily because it exhibited the best low temperature ductility of the membranes which had been examined in the laboratory at that time, and liner installation occurred during the winter months.

3 EPS INSPECTION TOUR, 1975

Details of the lined fuel storage sites visited by the authors in August, 1975, are indicated in Table 1.

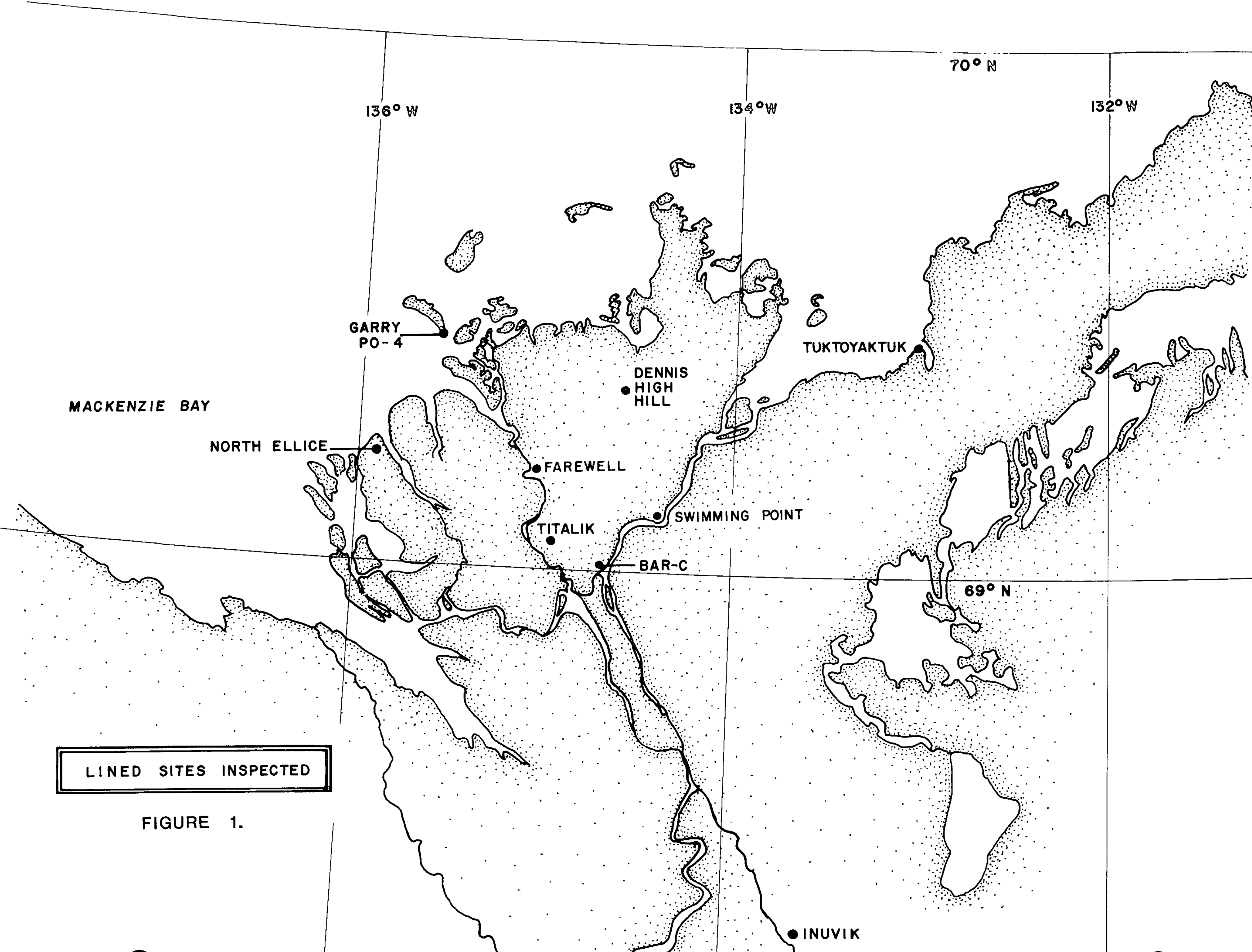
3.1 Bar-C

Oil PVC membrane was installed in the tank floor and in the dykes during construction of the depot gravel foundations. Generally, temperatures close to 20°C were experienced during installation. Prior to backfill emplacement any minor holes were easily mended using PVC cement and patches of lining material.

