



Environment
Canada

Environnement
Canada

Environmental
Protection
Service

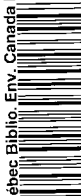
Service de la
protection de
l'environnement

12 627

P5 m05

Evaluation of the Hydrocarbon Leak Detection Device Leak "X"

Rég. Québec Biblio. Env. Canada Library



38 502 847

TD
182
R46
4-EC-78-10

Technology Development

Report EPS 4-EC-78-10

Environmental Impact Control Directorate
December 1978

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Technology Development Reports describe technical apparatus and procedures, and results of laboratory, pilot plant, demonstration or equipment evaluation studies. They provide a central source of information on the development and demonstration activities of the Environmental Protection Service.

Other categories in the EPS series include such groups as Regulations, Codes, and Protocols; Policy and Planning; Technology Development; Surveillance; Briefs and Submissions to Public Inquiries; and Environmental Impact and Assessment.

Inquiries pertaining to Environmental Protection Service Reports should be directed to the Environmental Protection Service, Department of the Environment, Ottawa, K1A 1C8, Ontario, Canada.

© Minister of Supply and Services Canada 1978

Cat. No. En 46-4/78-10

ISBN 0-662-10063-8

EVALUATION OF THE HYDROCARBON LEAK DETECTION DEVICE LEAK "X"

by

Materials Science Division
R.M. Hardy & Associates Limited
Calgary, Alberta

for the

Environmental Emergencies Section
Environmental Protection Service
Department of the Environment
Northwest Region
Edmonton, Alberta

EPS 4-EC-78-10
December 1978

REVIEW NOTICE

This report has been reviewed by the Environmental Impact Control Directorate, Environmental Protection Service, and approved for publication. Approval does not necessarily infer that the content reflects the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

ABSTRACT

A laboratory evaluation of the petroleum leak detection device, Leak "X", was performed to evaluate the response times to various petroleum products. Response times of one to two hours were found for gasoline and overhead naphtha. In diesel fuel, response times varied from three to nineteen hours, depending on the temperature. In crude oil, the reaction time varied from two hours to several days, depending on the type of cable used and the temperature. Tests conducted in various types of soils showed that in impervious clays and silts the reaction time is two to three times slower than in sands or gravels. Preliminary evaluation of weathering effects on the detection cable were performed and it was concluded that long-term evaluation of weathering effects on the cable should be performed.

RÉSUMÉ

Nous avons évalué en laboratoire le temps de réaction du détecteur Leak "X" de fuites d'hydrocarbures pour divers produits pétroliers. Pour l'essence et le distillat naphta de tête, ce temps était d'une à deux heures; il variait de trois à 19 heures pour le gas-oil, selon la température et de deux heures à plusieurs jours pour le "brut", selon la température et le type de câble servant à la détection. Des tests effectués dans divers sols ont montré que le détecteur réagissait deux à trois fois moins vite dans les argiles et les limons imperméables que dans les sables ou les graviers. Nous avons fait une évaluation préliminaire des effets d'altération sur le câble de détection et avons conclu à la nécessité de l'étudier à long terme.

FOREWARD

The work described in this report was performed by R.M. Hardy & Associates Limited under contract to the Environmental Emergency Branch, Department of the Environment.

Mr. Robert H. Weir, Environmental Protection Service, Northwest Region, acted as scientific authority for this project, in cooperation with Mr. David E. Thornton, Environmental Emergency Branch, Edmonton, and Mr. Mervin F. Fingas, Environmental Protection Service, Ottawa.



TABLE OF CONTENTS

| | Page |
|--|------|
| ABSTRACT | i |
| RÉSUMÉ | ii |
| FOREWARD | iii |
| LIST OF PLATES | vi |
| LIST OF TABLES | vii |
| 1 INTRODUCTION | 1 |
| 1.1 Leak "X" Equipment | 1 |
| 2 "TIME TO ALARM" EXPERIMENTAL PROCEDURES | 3 |
| 2.1 Tests in Pure Hydrocarbons | 3 |
| 2.2 Hydrocarbon/Compacted Soil Tests | 4 |
| 2.3 Discussion of "Time to Alarm" Determinations | 4 |
| 3 LONG-TERM BEHAVIOUR OF CABLE | 14 |
| 3.1 Laboratory Methods Presently Available | 14 |
| 3.2 Assessment of Cable Characteristics | 14 |
| 3.2.1 Experimental Procedures | 15 |
| 3.2.2 Observations | 16 |
| 4 SUMMARY AND CONCLUSIONS | 18 |
| APPENDIX A SOILS CHARACTERIZATION AND OTHER DATA | 19 |

LIST OF PLATES

| Plate | | Page |
|-------|--|------|
| 1 | CONDITION OF CABLE A AFTER TEST IN GASOLINE | 6 |
| 2 | CONDITION OF CABLE B AFTER TEST IN GASOLINE | 7 |
| 3 | CONDITION OF CABLE D AFTER TEST IN CRUDE OIL | 8 |
| 4 | CABLE D WITHOUT EXPOSURE TO HYDROCARBONS, AND CABLE B WITHOUT EXPOSURE TO OIL | 9 |

LIST OF TABLES

| Table | | Page |
|-------|--|------|
| 1 | LEAK "X" CABLE TYPES USED IN "TIME TO ALARM" EXPERIMENTS | 3 |
| 2 | "TIME TO ALARM" DETERMINATIONS IN PURE HYDROCARBON LIQUIDS | 5 |
| 3 | "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON COMPACTED SOIL TESTS (UNLEADED GASOLINE AT 20°C) | 11 |
| 4 | "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON COMPACTED SOIL TESTS (DIESEL OIL AT 20°C) | 11 |
| 5 | "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON COMPACTED SOIL TESTS (OVERHEAD NAPHTHA AT 20°C) | 12 |
| 6 | "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON SOIL TESTS (UNCOMPACTED, DRY, WASHED, CRUSHED SAND AT 20°C) | 12 |
| 7 | "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON COMPACTED SOIL TESTS (CRUDE OIL) | 13 |
| 8 | DISSOLVED MINERAL CONTENT OF TEST SOLUTIONS | 15 |
| 9 | PROPERTIES OF AGED DIELECTRIC CABLE | 17 |
| 10 | ABSORBED ENERGY REQUIRED TO PULL DIELECTRIC APART | 17 |

1 INTRODUCTION

R.M. Hardy and Associates Limited evaluated a hydrocarbon detection system manufactured by Leak "X" Detection Devices Limited, of Ottawa, Ontario. (The term Leak "X" is used throughout this report, and generally refers to the cable and monitor system, or to the company, Leak "X" Detection Devices Limited.)

The investigation was conducted in two phases. Phase I consisted of testing the performance of a variety of Leak "X" cables under laboratory conditions with particular emphasis on the "time to alarm". Phase II dealt exclusively with the feasibility of using rapid aging methods to simulate cable condition following continued exposure to soil.

The Leak "X" sensor cable is a twisted pair of interwoven conductors which degrade upon contact with liquid phase hydrocarbons. The time required for deterioration to cause short circuiting of the system, and hence, to sound an alarm, is dependent upon the nature of the hydrocarbon and various environmental conditions.

The cable was continually monitored electrically, and when short circuited, a warning device was triggered.

The cable can be installed unprotected or with interlocking aluminum armour.

1.1 Leak "X" Equipment

The success of any system that informs an operator of a hydrocarbon spill depends upon the speed and accuracy with which that spill can be located. Present methods rely heavily on flow or pressure changes between metering and pumping stations, and level or pressure fluctuations in storage tanks, followed by visual identification of the hydrocarbon from the air.

Some metering systems are sufficiently sensitive to detect 0.1 percent changes of flow through pipelines. The Leak "X" system, on the other hand, is not dependent upon the magnitude of a hydrocarbon leak; it depends upon contact with liquid hydrocarbons.

In order to locate the precise point of short circuit caused by either physical cable damage or dielectric deterioration, Leak "X" makes use of an electrical fault locator and an open circuit locator. It was not within the scope of this investigation to evaluate the performance of these devices.

It should be added though that this system cannot at present distinguish fresh spills from "alarms" triggered by soil previously contaminated with oil. Leak "X" supplies several different types of cable for light and heavy petroleum products and for various applications. Six types of cable were evaluated in this study; descriptions of these appear in Table 1.

In the normal use of the devices in petroleum storage areas, detection cables are laid under and around the tanks and piping. Perforated plastic tubing is normally used to shield the cable from physical damage from the fill. The use of the tubing also permits replacement of the cable without excavation and removal of the tank.

The firm also markets a PORTA PROBE KIT which has application as a rapid "ball-park" method of locating hydrocarbon leaks underground. The components of this kit include an auger base, extensions, and sensor cable. The perforated steel pipe is bored into the ground manually or electrically at the location that is suspected of being contaminated by liquid hydrocarbons. The Leak "X" sensor cable with accompanying terminating resistor is inserted into the pipe and connected at ground level to a portable Leak "X" monitor. The cables used in the PORTA PROBE are the same as those tested in this program.

2 "TIME TO ALARM" EXPERIMENTAL PROCEDURES

2.1 Tests in Pure Hydrocarbons

Six types of sensor cable were used and are described in detail in Table 1. The liquid hydrocarbons used in all of these "time to alarm" experiments are identified in Table 2. Where possible, an effort has been made to anticipate the range of temperatures to which the Leak "X" sensor cable would be exposed during its operating lifetime.

Test cables of approximately 18 inches in length were connected to the electrical monitor and 100 K ohm resistor. The midsection was set in a beaker of hydrocarbon, which had been stabilized at a pre-determined temperature, and the timer was engaged. The "time to alarm" was noted as the time between first exposure and the short-circuit of the system.

TABLE 1 LEAK "X" CABLE TYPES USED IN "TIME TO ALARM" EXPERIMENTS

| | |
|----------|--|
| Cable A* | No. 20 A.W.G. 35 mil thick, 65 hardness butadiene copolymer insulation, seven strand tinned copperweld conducting core. |
| Cable B | No. 20 A.W.G. jacketed cable. Yellow jacket - 15 mil thick, 65 hardness butadiene copolymer white core insulation, 35 mil thick, 90 hardness, butadiene copolymer, seven strand tinned copperweld, conducting core. |
| Cable C | Armoured version of Cable A using interlocking aluminum jacket. |
| Cable D | Armoured version of Cable B using interlocking aluminum jacket. |
| Cable E | No. 20 A.W.G. 10 mil thick, 65 hardness black butadiene copolymer, using single strand stainless steel conducting core. |
| Cable F | No. 20 A.W.G. 15 mil thick, 30 hardness butadiene copolymer, seven strand tinned copperweld conducting core. |

* This designation has been assigned by R.M. Hardy & Associates Ltd. and is not related to the Leak "X" trade description of each cable.

The results of the "time to alarm" experiments are shown in Table 2 and the appearance of the test cables are illustrated in Plates 1 to 4. These results suggest that at low temperatures Cables E or F are most suitable for the detection of heavy hydrocarbons; and Cables A and B are most suitable for the detection of lighter, refined hydrocarbon liquids.

2.2 Hydrocarbon/Compacted Soil Tests

In order to generate sufficient baseline "time to alarm" data for the sensor cables tested, experiments were carried out in typical Canadian soils and soil conditions. No attempt, however, was made to reproduce conditions such as tundra or muskeg which are anticipated in northern Canada.

Petrographic characterizations of the clay, silt and sand used in these tests are presented in detail in Appendix A.

For each experiment, Leak "X" cables were located in a container of soil which was then compacted by means of a Marshall hammer. The ends of the cables protruding from the vessel were connected to the monitor and terminating resistor. The desired hydrocarbon was poured directly onto the surface of the soil, and the timer was engaged.

In all of the experiments, the depth of soil above the cable was maintained at three inches in order to compare results. The "time to alarm" includes the time required by the hydrocarbon to percolate through the soil and degrade the dielectric.