TABLE 1 LINED SITES INSPECTED

Site	Type	Liner	Supplier
Bar-C (IOL)	staging area	oil PVC (30 mil)	Staff Industries
Swimming Point (Gulf)	staging area	polyethylene (10 mil)	Modern Packaging Co.
Farewell Stockpile (Shell)	staging area	urethane (20 mil)	Staff Industries
Titalik A-16 (Shell)	drill site	laminated prestressed polyethylene (6 mil "Rufco")	Raven Industries
Garry P-04 (Sunoco)	drill site	reinforced polyurethane (30 mil "Polyfabric 1855") reinforced polyethylene (6 mil "Polyfabric 1425")	Inland Plastics
North Ellice (Chevron)	drill site	polyurethane (20 mil)	Unit Liner
Dennis High Hill (IOL)	repeater station	laminated prestressed polyethylene (6 mil "Rufco")	Raven Industries

The overburden consisted of 0.5 ft. to 1.5 ft. of Ya-Ya Lake gravel compacted with vibratory packers. During the inspection of this site by IOL personnel in 1974, a total of 13 sq. ft. of membrane was exposed in a series of 5 excavations. At that time a total of three small pinholes and three 0.25 inch long cuts were uncovered by two of the excavations. During the EPS inspection in 1975 a total of 5 sq. ft. of liner was exposed at two locations. Photo 1 illustrates the indentations in the oil PVC liner caused



LINED SITES INSPECTED

FIGURE 1.

by the underlying gravel base. However, no punctures were observed. Apparently, melt-water is retained in the tank lot for a lengthy period of time during the spring indicating that losses through flaws in the membrane are small.

3.2 Swimming Point

The foundation for the tank-lot liner was prepared by forming approximately 2 inches of polyurethane foam over a 2-3 ft. thick gravel base. The foam served to insulate thermally the underlying permafrost and provided a smooth bedding for the polyethylene liner which was installed during summer months. Approximately 1-2 ft. of gravel overburden was emplaced over the liner, which extended up into the dyke walls.

A total of 12 sq. ft. of membrane were exposed at three locations, two of which are illustrated in Photos 3 and 4, and no punctures were observed. Clearly, careful preparation of the bedding and a substantial cover of relatively fine-grained overburden had admirably protected a rather thin membrane. Such protection is vital for this particular material since it is subject to deterioration if exposed to the weather, and has a poor puncture resistance.

3.3 Farewell Stockpile

At this tank lot a urethane liner was sandwiched between two layers of sawdust, each a few inches thick; (see Photo 5) to protect the membrane from a fine, sandy gravel base and overburden of 0.5-2 ft. in thickness. This procedure would appear to have been sucessful since no flaws were detected in 6 sq. ft. of membrane exposed at three points on the storage area floor. In fact, as shown in Photo 6, at the excavation with the lowest elevation water began to seep immediately into the hole. Apparently, it is necessary to pump out pooled meltwater from the lot during spring.

A portion of damaged liner was visible in the dyke wall adjacent to valves on piping through the dyke as shown in Photo 7. Presumably the liner had become exposed due to some sloughing of the dyke wall caused by increased activity in the area, and consequently been damaged.

3.4 Titalik A-16

A prestressed, laminated polyethylene liner had been installed on the floor of the fuel storage area of this drill site, which, at the time of the visit, was in the initial stages of being dismantled. An underlay of polyurethane blankets (foamed onto sacking) had been emplaced under the liner to provide thermal insulation for the underlying ice-rich silt and to form a protective bedding for the membrane. It was noted that the permafrost extended to the surface under the polyurethane, providing protection against thaw instability, whereas an active layer of about 1.5 ft. was present exterior to the storage area.

Additional polyurethane blankets and a thin cover of gravel had been placed over the liner where equipment was placed or where activity was expected. At the time of the visit much of this cover had been removed by the billowing action of the wind under the liner, as shown in Photo 9. The liner did not extend into the uncompacted silt dykes (Photo 10) present on three sides of the storage area. Generally, a liner installed on a storage area floor in this manner would encourage a spill to flow to the unconsolidated dykes, from where it may be nearly impossible to recover the spilled product. However, serving to reduce this possibility, the drilling sump provided a boundary on the fourth side, as is common practice at northern drill sites, and would have served as a catchment basin in the event of a spill. Considering the exposure of the membrane, as shown in Photo 9, it was in remarkably good condition. The high puncture resistance of the liner is evidenced by the lack of holes despite the deep indentations shown in Photo 11 caused by particles and chunks of gravel which had been pressed into the surface by human activity. However, despite the considerably strength of the membrane, numerous tears were visible. Examples are shown in Photos 12 and 13. Moreover, since the liner material is polyethylene, it cannot be expected to function effectively for more than approximately one year when exposed to the degrading effects of direct sunlight. Laminated, prestressed polyethylene apparently exhibits good low temperature ductility, since the liner at this site was installed during the winter at temperatures around -30°C. In order to reduce the possibility of damage due to brittleness at low temperatures, the folded liner was heated using forced air heaters and rolled quickly into position.

3.5 Garry P-04

Sheets of fibre-reinforced polyurethane had been placed over a gravel foundation under some fuel storage bladders as shown in Photo 14. The spill retention effectiveness of this limited application of liner is extremely doubtful.