2.3 Discussion of "Time to Alarm" Determinations

The data presented in Table 2 indicate that when the Leak "X" cables are located in hydrocarbon only, all are relatively sensitive over a fairly broad temperature range to the lighter fluids such as gasoline and overhead naphtha. The cables with harder dielectrics (in particular, Cable B) are less sensitive to liquid hydrocarbons of greater specific gravities as evidenced by the increased in "time to alarm".

An increase in the operating temperature of the system contributes to a decrease in the times for Cable B in the presence of the heavier fluids. This can be explained by the fact that at higher temperatures the physical properties of heavy hydrocarbons are such that the fluids permeate the cable dielectric more rapidly than at lower temperatures.

The use of aluminum armour on Cables C and D did not interrupt the free flow of light hydrocarbons to the cables; the "times to alarm" are essentially identical for armoured and unarmoured cables in gasoline, naphtha and diesel oil. Crude oil did not

TABLE 2 "TIME TO ALARM" DETERMINATIONS IN PURE HYDROCARBON LIQUIDS

| | CABLE A | | CABLE B | | CABLE C | | CABLE D | | CABLE E | | CABLE F | |
|---|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|
| | Temp. °C | Time (hr) | Temp. °C | Time (hr) | Temp. °C | Time (hr) | Temp. °C | Time (hr) | Temp. °C | Time (hr) | Temp. °C | Time (hr) |
| Unleaded Gasoline (67.7° API at 60°F) | 4 | 0.85 | 2 | 3.55 | 0 | 0.93 | 5 | 3.55 | | | | |
| | 13.5 | 0.52 | | | | | | | | | | |
| | 21 | 0.43 | 19.5 | 1.73 | 21 | 0.45 | 22 | 1.80 | | | 21 | 0.20 |
| Diesel Oil (35.1° API at 60°F) | 5 | 17.17 | 5 | 17.38 | 5 | 8.58 | 5 | 19.12 | | | | |
| | 20.6 | 2.82 | 22.8 | 9.10 | 23 | 3.45 | 23 | 10.87 | | | 21 | 0.75 |
| | | | | | | | | | | | | |
| Overhead Naphtha (49.9° API at 60°F) | 6 | 1.42 | 6 | 4.35 | | | | | | | | |
| | | | 8 | 4.25 | | | | | | | | |
| | 10 | 1.65 | 10 | 6.92 | 10 | 1.83 | 10 | 6.83 | | | | |
| | 23 | 0.85 | 23 | 2.68 | 22 | 0.73 | 22 | 2.73 | | | 21 | 0.37 |
| Crude Oil (23.6° API at 60°F) | 22 | 24.00 | 22 | 28.00 | 22 | 28.00 | 22 | 28.00 | 23 | 12.33 | 21 | 10.07 |
| | 41 | 5.00 | | | 41 | 7.77 | | | | | | |
| | 54 | 2.52 | 54 | 7.33 | 54 | 3.30 | 50 | 24.00 | 50 | 1.30 | 34 | 4.25 |
| | | | | | | | 54 | 24.00 | | | | |

5

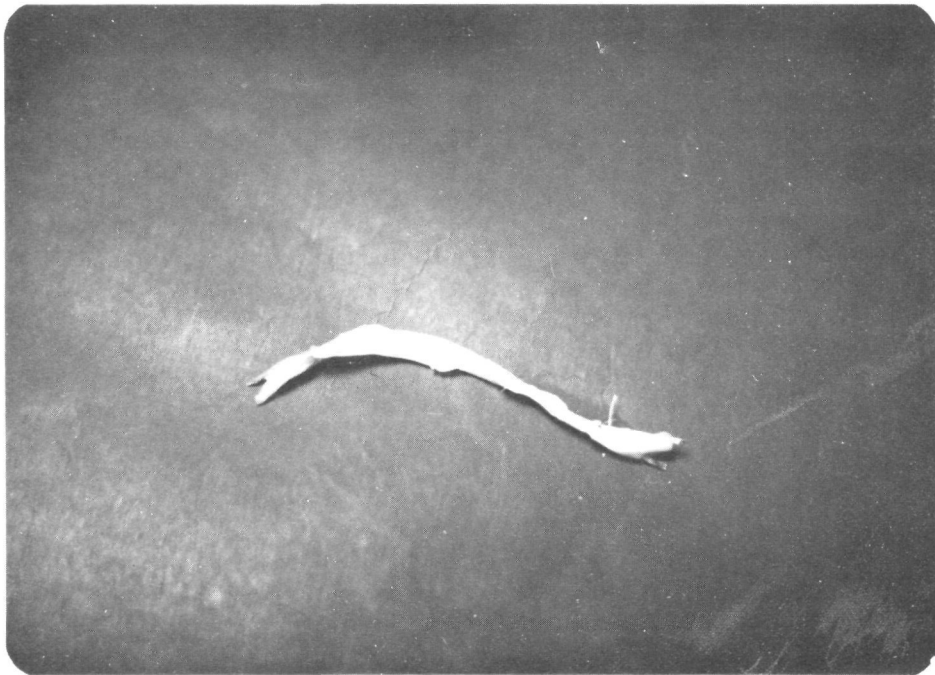


PLATE I CONDITION OF CABLE A AFTER TEST IN GASOLINE

THIS INDICATES THE CONDITION OF CABLE A FOLLOWING EXPOSURE TO GASOLINE UNTIL "TIME TO ALARM". THE DIELECTRIC HAS BECOME EXTREMELY SOFT; WHILE IN THE SOFT CONDITION, IT IS VERY SUSCEPTIBLE TO DETERIORATION BY ABRASION.