The sheets of reinforced polyurethane had previously been used at other locations over a period of years, and had even been returned to the factory for repair, and a patch is shown in Photo 15. A number of tears were evident in the exposed sheets, and an example is shown in Photo 16. However, the age of the sheets and their frequent reuse testifies to the strength of material. Although such fabric-reinforced films tend to be stronger than their unreinforced counterparts, they tolerate very little deflection before failing.

A small sheet of fibre-reinforced polyethylene was installed on the gravel surface under a skid mounted tank. As shown in Photo 17, the skid had sunk into the uncompacted gravel, pinning the liner and causing it to be torn under the action of wind.

3.6 North Ellice

As shown in Photo 18, a large sheet of polyurethane liner was draped loosely over the gravel floor and dykes of the fuel storage area at this rig site. Prior to installation the liner had been left lying on the ice and had been successfully unfolded and installed at temperatures of -35°C. No brittle fractures were apparent during the inspection, indicating excellent low temperature ductility. The pooling of water on the liner, visible in Photo 18, indicates generally the overall integrity of the liner. However, as might be expected with an exposed liner, a number of flaws were apparent, and examples are shown in Photos 19 and 20. Merely walking on the liner overlaying the gravel was insufficient to cause damage, so that it is surmised that the flaws were associated with the movement of equipment in the storage area. Clearly, however, this liner exhibits some important characteristics desirable for northern application.

3.7 Dennis High Hill

A liner of prestressed, laminated polyethylene had been installed in a small gravel fuel storage area at this unmanned repeater station. Sawdust had been used to cushion the membrane from the coarse bedding and overburden. At the time of the visit, the fuel tanks were empty and had been removed from the lined area. Upon examination of the liner, it was apparent that a fire had occurred previously and had consumed considerable portions of the membrane and sawdust (see photos 21 and 22). Little evidence of damage caused by other mechanisms was apparent on examination of unburned segments of material.

4 DISCUSSION

The pioneering use of plastic membranes by the oil industry to enhance the fuel spill retention capabilities of deficient soils at remote northern locations appears to be a generally sound economical approach. In particular, installation of plastic lining materials seems effective at the larger staging areas or fuel tank lots, where liners are emplaced carefully during construction of the facility. The labour required in this case is relatively low in comparison with the effort and difficulty of effectively fitting a membrane around and under existing facilities. However, careful preparation of the membrane foundation and adequate protection from damage by the overburden is extremely important. In fact, preparation of the materials contacting the membrane can dominate the ultimate effectiveness of the installation more than the individual film properties.

Given adequate basic film characteristics such as chemical stability in contact with soil or fuel, a relatively thin, weak film such as 10 mil. polyethylene, with poor puncture strength, low resistance to weathering and only fair ductility can perform satisfactorily. Conversely, even the most suitable membranes likely would not serve the design purpose because of severe puncturing if placed in direct contact with sharp-edged aggregate, such as crushed gravel. However, membranes of high puncture strength and good ductility require less intensive bedding preparations than more fragile ones.

Foundations of sawdust and polyurethane foam provide apparently very adequate bedding materials. Cushioning layers of sand or finer-grained soils could also provide a comparable service. Particle sizes significantly greater than the membrane thickness generally require that the base on which the membrane is placed be smoothed and compacted for best results. Membranes installed in other circumstances will allow some seepage, the amount depending on the individual installation and particular membrane selected, but in all but the worst cases a membrane of high puncture resistance would likely contain any significant spills for a period sufficient to permit recovery of most of the fuel.

For liners which are to be in place over an extended period and be exposed to considerable human activity, an adequate cover of protective overburden is essential. This is true particularly for membranes which have poor resistence to weathering and are subject to brittle fracture at low temperatures. Should an area of a buried liner become exposed at a site, the protective cover should be replaced as soon as possible since exposed liners invariably become damaged-the time scale of the process depending upon the properties of the liner and the level of activity in the area.

Buried liners should preferably exhibit good low temperature ductility, although if installation is performed during the summer months the property is not strictly necessary. However, the occasional cool summer days experienced in the North could unexpectedly and inconveniently produce ambient temperatures below the membrane ductile-brittle transition temperature if an inappropriate membrane is selected. Moreover, good low-temperature ductility reduces the probability of damage should patches of the buried liner become exposed.