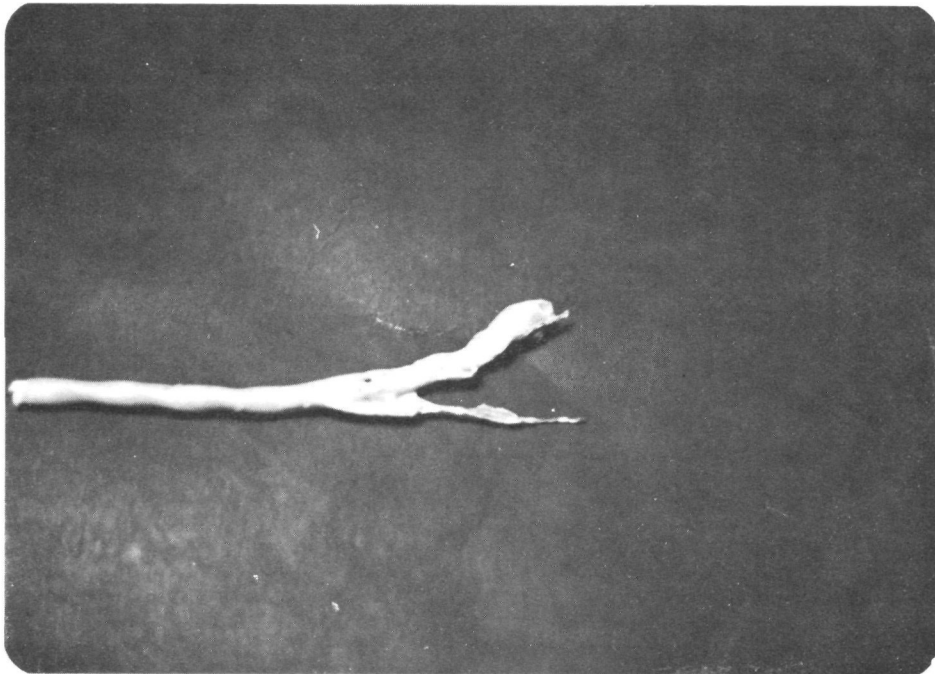


PLATE 2 CONDITION OF CABLE B AFTER TEST IN GASOLINE

THIS INDICATES THE CONDITION OF CABLE B FOLLOWING EXPOSURE TO GASOLINE UNTIL "TIME TO ALARM" OF APPROXIMATELY 1.7 HOURS. THE CONDUCTING CORES WERE MANUALLY SEPARATED AND DID NOT SHOW SIGNS OF MIGRATING APART WHEN SATURATED WITH HYDRO-CARBON. WHILE IN THIS CONDITION, CABLE B IS ALSO VERY SUSCEPTIBLE TO DETERIORATION BY ABRASION.

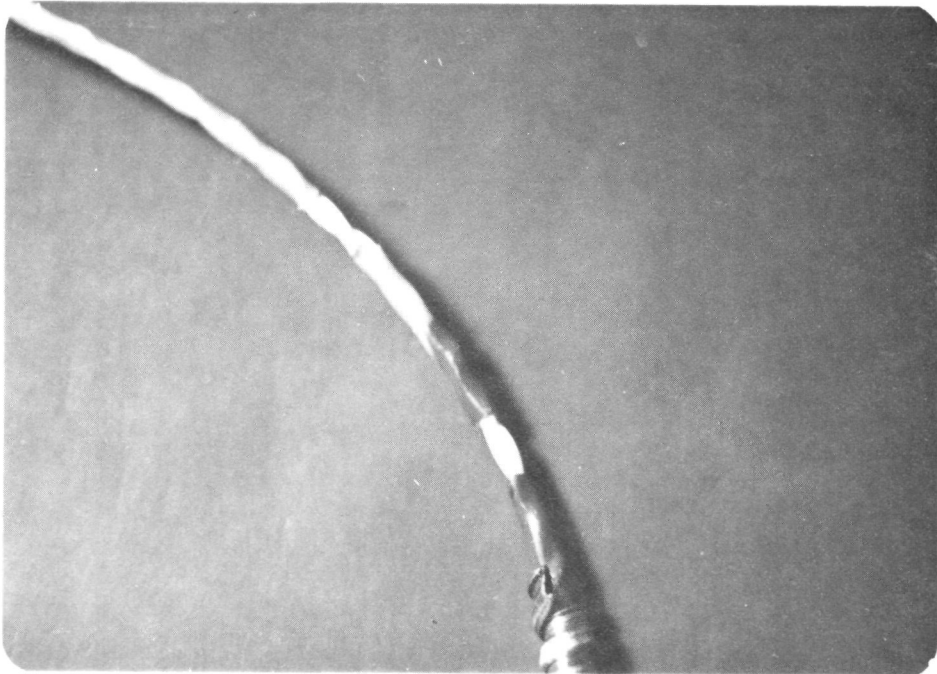


PLATE 3 CONDITION OF CABLE D AFTER TEST IN CRUDE OIL

THIS INDICATES THE CONDITION OF CABLE D FOLLOWING EXPOSURE TO CRUDE OIL FOR OVER 28 HOURS. TO AVOID CUTTING THE CABLE, THE ALUMINUM ARMOUR WAS REMOVED, AND SURFACE OIL WAS WIPED AWAY. THE YELLOW JACKET WAS REMOVED IN ORDER TO EXPOSE THE CORE INSULATION FOR VISUAL EXAMINATION AT A POINT WHERE THE CABLE WAS IN CONTACT WITH THE OIL, AND ALSO AT A LOCATION OF NO CONTACT WITH OIL.