At small, temporary locations in the North, surface or near-surface liner installation is attempted frequently. In such cases suitable preparation for the liner bedding is desirable as for buried applications. Moreover, it is particularly important in this case to ensure that the liner is anchored adequately to ensure some protection from damage by wind. However, for surface or near-surface installation the properties of the liner are paramount. Problems with deterioration caused by exposure to ultra-violet radiation, severe puncturing and total failure due to extensive brittle fractures have been experienced with some liners in the past. Of the membranes viewed by the authors, three liners appeared to show promise for this type of application Polyurethane (20 mil.), prestressed laminated polyethylene and fibre-reinforced polyurethane, although the latter, because of the characteristics afforded by the fibre reinforcement, would tolerate very little deflection before failing. Consequently, it seems likely that this film, and fibre-reinforced films in general, would require more substrate preparation than comparable unreinforced films to eliminate unsupported areas. Further field experience with these membranes, and others, will doubtlessly continue to provide additional information on their capabilities. However, regardless of the qualities of the liner material, surface deployment will, in time, result in damage to the membrane. Hence, this type of application must be considered as an inferior approach to burial, and will provide effective spill protection only over relatively short operating periods - perhaps one or two seasons. Surface deployment allows the possibility of liner recovery and reuse if the membrane is still intact. However, retrieval attempts frequently must be carried out during winter months and removal may be foiled by the presence of snow and ice.

5 SUMMARY AND CONCLUSIONS

Carefully chosen and properly installed plastic membranes can be effective and economical for artificially enhancing spill retention capabilities of tank lots. In particular, plastic membranes appear applicable for buried installation in permanent remote tank lots during the initial foundation construction, but not suited for improving existing installations.

Ideally, a membrane should be placed between two cushioning layers of bedding material such as sawdust, polyurethane, or fine grained soil. Careful bedding preparation becomes less critical if the membrane has a high puncture resistance, but is always important. Adequate thickness of protective overburden is desirable, since exposed membranes invariably become damaged. In general, unreinforced films seem suited for this application because of their higher elasticity compared to reinforced films.

Spill retention at remote, temporary fuel storage sites can be effected, in the short-term at least, by the deployment of plastic films at the ground surface, although burial is preferable. For surface application, film properties such as puncture resistance, low temperature ductility and resistance to weathering are paramount and adequate anchoring of the liner is also extremely important to reduce damage caused by wind. Certain liner types are currently in use in the North which exhibit many desirable characteristics, and would also prove particularly effective materials for buried installations.

6 ACKNOWLEDGEMENT

The authors would like to express their thanks for the assistance supplied by DINA, Gulf, Imperial Oil and Shell personnel during the field trip in August, 1975.

7 REFERENCES

Auld, R.G., Marion, T.L., Purdy, I.L., and Sangster, R.H.B., "State of the Art Review of Petroleum Product Spill Containment Dykes in the North", Imperial Oil Ltd., report prepared for the Environmental Emergency Branch, Environmental Protection Service, Environment Canada, Rep. No. EPS 3-EE-74-1, (September, 1974).

Marion, T.L., "Spill Retention with Plastic Films", Production Research and Technical Service Laboratory, Imperial Oil Ltd., Internal Laboratory Report No. L-46174 (July, 1974).

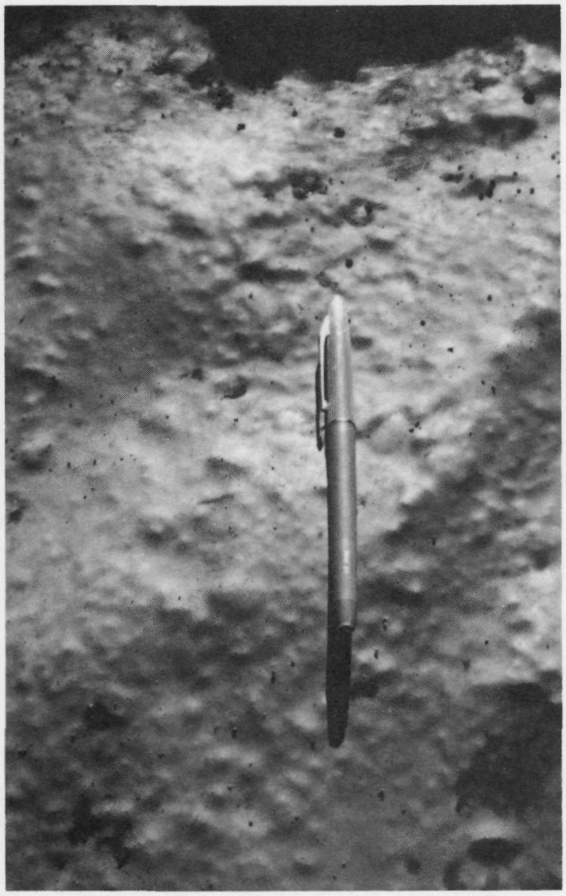


Photo 1: IOL Bar C (30 mil. oil PVC)

- installed under .5 - 1.5 ft. gravel on a gravel foundation. Note the indentations caused by the gravel particles and chunks below. No punctures are visible, however.