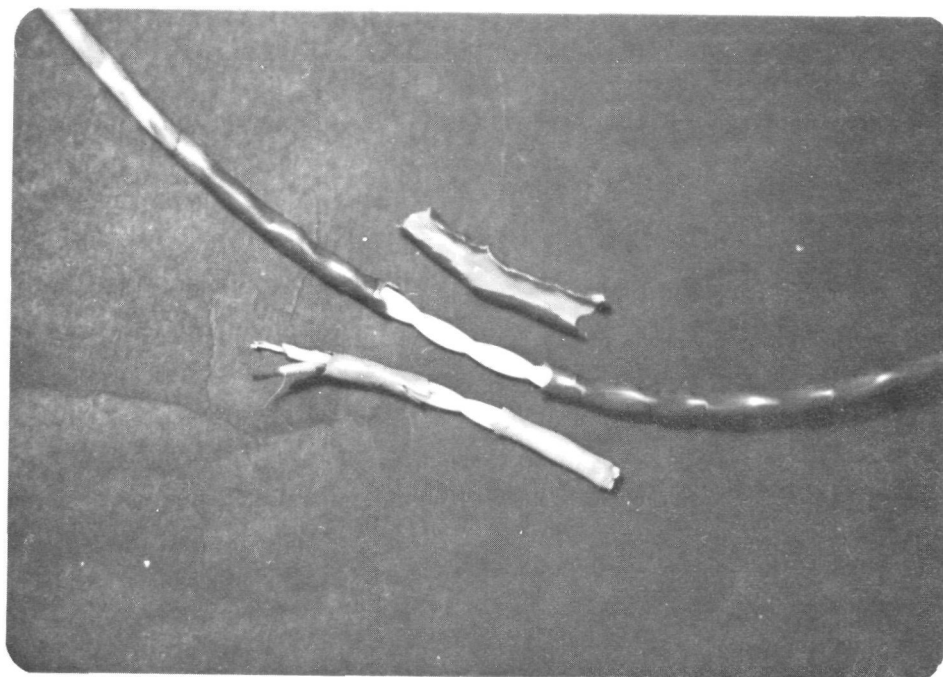


PLATE 4 CABLE D WITHOUT EXPOSURE TO HYDROCARBONS, AND CABLE B WITHOUT EXPOSURE TO OIL

THIS INDICATES ANOTHER SECTION OF THE CABLE SHOWN IN PLATE 3. THE CABLE HAS BEEN SLIT OPEN FOR VISUAL EXAMINATION AFTER THE ARMOUR HAS BEEN REMOVED. CABLE B IS SITUATED IN THE FOREGROUND; IT IS NOT EXPOSED TO OIL. THE MAJOR NOTICEABLE DIFFERENCE BETWEEN THE TWO IS A SLIGHT DISCOLOURATION OF THE YELLOW JACKET, BUT THERE IS NO VISIBLE SOFTENING OF THE CORE INSULATION ON ABSORPTION OF OIL.

pass through the interlocking armour as rapidly; hence, there was an increase in the time before the monitor "alarmed". An experiment with Cable A in crude oil at room temperature failed to "alarm" after 168 hours. Examination of the cable revealed that deterioration of the dielectric was insufficient to cause the sensor wires to touch and trigger the monitor. Therefore, it was decided that experiments conducted at room temperature with Cables A, B, C and D in crude oil would be terminated after 24 or 28 hours if the monitor had not "alarmed".

The most significant "time to alarm" data in crude oil was achieved using Cables E and F which have thinner and softer dielectrics.

In experiments where Cables A and B were tested in soil, the "times to alarm" generally increased as the soil medium decreased in permeability. Gasoline passed through the crushed sand very rapidly, disturbing the original compaction. The "times to alarm" determined in sand are basically the same as those determined in the liquid phase at 20°C.

In comparison, the silt and Lake Agassiz clay have higher indices of plasticity and lower coefficients of permeability, creating a substantial barrier to the flow of hydrocarbon to the cables.

The heavier diesel oil did not pass through any of the soil media as rapidly as the gasoline (Table 3). Hence, there was a dramatic increase in reaction times over the baseline data generated without soil present. The unwashed, crushed sand contained approximately six times more mineral filler than the washed, resulting in fewer void spaces to be filled by the free-flowing hydrocarbon. It is believed that this characteristic contributed to an increase in the "time to alarm".

Data in Tables 3, 4 and 5 indicate that Cables A and B, when exposed to gasoline, diesel oil and naphtha, generally had longer reaction times in silt or clay than in sand or gravel. This phenomenon is related to the lower permeabilities of the silt and clay vis-à-vis the hydrocarbons. Tests were also conducted with crude oil as the test medium. Table 7 presents results of tests using crude oil in compacted soil. These results indicate the effect of increasing viscosity upon the cables: the greater the viscosity of the product, the greater the "time to alarm".

"Times to alarm" were also determined in uncompacted, washed, crushed sand (Table 6). When wet with hydrocarbon, the consolidation of the sand decreased rapidly, permitting easy access of light hydrocarbons to the Leak "X" cable.

The data presented suggest that the Leak "X" cable and monitor will warn an operator of a hydrocarbon leak within a reasonable length of time; however, the "time to alarm" is dependent on field conditions.

TABLE 3 "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON
COMPACTED SOIL TESTS (UNLEADED GASOLINE @ 20°C/68°F)

| | CABLE A | CABLE B |
|-----------------------------|--------------|---------|
| | Time (hours) | |
| Dry, washed, crushed sand | 0.55 | 2.15 |
| Dry, unwashed, crushed sand | 0.75 | 1.96 |
| Pit run gravel | 0.75 | |
| Silt | 1.53 | 2.35 |
| Lake Agassiz clay | 1.92 | 16.08 |

TABLE 4 "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON
COMPACTED SOIL TESTS (DIESEL OIL @ 20°C/68°F)

| | CABLE A | CABLE B |
|-----------------------------|--------------|---------|
| | Time (hours) | |
| Dry, washed, crushed sand | 5.12 | 17.55 |
| Dry, unwashed, crushed sand | 6.35 | 4.42 |
| Silt | 9.08 | 20.36 |
| Lake Agassiz clay | 5.46 | 12.98 |

TABLE 5 "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON
COMPACTED SOIL TESTS (OVERHEAD NAPHTHA @ 20°C/68°F)

| | CABLE A | CABLE B |
|-----------------------------|---------------------|---------|
| | <u>Time (hours)</u> | |
| Dry, washed, crushed sand | 1.27 1.25 | 4.17 |
| Dry, unwashed, crushed sand | 1.37 | 4.12 |
| Pit run gravel | 1.37 | |
| Silt | 1.51 | 12.00 |
| Lake Agassiz clay | 5.28 | 17.52 |

TABLE 6 "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON
SOIL TESTS (UNCOMPACTED, DRY, WASHED, CRUSHED SAND
@ 20°C/68°F)

| | CABLE A |
|-------------------|---------------------|
| | <u>Time (hours)</u> |
| Unleaded gasoline | 0.58 |
| Diesel oil | 3.02 |
| Overhead naphtha | 1.27 |

TABLE 7 "TIME TO ALARM" DETERMINATIONS IN LIQUID HYDROCARBON COMPACTED SOIL TESTS (CRUDE OIL)

| | | CABLE F | CABLE A |
|-------------------|---------------|--------------|---------|
| | | Time (hours) | |
| Unwashed sand | @ 30°C/86°F | 2.0 | 10.42 |
| Lake Agassiz clay | @ 32°C/89.6°F | 1.42 | |
| Silt | @ 30°C/86°F | 5.37 | |

The type of cable employed in the field must be closely allied to the flow characteristics of the hydrocarbon under surveillance. Thick, hard dielectric insulators are not suitable for detecting highly viscous crude oils. Also, the proximity of the cable to the installation will very much affect the "time to alarm".

The experiments described cannot be considered to be scaled replicas of situations in the field, but the data support the theory that clays and silts will impair the performance of this device more than highly porous sands or gravel.

The soft dielectric cables are well suited to the detection of crude oils or similar, heavy hydrocarbons. However, without adequate protection in the form of armour or P.V.C. conduit, these cables will have a much shorter lifetime than the more rugged jacketed cables (Cables B or D), due to abrasion during installation or ground settlement.

Although the threshold hydrocarbon concentrations required to "alarm" each cable in soil were not determined, it is felt that installations of the Leak "X" system in terrain containing hydrocarbons will most likely predicate "false alarms", necessitating cable replacement.

3 LONG-TERM BEHAVIOUR OF CABLE IN SOIL

3.1 Laboratory Methods Presently Available

Prior to the initiation of any techniques to facilitate the aging or deterioration of the Leak "X" cable insulation, the methods suggested by the American Society for Testing and Materials were reviewed for their correlative applicability to the anticipated conditions imposed upon the butadiene copolymer during its operating life. (See ASTM D454, D518, D573, D865-62, D1870-68 and D3395-75.)

In general, these methods cover the estimation of the relative resistance of vulcanized rubber to age deterioration as brought about by exposure to high temperatures under controlled conditions of air circulation, variable atmospheric pressures, or ozone concentrations. Before and after aging, the test specimens are characterized according to their tensile strength and elongation, dielectric strengths, or resistance to abrasion. It is anticipated that by using these test methods no exact correlation will exist between the results of these tests and the performance of the cable dielectric during normal life conditions because the aging of insulation in soils is of a more complex nature than implied in the ASTM procedures.

Since it is felt that aging of the cable is due to the deterioration or corrosion of the cable by harmful soil or water conditions, specially designed experiments incorporating these factors were performed to measure the effects of aging.

3.2 Assessment of Cable Characteristics

Originally, a broad range of physical, chemical and electrical tests were proposed by which the cable properties could be characterized prior to and following aging. Because the M-105 monitor "alarmed" much sooner than anticipated during these aging tests, it was decided that only those tests that would illustrate dramatic changes in the cables would be used. These tests are:

- Dielectric Breakdown Voltage
- Dielectric Strength
- Energy required to break dielectric. (This is representative of the tensile strength at maximum elongation.)

Although it is significant that there was little change in physical properties during these experiments, it is notable that the cables alarmed without the presence of hydrocarbons after only 17 hours.

3.2.1 Experimental Procedures

The environments for these aging experiments were prepared by mixing 4.0 kg of unwashed sand with two litres of the test solutions noted in Table 8. In each experiment five feet each of Cables A and B were connected, placed in a metal container, and the above mixtures added until the cables were immersed in the liquid environment. A stainless steel tube (1/8 in ID) crimped at the outlet was fixed in the container prior to the addition of the mixture. This tubing permitted the addition of gaseous carbon dioxide to the environment.

TABLE 8 DISSOLVED MINERAL CONTENT AND CHARACTERISTICS OF TEST SOLUTIONS

| | Solution A (mg/l) | Solution B (mg/l) |
|--------------|----------------------|----------------------|
| Calcium | 1972 | 1935 |
| Magnesium | 104 | trace |
| Chloride | 6090 | 5690 |
| Bicarbonate | 400 | 710 |
| Sulphate | 7250 | 6650 |
| Sodium | 5450 | 5450 |
| Potassium | 30 | 30 |
| pH | 7.32 | 6.66 |
| Conductivity | 16.6 milli mhos | 16.0 milli mhos |
| Resistivity | 0.6020 ohms/m | 0.6250 ohms/m |

The Leak "X" cables were connected in series to the M-105 Leak "X" monitor for the duration of the experiment, and the temperature of the solution was maintained at 30 - 60°C by means of an external heater. In both instances, carbon dioxide was bubbled into the liquid via the steel tubing at a rate of approximately 500 cc/min for one hour. The experiment was terminated in both cases when the M-105 monitor was "alarmed". (These times were 16.97 hours for Solution A and 16.47 hours for Solution B.)

Experiment containers were then cut open and the cables removed in a fashion that avoided unnecessary deterioration by abrasion. Water samples were retained for analyses and the cables were allowed to dry at room temperature and then tested.

Tests to discern the energy required to pull apart the dielectrics and elongation measurements were carried out on Cables A and B prior to and after aging on an MTS 810 Material Test System. A distinction was made in the case of Cable B between the external sheathing and the internal dielectric.

The dielectric strengths and breakdown voltages were measured in accordance with ASTM D-149.

3.2.2 Observations

The properties presented in Tables 9 and 10 suggest little measurable difference in the nature of the cable dielectric. Nevertheless, during the brief aging experiments some subtle changes appeared to occur that caused electrical conductance between the sensing cores. Prior to testing, the cables were allowed to dry for at least sixteen hours in the atmosphere; and it is quite conceivable that this was sufficient time to allow the cables to return, at least partially, to their original state.