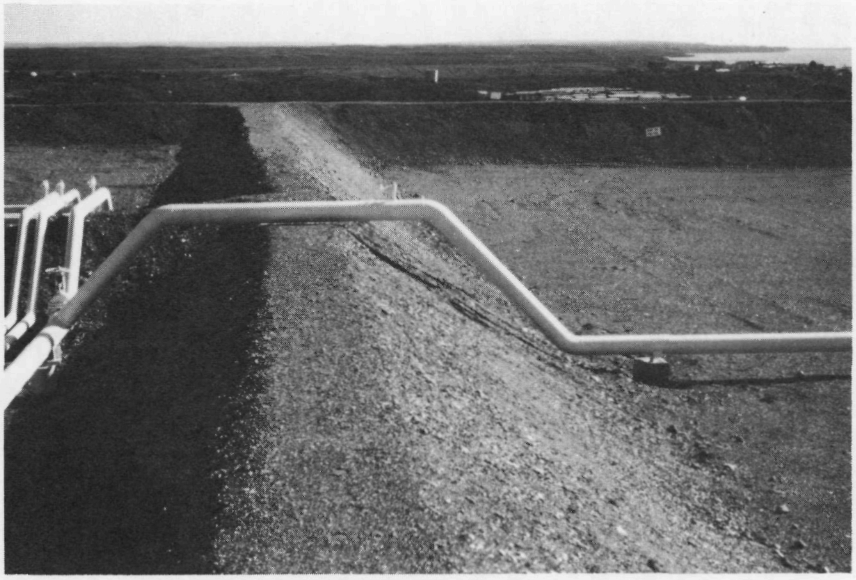


Photo 2: IOL Bar C (30 mil. oil PVC)

- liner extends into these well formed dykes. A little minor sloughing can be seen on the inside surface of the dykes in the upper right. Note the pipeline passes over the dyke--a preferable practice to placing it through the dyke wall.

Photo 3: Gulf Swimming Point (10 mil. polyethylene)

- installed under 1-2 ft. gravel overburden on about 2 inches of polyurethane foam bedding. The colour and texture of the polyurethane foam can be seen through the transparent liner. The line has been well protected by the overburden and no flaws are visible

Photo 4: Gulf Swimming Point (10 mil. polyethylene)

- creases are visible in the liner, but no punctures.

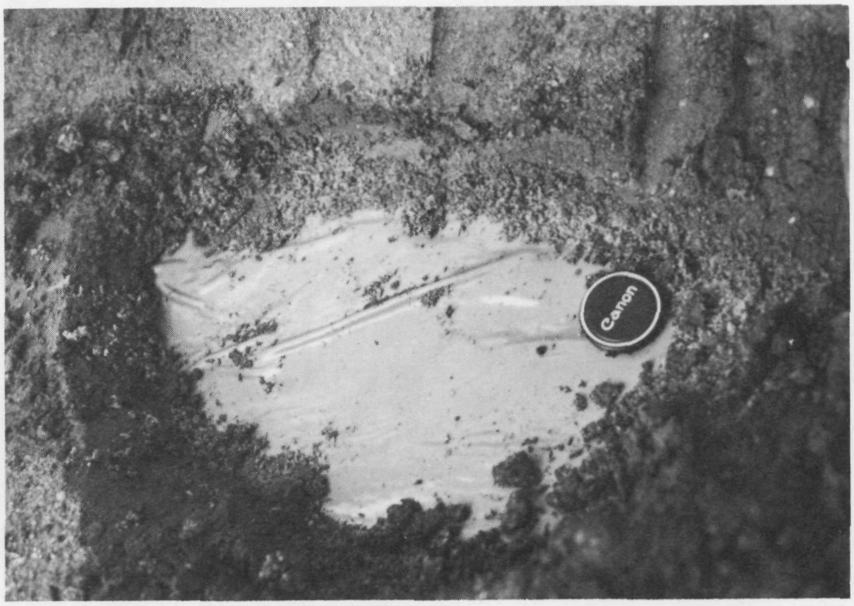


Photo 5: Shell Farewell (20 mil. urethane)

- liner installed between layers of sawdust about 2 inches thick and buried under 0.5-2 ft. of sandy gravel. The liner has been well protected.

Photo 6: Shell Farewell (20 mil. urethane)

- note water seeping into the excavation indicating that little seepage occurs through the liner.

Photo 7: Shell Farewell (20 mil. urethane)

- a portion of liner in the dyke wall has been exposed and damaged. The liner is adjacent to valves on piping passing through the dyke wall and, presumably, this area receives a fair amount of traffic.