TABLE 9 PROPERTIES OF AGED DIELECTRIC CABLE

| | Breakdown Voltage K volts rms | | Dielectric Strength volts per mil | |
|------------------------|----------------------------------|---------|--------------------------------------|---------|
| | Cable A | Cable B | Cable A | Cable B |
| Prior to Aging | 9.2 | 24.0 | 341 | 545 |
| Following Experiment A | 9.8 | 22.8 | 362 | 518 |
| Following Experiment B | 10.1 | 24.1 | 347 | 548 |

Laboratory Conditions at Time of Test

| | |
|---------------------|--------------|
| Barometric Pressure | 706.4 mm Hg |
| Temperature | 23.3°C |
| Relative Humidity | 33.6 percent |

The test samples were allowed to settle at these conditions for twenty-four hours prior to testing.

Thickness of Insulation

| | |
|---------|---|
| Cable A | 27 mil |
| Cable B | 17 mil for jacket; 27 mil for conductor insulation |

TABLE 10 ABSORBED ENERGY REQUIRED TO PULL DIELECTRIC APART (ft-lb)*

| | Prior to Aging | | Following Immersion in Solution A | | Following Immersion in Solution B | |
|--------------------|----------------|----------|---|----------|---|----------|
| Cable A Insulation | 1.61 | (2.183) | 1.27 | (1.722) | 1.39 | (1.885) |
| Cable B Jacket | 13.28 | (18.005) | 14.82 | (20.093) | 13.06 | (17.707) |
| Cable B Insulation | 3.81 | (5.166) | 5.42 | (7.348) | 4.65 | (6.304) |

*The values in parentheses are the metric equivalents $\times 10^7$ centimeter dynes.

4 SUMMARY AND CONCLUSIONS

The laboratory study showed that Leak "X" responds fairly rapidly to gasoline products and overhead naphtha (i.e., in about one hour). Activation in the case of diesel oil varied from two to twenty hours. In crude oil the cable activated in two hours at warm temperatures but did not activate at all within one day at lower temperatures.

The detection device was also tested under soils of various types. As might be expected, porous soils did not greatly change the activation time. However, with crude oil and impermeable soils, reaction time was very long.

On the basis of these results, it is concluded that Leak "X" is best suited for the detection of light petroleum products in porous soils. The activation times for crude oil - especially at lower temperatures - were not measured and are estimated to be at least in the order of days.

An attempt was made to evaluate the effect of weathering on the cable. Since this portion of the study did not yield any firm conclusions, it is recommended that the long-term evaluation of weathering effects on Leak "X" cable be investigated further.

The concept of Leak "X" appears to offer an economical method of detecting leaks of light petroleum products. Its advantages include the absence of operator input in the form of readings or calculations; the flexibility of the cable itself, thus permitting installation in most situations; and the ability to actually locate the area of the spill. The disadvantages of the product include non-renewability of the cable (replacement is required after an alarm); the device is non-quantitative; slow "time to alarm" for heavier petroleum products; uncertainty regarding the behaviour of the cable over long time periods in adverse environments; and the possibility of "false alarms" from soil previously contaminated with oil.

APPENDIX A

SOILS CHARACTERIZATION AND OTHER DATA

1 CHARACTERIZATION OF SOIL TYPES

1.1 Lake Agassiz Clay

| | |
|------------------------------------|-----------------------|
| Specific Gravity | 2.87 |
| Liquid Limit (Percent) | 111 |
| Plastic Limit | 29 |
| Plasticity Index (Percent) | 82 |
| Natural Moisture Content (Percent) | 41.4 |
| Bulk Density p.c.F. | 94.4 after compaction |

Visual Description:

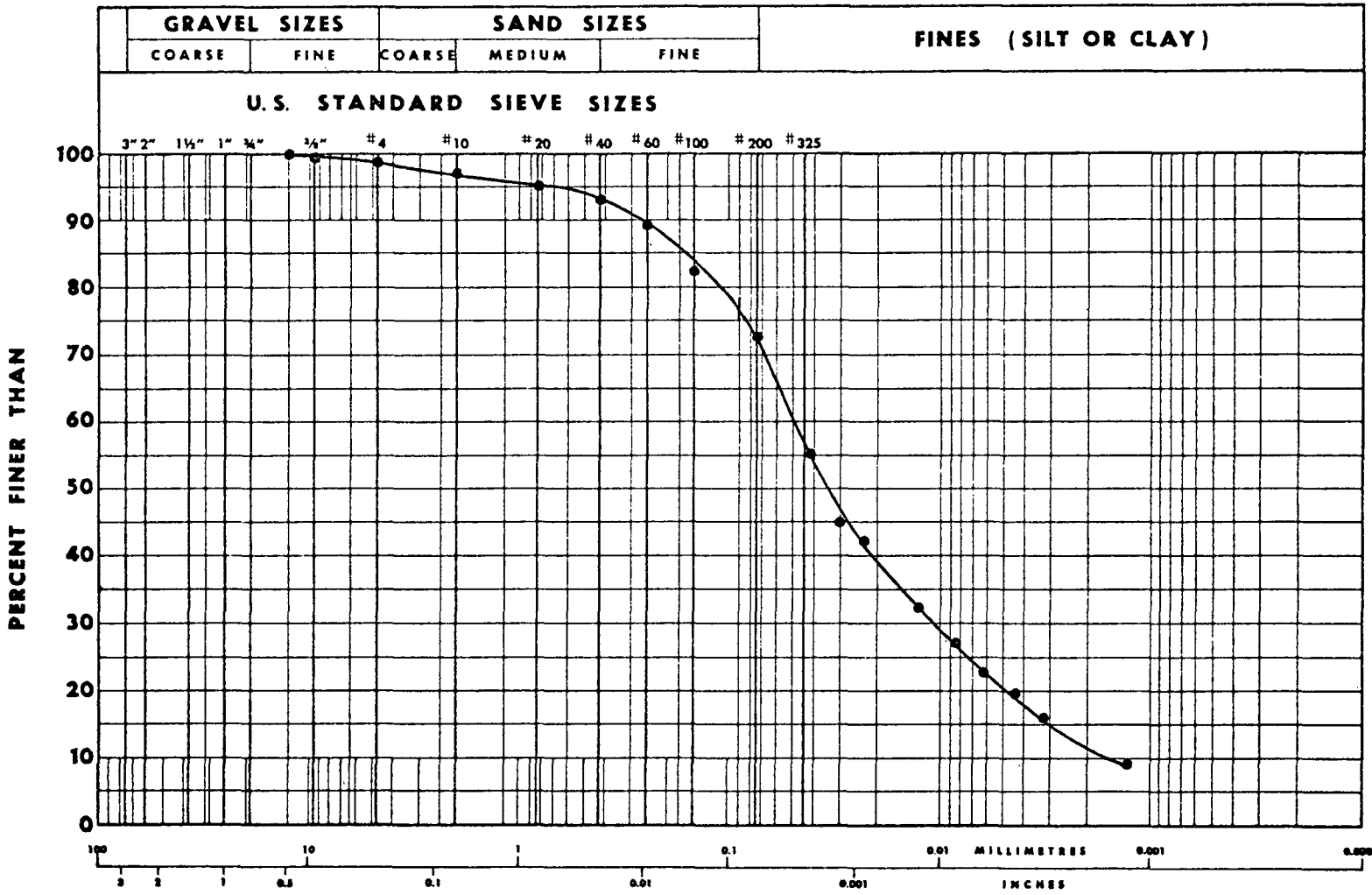
Clay, silty, high plastic, medium to dark brown colour, streaked with white, layered, sulphates, moist.