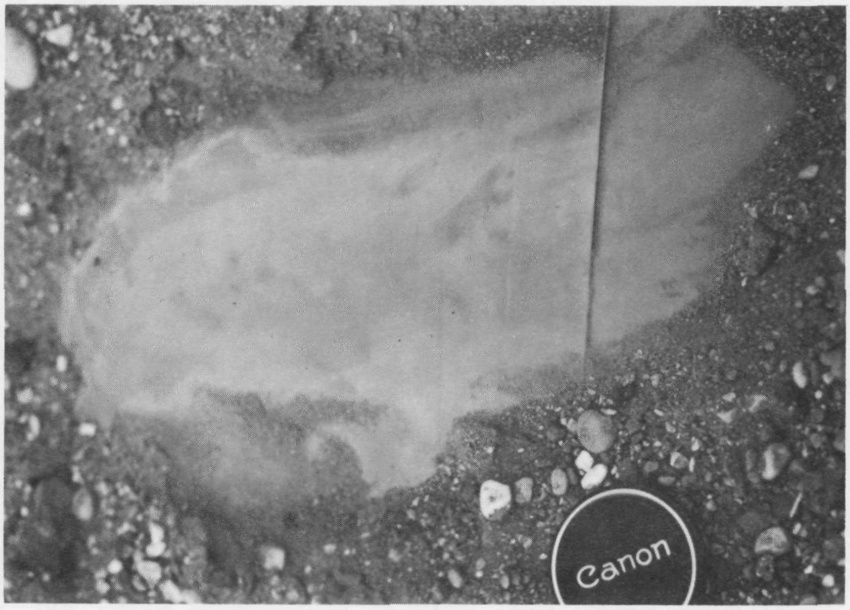


Photo 8: Shell Farewell (20 mil. urethane)

- an excavation in the exterior wall of the dyke uncovered this portion of the liner, showing a seam.

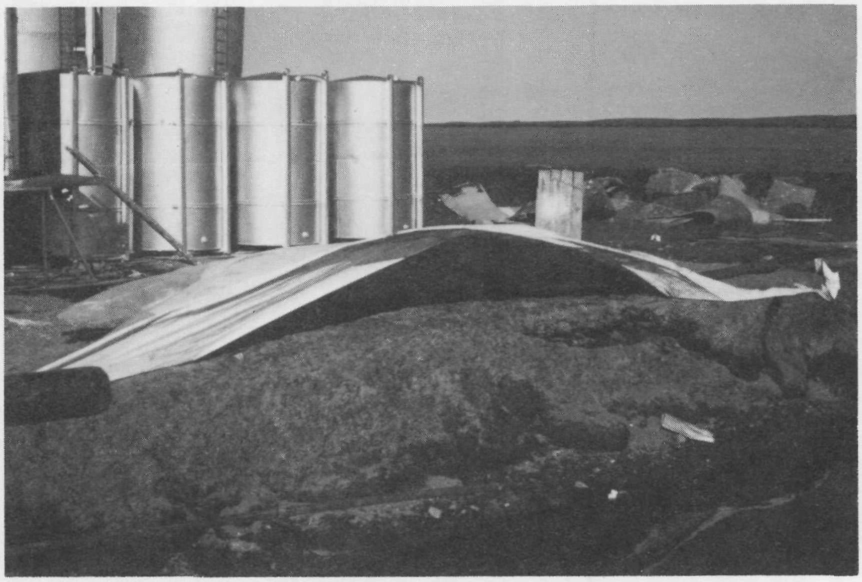


Photo 9: Shell Titalik A-16
(6 mil. Rufco)

- The billowing action of the wind is lifting one edge of the liner and a section of the polyurethane foamed sacking which was used as a bedding under the liner can be seen. Many other blankets which were originally emplaced on top of the liner for protection have been displaced by the wind and are resting against the unconsolidated silt dykes on the right of the picture. Note the drill rig sump on the lower right which forms a spill catchment basin along one side of the fuel storage area. Despite the punishment afforded by the action of the wind, the liner is remarkably intact.

Photo 10: Shell Titalik A-16 (6 mil. Rufco)

- the liner does not extend up into the uncompacted silt dyke on the left. Note the protective cover of polyurethane blankets just showing under a thin layer of gravel.

Photo 11: Shell Titalik A-16 (6 mil. Rufco)

- Pedestrian activity has pressed the particles and chunks of gravel into the liner producing marked indentations, but no punctures.

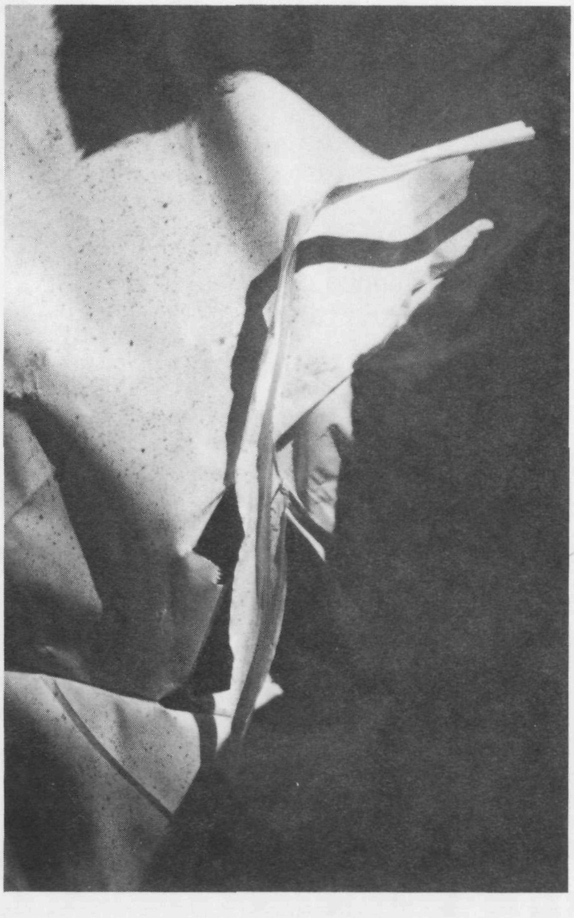


Photo 12: Shell Titalik A-16 (6 mil. Rufco)

- a section of liner torn along a seam. The damage was probably caused by wind action.

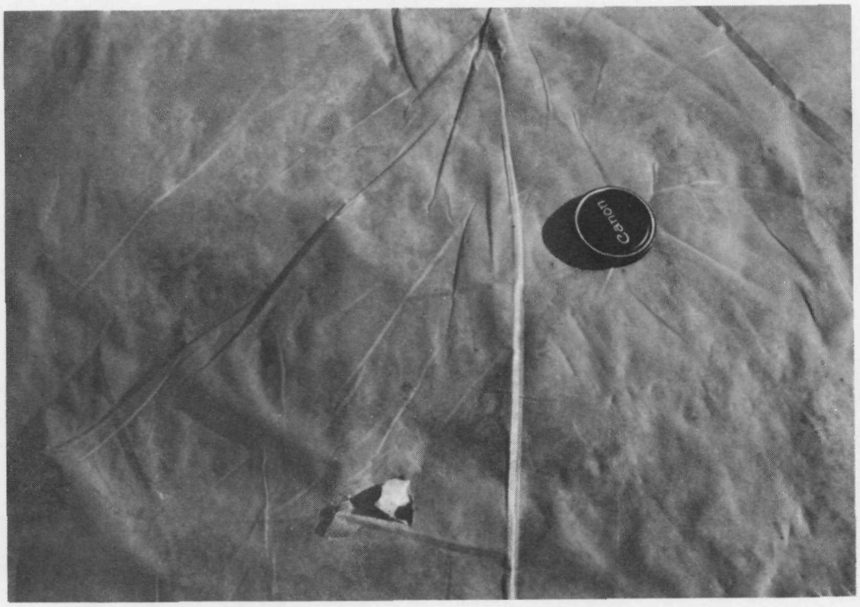


Photo 13: Shell Titalik A-16 (6 mil. Rufco)

- possibly a snag tear

Photo 14: Sunoco Garry P-04
(Polyfabric 1855)

- this fibre-reinforced liner is deployed in blankets under bladders, directly on top of a gravel base. It is doubtful that this limited use of lining material would serve effectively in the event of a spill. Uncompacted silt dykes around the fuel storage area can be seen in the background.

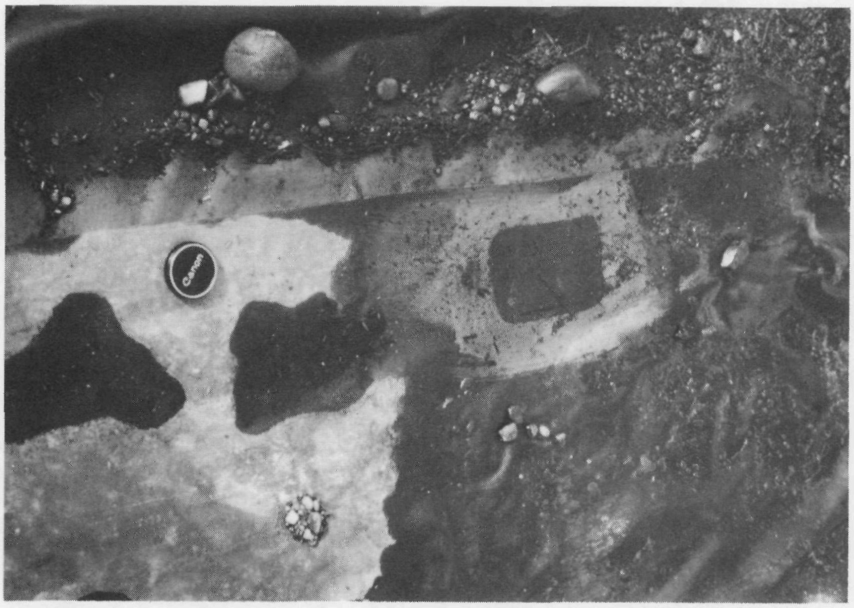


Photo 15: Sunoco Garry P-04 (Polyfabric 1855)

- showing a puncture at the lower left and a patch installed at the factory. The liner had been reused on a number of occasions.