1.2 Silt

| | |
|------------------------------------|------------------------|
| Specific Gravity | 2.71 |
| Liquid Limit (Percent) | 25 |
| Plastic Limit | 14 |
| Plasticity Index (Percent) | 11 |
| Natural Moisture Content (Percent) | 11.3 |
| Bulk Density p.c.F. | 109.0 after compaction |

Visual Description:

Clay, silty, traces of sand, low plastic pebbles to one-half inch, olive coloured, moist.



SILT

1.3 1/4 INCH MINUS CRUSHED SAND SIEVE ANALYSIS (Unwashed as Received)

| Sieve Size | Weight Retained (gm) | Percent Passing (Total) |
|-------------------------------|-------------------------|----------------------------|
| 1.5 in | | |
| 1.0 in | | |
| 0.75 in | | 100.0 |
| 0.375 in | 5.4 | 99.3 |
| No. 4 | 61.9 | 90.9 |
| No. 8 | 112.6 | 75.7 |
| No. 16 | 69.6 | 66.3 |
| No. 30 | 64.6 | 57.6 |
| No. 50 | 143.7 | 38.2 |
| No. 100 | 155.4 | 17.3 |
| No. 200 | 46.0 | 11.1 |
| Filler | 82.1 | |
| Total | 741.3 gm | |
| Weight of original sample | 741.3 | |
| Weight of washed sample | 661.3 | |
| Filler by washing | 80.0 | |
| Filler by sieving | 2.1 | |
| Total filler | 82.1 | |
| Bulk density after compaction | 115.6 p.c.F. | |

1.4 1/4 INCH MINUS CRUSHED SAND SIEVE ANALYSIS (Washed)

| Sieve Size | Weight Retained (gm) | Percent Passing (Total) |
|-------------------------------|-------------------------|----------------------------|
| 1.5 in | | |
| 1.0 in | | |
| 0.75 in | | |
| 0.50 in | | 100.0 |
| 0.375 in | 8.8 | 98.9 |
| No. 4 | 102.4 | 85.6 |
| No. 8 | 176.7 | 62.6 |
| No. 16 | 81.5 | 52.0 |
| No. 30 | 71.2 | 42.8 |
| No. 50 | 143.4 | 24.2 |
| No. 100 | 136.8 | 6.4 |
| No. 200 | 35.5 | 1.8 |
| Filler | 13.8 | |
| Total | 770.1 gm | |
| Weight of original sample | 770.0 | |
| Weight of washed sample | 761.9 | |
| Filler by washing | 8.1 | |
| Filler by sieving | 5.7 | |
| Total filler | 13.8 | |
| Bulk density after compaction | 98.2 p.c.F. | |

1.5 VISUAL PETROGRAPHIC EXAMINATION OF CRUSHED SAND

-
- (a) Sieve Size: No. 4
- (b) Particle Shape: (Percent)
- | | | |
|----------------------------|-----------------|---------------------|
| Subrounded to rounded - 30 | (Isometric - 30 | Flat, rodlike - 70) |
| Subrounded to angular - 70 | (Isometric - 20 | Flat, rodlike - 80) |
- (c) Particle Surface:
- Subrounded to rounded - smooth, even
- Subangular to angular - rough, irregular
- Slightly dirty, Calcareous coating - 1 percent
- (d) Mineral Composition: (Percent)
- | | |
|---------------------|------|
| Limestone | 24.2 |
| Silicious Sandstone | 23.3 |
| Sandstone | 14.4 |
| Altered Rocks | 11.9 |
| Quartzite | 10.6 |
| Siltstone | 10.2 |
| Chert | 4.2 |
| Encrustation | 0.8 |
| Ironstone | 0.4 |
- (e) Deleterious Components:
- Chert
- Ironstone
- Encrustation
- (f) Partical Counts: 441
- (g) Comments:
- Altered rocks refer to sandstone siltstones.
- Limestones are sandy and silty.
- No weathering.
-

1.6 SUMMARY OF CRUSHED SAND

| Rock Type | Weighted Percentage of Constituents (in +4 sieve) Fraction | Total Weighted Composition |
|--------------------------------|--|-------------------------------|
| Quartzite | 10.6 | 1.4 |
| Silicious Sandstone | 23.3 | 3.1 |
| Sandstone | 14.4 | 1.9 |
| Siltstone | 10.2 | 1.35 |
| Limestone | 24.2 | 3.25 |
| Altered Rocks | 11.9 | 1.60 |
| Chert | 4.2 | 0.55 |
| Encrustation | 0.8 | 0.1 |
| Ironstone | 0.4 | 0.005 |
| Bulk Density of Unwashed Sand: | 115.6 pcF | |
| Water Content: | dry as received | |