Photo 16: Sunoco Garry P-04 (Polyfabric 1855)

- a tear in the fibre-reinforced liner

Photo 17: Sunoco Garry P-04 (Polyfabric 1425)

- a tear caused by a skid sinking into uncompacted gravel and the action of wind.

Photo 18: Chevron North Ellice (20 mil. polyurethane)

- liner installed on the surface of uncompacted gravel dykes and pad. The inadequate anchoring of the liner into the dyke crests could cause problems resulting from wind action. The water pooling in the storage area floor indicates the general integrity of the liner.

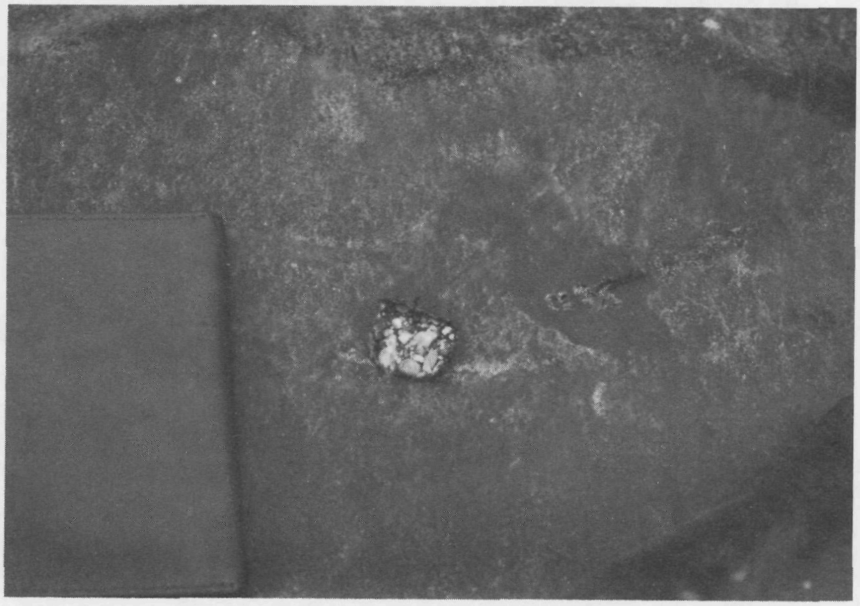


Photo 19: Chevron North Ellice (20 mil. polyurethane)

- a severe puncture in the centre of the picture, showing the poorly sorted gravel beneath. A scar on the liner with pinhole punctures is visible just to the left. This damage was probably associated with the movement of equipment over the liner as foot traffic apparently made little impression, at least at a temperature of about 5°C. For scale, the pocket-book on the left measures 6 inches.

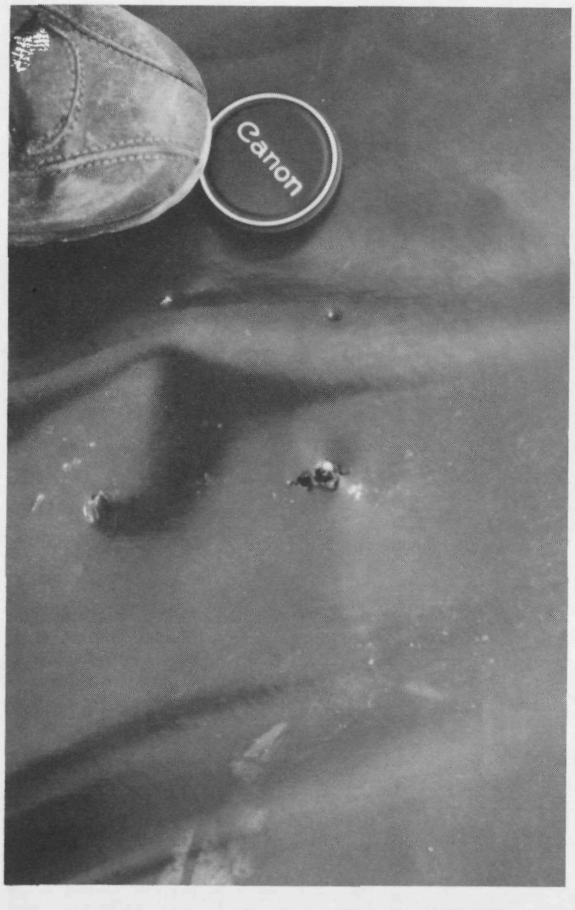


Photo 20: Chevron North Ellice (20 mil. polyurethane)

- a number of small punctures in the liner produced by surface activity and gravel particles penetrating from below. Even this particularly strong lining material is subject to damage when installed on an unprepared surface.

Photo 21: IOL Garry Repeater, Dennis High Hill (6 mil. Rufco)

- the liner has been installed between two layers of sawdust and given a thin cover of gravel for protection. Apparently a fire had occurred at some time and damaged the liner.

Photo 22: IOL Garry Repeater, Dennis High Hill (6 mil. Rufco)

- a close-up of the fire-damaged liner.